SPACE SECURITY

2009

spacesecurity.org

SPACE SECURITY

2009

SPACESECURITY.ORG

Library and Archives Canada Cataloguing in Publications Data

Space Security 2009

ISBN : 978-1-895722-74-1

Edited by Jessica West

Design and layout by Graphics, University of Waterloo, Waterloo, Ontario, Canada

Cover image: STS-112 Astronaut Wolf Participates in Extravehicular Activity
NASA, 10 December 2002

Printed in Canada

Printer: Pandora Press, Kitchener, Ontario

First published August 2009

Please direct inquiries to:
Project Ploughshares
57 Erb Street West
Waterlo, Ontario
Canada N2L 6C2
Telephone: 519-888-6541
Fax: 519-888-0018
Email: plough@ploughshares.ca

TABLE OF CONTENTS

ACRONYMS

3GIRS	Third Generation Infrared Surveillance Program (formerly AIRSS — US)
ABM	Anti-Ballistic Missile
ABL	Airborne Laser (US)
AEHF	Advanced Extremely High Frequency system (US)
ANGELS	Autonomous Nanosatellite Guardian for Evaluating Local Space (US)
ASEAN	Association of Southeast Asian Nations
ASAT	Anti-Satellite Weapon
ASI	Italian Space Agency
ATV	Automated Transfer Vehicle or Jules Verne (Europe)
BASIC	Broad Area Satellite Imagery Collection program (US)
BMD	Ballistic Missile Defense
BNSC	British National Space Centre
BOC	Besoin Operationnel Commun (Europe)
BX-1	BinXiang-1 (China)
CASC	China Aerospace Corporation
CD	Conference on Disarmament
CFE	Commercial and Foreign Entities
CFSP	Common Security and Foreign Policy (Europe)
CNES	Centre National d'Études Spatiales (France)
CNSA	Chinese National Space Administration
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
COSPAS-SARSAT	International Satellite System for Search and Rescue
COTS	Commercial Orbital Transportation System (US)
CSA	Canadian Space Agency
CSSI	Center for Space Standards & Innovation
DARPA	Defense Advanced Research Projects Agency (US)
DART	Demonstration of Autonomous Rendezvous Technology (US)
DBS	Direct Broadcasting by Satellite
DGA	Délégation Générale pour l'Armement (French Agency for Defense Development)
DISCOS	Database and Information System Characterising Objects in Space (Europe)
DLR	German Aerospace Center
DOD	Department of Defense (US)
DRDO	Defence Research and Development Organization (India)
DSCS	Defense Satellite Communications System (US)
DSP	Defense Support Program (US)
EADS	European Aeronautics Defence and Space Company
EC	European Commission
EELV	Evolved Expendable Launch Vehicle (US)
EHF	Extremely High Frequency
EKV	Exoatmospheric Kill Vehicle
ELINT	Electronic Intelligence
EMP	Electromagnetic pulse (or HEMP for High Altitude EMP)
EORSAT	Electronic Intelligence Ocean Reconnaissance Satellite (Russia)

ESA	European Space Agency
ESDP	European Security and Defence Policy
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration (US)
FAST	Fast Access Spacecraft Testbed (US)
FCC	Federal Communications Commission (US)
FMCT	Fissile Material Cut-off Treaty
FOBS	Fractional Orbital Bombardment System (Russia)
FREND	Front-End Robotics Enabling Near-Term Demonstration (US)
FSS	Fixed Satellite Service
GAGAN	GPS and GEO Augmented Navigation (India)
GEO	Geostationary Orbit
GEOSS	Global Earth Observation System of Systems
GLONASS	Global Navigation Satellite System (Russia)
GMES	Global Monitoring for Environment and Security (Europe)
GNSS	Global Navigator Satellite System
GPS	Global Positioning System (US)
GRAVES	Grande Réseau Adapté à la Veille Spatiale (France)
GSLV	Geostationary Satellite Launch Vehicle (India)
HAND	High Altitude Nuclear Detonation
HAARP	High Frequency Active Auroral Research Program (US)
HEO	Highly Elliptical Orbit
IADC	Inter-Agency Space Debris Coordinating Committee
IAI	Israeli Aerospace Industries
ICBM	Intercontinental Ballistic Missile
IGS	Information Gathering Satellites (Japan)
IIRS	Indian Institute of Remote Sensing
ILS	International Launch Services
Inmarsat	International Maritime Satellite Organization
Intelsat	International Telecommunications Satellite Consortium
IRNSS	Indian Regional Navigation Satellite System
ISON	International Scientific Optical Network
ISRO	Indian Space Research Organization
ISS	International Space Station
ITAR	International Traffic in Arms Regulation (US)
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
JHPSSL	Joint High-Power Solid-State Laser (US)
JSpOC	Joint Space Operations Center (US)
KARI	Korean Aerospace Research Institute
KEI	Kinetic Energy Interceptor
KSLV	Korean Space Launch Vehicle
LEO	Low Earth Orbit

M3MSat	Maritime Monitoring and Messaging Microsatellite (Canada)
MDA	Missile Defense Agency (US)
MEO	Medium Earth Orbit
MEP	Multiple Engagement Payload (US)
MiDSTEP	Microsatellite Demonstration Science and Technology Experiment Program
Milstar	Military Satellite Communications System (US)
MIRACL	Mid-Infrared Advanced Chemical Laser (US)
MiTEX	Micro-satellite Technology Experiment (US)
MKV	Miniature Kill Vehicle (US)
MPX	Micro-satellite Propulsion Experiment (US)
MSS	Mobile Satellite Service
MTCR	Missile Technology Control Regime
MUSIS	Multinational Space-based Imaging System (France)
NATO	North Atlantic Treaty Organization
NASA	National Aeronautics and Space Administration (US)
NEO	Near-Earth Object
NEOSSat	Near Earth Object Surveillance Satellite (Canada)
NFIRE	Near-Field Infrared Experiment satellite (US)
NGA	National Geospatial-Intelligence Agency (US)
NGO	Nongovernment Organization
NOAA	National Oceanic and Atmospheric Administration (US)
NORAD	North American Aerospace Defense Command
NRL	National Research Laboratory (US Navy)
NRO	National Reconnaissance Office (US)
NSSO	National Security Space Office (US)
NTM	National Technical Means
ORS	Operationally Responsive Space (US)
OST	Outer Space Treaty
PAROS	Prevention of an Arms Race in Outer Space
PGS	Prompt Global Strike program (US)
PLA	People's Liberation Army (China)
PPWT	Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects
PRS	Public Regulated Service (for European Galileo)
PSLV	Polar Satellite Launch Vehicle
QZSS	Quazi-Zenith Satellite System (Japan)
RAIDRS	Rapid Attack Identification Detection and Reporting System
RAMOS	Russian-American Observation Satellite program
RORSAT	Radar Ocean Reconnaissance Satellites (Russia)
Roscosmos	Russian Federal Space Agency
SALT	Strategic Arms Limitations Talks
SAR	Synthetic Aperture Radar
SASSA	Self-Awareness Space Situational Awareness program (US)

SBI	Space-Based Interceptors
SBIRS	Space Based Infrared System (US)
SBL	Space Based Laser
SBSS	Space Based Surveillance System (US)
SHF	Super High Frequency
SHSP	Strategic Headquarters for Space Policy (Japan)
SIGINT	Signals Intelligence
SM-3	Standard Missile 3 (US)
SOCRATES	Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space
SSA	Space Situational Awareness
SSN	Space Surveillance Network (US)
STSS	Space Tracking and Surveillance System (US)
SUIRG	Satellite Users Interference Reduction Group
System F6	Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange (US)
TCBM	Transparency and Confidence-Building Measure
TICS	Tiny Independent Coordinating Spacecraft program (US)
TIRA	German Tracking and Imaging Radar
TSAT	Transformational Satellite Communications system (US)
TLE	Two-line elements
TT&C	Tracking, telemetry and command
UHF	Ultra High Frequency
UAV	Unmanned Aerial Vehicle
UNGA	United Nations General Assembly
UNISPACE	United Nations Conference on the Exploration and Peaceful Uses of Outer Space
UNITRACE	United Nations International Trajectography Centre
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USAF	United States Air Force
USML	United States Munitions List
WGS	Wideband Global SATCOM
XSS	Experimental Spacecraft System (US)

"Space is in the news more than ever. With both Iran and North Korea developing space programs, and with both the United States and China demonstrating new capabilities to shoot down satellites, international concerns for space security have never been greater. In the Space Security Index, policy makers, journalists, and technical professionals, as well as those just interested in space, have a single reliable resource for information on space security. There is no more comprehensive and up-to-date source of information on developments in space, and the threats to space security."

Hon. Philip E. Coyle
Senior Advisor, Center for Defense Information
Former Assistant Secretary of Defense and Director, Operational Test and Evaluation, US Department of Defense

This is the sixth annual report on trends and developments related to security and outer space, covering the period January to December 2008. It is part of the wider Space Security Index (SSI) project that aims to improve transparency with respect to space activities and provide a common, comprehensive knowledge base to support the development of national and international policies that contribute to space security.

The definition of space security guiding this report is in keeping with the express intent of the 1967 Outer Space Treaty that space should be preserved as a global commons to be used by all for peaceful purposes:

The secure and sustainable access to, and use of, space and freedom from space-based threats.

This broad definition encompasses the security of space as a particularly unique environment, the security of Earth-originating assets in space, and security from threats originating from space-based assets. The primary consideration in the SSI definition of space security is not the interests of specific national or commercial entities using space, but the security of space as an environment that can be used safely and sustainably by all.

The actions and developments related to space security are assessed according to eight indicators that are organized under three themes:

- The condition of the operating environment
  1) The space environment
  2) Laws, policies, and doctrines
- The type of actors in space and how space is used
  3) Civil space programs and global utilities
  4) Commercial space
  5) Space support for terrestrial military operations
- The status of space-related technology as it pertains to protecting or interfering with space systems, or harming Earth from space
  6) Space systems protection
  7) Space systems negation
  8) Space-based strike capabilities.

Each of the eight indicators is examined in a separate chapter that provides a description of the indicator and its overall impact on space security. A discussion of the prevailing trends associated with that indicator is followed by an overview of key developments throughout the year, and an assessment of their short-term effects on established trends and the broader security of outer space.

The physical properties of outer space are distinctly different from the terrestrial environment. Human activities such as debris creation cannot be corrected with technology currently available and debris poses a direct, destructive risk to space assets. Conflicts between states involving space assets could create debris fields that would render important parts of space un-useable. While space activities are a strategic focus for national security interests, the pervasive dual use of space assets for military and civilian purposes contributes to human security by, for example, tracking weather patterns to support agriculture, assisting responses to natural calamities, and monitoring criminal activities and human rights violations.

The annual, systematic assessment undertaken by the Space Security Index makes it increasingly possible to note longer-term trends. For example, the predominance of dual-use space assets means that more states are using space for military and national security purposes. The distinctions between civil, military, and commercial space assets are blurring, creating interdependence and mutual vulnerabilities. The way in which stability is maintained is changing; efforts to adopt new international treaties are being replaced by non-binding, technical approaches to govern outer space. This shift is in part supported by a transition in the way in which space surveillance data is collected and shared. Greater international cooperation supports transparency and confidence in space activities. However, the ongoing development of technology, which better enables the use of space for some purposes and certain actors, may also deny the secure use of space for other legitimate purposes and actors.

Developments captured in the SSI also illustrate the contradictions and complexities intrinsic to outer space activity. The year 2008 marked the tenth anniversary of the International Space Station (ISS). Its success attests to the benefits of international cooperation in space, even while the administration of the ISS was bedeviled by political obstacles that had to be overcome and changing goals of the national civil space programs of participating governments. One of the most significant events of the year was the US destruction of the failed and de-orbiting USA-193 satellite with an interceptor designed for missile defense. It illustrated the ongoing struggle to balance security on Earth and security in space. While the US claimed that the satellite had to be destroyed before it returned to Earth to avoid potential harm from its dangerous contents, its on-orbit destruction could have resulted in a debris field that would threaten other objects in space.

Space Security 2009 does not provide absolute positive or negative assessments of 2008 outer space activities. Instead, it indicates the range of implications that developments could have on the security of space across the various indicators and highlights the difficult challenges faced by policymakers.

Information contained in *Space Security 2009* is from open sources. Great effort is made to ensure a complete and factually accurate description of events, based on a critical appraisal of the available information and consultation with international experts. Strategic and commercial secrecy with respect to space activities inevitably poses a challenge to the comprehensive nature of this report. But space assets and activities by their very nature are generally in plain view to those with the technical ability to observe them. Increasingly that includes so-called amateurs who make their observations widely available.

Expert participation in the Space Security Index is a key component of the project. The primary research is peer reviewed prior to publication through three processes:

1) The annual Space Security Online Consultation provides insights into the perceptions, concerns, and priorities of space stakeholders around the world, as well as critical feedback on the draft research report.
2) The Space Security Working Group consultation is held each spring for two days to review the text for factual errors, misinterpretations, gaps, and statements about impacts. This meeting also provides an important forum for related policy dialogue on recent outer space developments. (Participants are listed in Annex 1.)
3) Finally, the Advisory Group to the Space Security Index provides its comments on the penultimate draft of the text before publication.

For further information about the Space Security Index, its methodology, project partners, and sponsors, please visit the website **www.spacesecurity.org**, where the publication is also available in PDF format. Comments and suggestions to improve the project are welcome.

ACKNOWLEDGEMENTS

The research for *Space Security 2009* was directed by Jessica West at Project Ploughshares and Dr. Ram Jakhu at the McGill University Institute of Air and Space Law. The research team included:

Taylor Binnington (MSc), University of Guelph

August Claxton (MA), University of Waterloo

Catherine Doldrina (DCL), McGill University

Eugene Miakinkov (MA), University of Waterloo

Amanda Mowle (LLM), McGill University

Kshama Nargund (LLM), McGill University

Brian Weeden, Technical Consultant, Secure World Foundation

The Governance Group for the Space Security Index would like to thank the research team and the many advisors and expert participants who have supported this project. Managing Editor Jessica West has been responsible for the completion of the last three annual SSI publications. She provides the day-to-day guidance and coordination of the project and ensures that the myriad details of the publication come together, and also supports the Governance Group and Advisory Board. In September 2009 Jessica will return to graduate studies. We want to thank her for the contribution she has made to the growth and development of the SSI and wish her much success in her future endeavors. We also want to thank Brian Weeden at Secure World Foundation for providing his time and technical expertise to the project in addition to being part of the research team, and Jonathan McDowell, who has made an increasingly important contribution to the SSI through his dedication and diligence in tracking and interpreting what takes place in outer space.

Thanks to Wendy Stocker at Project Ploughshares for copyediting and to Graphics at the University of Waterloo for design work. For comments on drafts of the text we are in debt to the members of the Advisory Board, those who provided valuable input through the Space Security Online Consultation, and participants in the Space Security Working Group. For organizing the Space Security Working Group meeting on 5-6 May 2009, we are grateful to the McGill University Institute of Air and Space Law, in particular Ms. Maria D'Amico, Ms. Catherine Doldrina, Dr. Paul Dempsey, Dr. Nicholas Kasirer, and Dr. Ram Jakhu.

This project would not be possible without the generous financial support of the following organizations:

- Secure World Foundation
- The Simons Foundation
- International Security Research and Outreach Programme at the Department of Foreign Affairs and International Trade Canada
- Erin J.C. Arsenault Trust Fund at McGill University
- Intelsat General Corporation
- Telesat.

While we as the Governance Group for the Space Security Index have benefited immeasurably from the input of the many experts indicated, responsibility for any errors or omissions in this volume finally rests with us.

Dr. Wade Huntley

Dr. Ram Jakhu

Dr. William Marshall

Mr. John Siebert

Dr. Ray Williamson

The Space Environment

TREND 1.1: Growing risk to spacecraft as orbital debris continues to increase — Traveling at speeds of up to 7.8 kilometers per second, space debris poses a significant threat to spacecraft. The number of objects in Earth orbit has increased steadily; today the US Department of Defense (DOD) is using the Space Surveillance Network to track more than 19,000 objects approximately 10 centimeters in diameter or larger. It is estimated that there are over 300,000 objects with a diameter larger than one centimeter, and millions smaller. The annual growth rate of new debris tracked began to decrease in the 1990s, largely due to national debris mitigation efforts, but has accelerated in recent years.

2008 Developments:

- Short-lived debris created by destruction of USA-193 satellite to mitigate risk posed by reentry
- Growth rate of new space debris declines for first time in four years
- Increased risk of spacecraft posed by debris

Space Security Impact

With no major on-orbit fragmentations in 2008, there was minimal additional risk by new debris, but existing debris continues to pose hazards to operational spacecraft, particularly in Low Earth Orbit (LEO). Concerns are also raised by intentional satellite breakups, as well as the ongoing presence in orbit of satellites with a history of severe fragmentation. Although relatively little lasting debris was created, the US destruction of the failed USA-193 satellite prior to its reentry in Earth's atmosphere raises a challenge for space security in which the sustainability of the space environment can potentially conflict with security from threats posed by objects in space.

TREND 1.2: Continued efforts to develop and implement debris mitigation practices — Significant on-orbit collisions, such as the collision of the French military satellite Cerise with a portion of an Ariane rocket in 1996, and improved tracking abilities have encouraged the recognition of space debris as a growing threat. Since the mid-1990s, many spacefaring states, including China, Japan, Russia, the US, and the European Space Agency have developed debris mitigation standards, and the United Nations has adopted voluntary guidelines.

2008 Developments:

- International recognition and adoption of UN Debris Mitigation Guidelines
- NASA studies potential value of physically removing debris from orbit

Space Security Impact

Reporting by some states on efforts to implement the Debris Mitigation Guidelines of the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and evidence that some states are factoring the guidelines into decision-making are positive signs that the Mitigation Guidelines are becoming part of state practice. However, responsible actions by a few spacefaring states will not guarantee progress in reducing the creation of space debris. In particular, efforts are needed to make emerging and developing space states aware of the consequences of space debris and their international responsibilities, and to help them develop the technical means to meet those responsibilities. Finally, while the US asserts that it adhered to the guidelines when destroying the de-orbiting USA-193 satellite, it is not clear how other states may engage in similar actions over the long term (see Laws, Policies, and Doctrines).

TREND 1.3: Space surveillance capabilities to support collision avoidance slowly improving — Efforts in the 1980s to create an international space surveillance system to support collision avoidance and debris reentry were unsuccessful, but several states have pursued national systems. The US Space Surveillance Network uses 30 sensors worldwide to monitor over 19,000 space objects in all orbits, but since 2004 has provided limited access to its data, out of concern for national security. Russia maintains a Space Surveillance System using its early-warning radars and monitors some 5,000 objects (mostly in LEO), but does not widely disseminate data. China, the EU, France, Germany, and Japan are all developing independent space surveillance capabilities. Discussions have once again been initiated about the practicalities of sharing such data.

2008 Developments:

- The US, European Space Agency, and Russia take steps to improve access to independent space surveillance data
- Efforts to better coordinate international space surveillance data increase

Space Security Impact

The various national efforts to improve independent space surveillance capabilities in 2008 are positive for space security because they provide better and redundant tracking of space objects and greater transparency of space activities. However, ongoing challenges to greater cooperation and collaboration include hesitancy to share information on satellites that are deemed sensitive, particularly since space surveillance information can be used to support space negation efforts; and technical difficulties associated with combining information in various formats and from different types of sensors. Consequently, the use of orbital data to adequately support collision avoidance remains limited, but events in 2008 indicate that such use may increase in the near future.

TREND 1.4: Growing demand for radio frequency spectrum and orbital slots — Expanding satellite applications are driving demand for limited resources in space, including radio frequencies and orbital slots. Satellite operators spend significant time addressing frequency interference issues, including conflicts such as the disagreement over frequency allocation between the US Global Positioning System, the EU Galileo system, and the Chinese Beidou system. The growth in military bandwidth consumption has also been dramatic: the US military used some 700 megabytes per second of bandwidth during operations in Afghanistan in 2001, compared to 99 megabytes per second during Operation Desert Storm in 1991. There are more than 800 operational satellites in orbit today. Increased competition for orbital slot assignments, particularly in GEO where most communications satellites operate, has caused occasional disputes between satellite operators. The International Telecommunication Union has been pursuing reforms to address slot allocation backlogs and related financial challenges.

2008 Developments:

- Continued uncertainty regarding future satellite navigation signals
- Efforts to overcome the costs of unintentional signal interference

Space Security Impact

Developments in 2008 further highlight both the scarcity of available slots in the radio frequency spectrum and the challenges with the existing governance mechanisms. In particular, the Chinese plan for Beidou appears to be consistent with current ITU regulations, and efforts to resolve the issue of frequency coordination were complicated by untimely release of technical details about Galileo. Moreover, as military and economic interests drive the growth of competing systems for similar services, additional demands are also made on their related orbits — in this case, highly elliptical orbit. Determining the nature of solutions to satellite signal interference, both accidental and hostile, will continue to be a challenge for the foreseeable future and is a significant deterrent to space security.

Space Laws, Policies, and Doctrines

TREND 2.1: Gradual development of legal framework for outer space activities shifting away from adoption of multilateral treaties — The international legal framework for outer space establishes the principle that space should be used for "peaceful purposes." Since the signing of the Outer Space Treaty (OST) in 1967, this framework has grown to include the Astronaut Rescue Agreement (1968), the Liability Convention (1972), the Registration Convention (1979), and the Moon Agreement (1979), as well as a range of other international and bilateral agreements and relevant rules of customary international law. The OST prohibits the stationing of nuclear weapons or any other weapons of mass destruction anywhere in space. The US withdrawal from the Anti-Ballistic Missile Treaty in 2002 eliminated a longstanding US/USSR-Russia prohibition on space-based conventional weapons, stimulating renewed concerns about the potential for space weaponization. What began as a focus on multilateral space treaties, however, has transitioned to a focus on what some describe as 'soft law' — referring to a range of non-binding governance tools including principles, resolutions, confidence-building measures, and policy and technical guidelines.

2008 Developments:

- US reiterates its rejection of legally binding approaches to security in space at the UN General Assembly
- US says destruction of failed satellite consistent with the Outer Space Treaty
- European Commission issues draft Code of Conduct for Outer Space Activities
- Implementation issues impede Hague Code of Conduct on Ballistic Missile Proliferation

Space Security Impact

International legal events in 2008 suggest a continued focus on non-binding governance tools, which some refer to as 'soft law', such as transparency and confidence-building measures and codes of conduct. Support for these measures indicates a growing commitment on the part of some leading spacefaring countries to better regulate activities in outer space by codifying generally accepted behaviors. However, the potential risk with this approach is that implementation will be arbitrary and selective, as demonstrated by the ongoing challenges faced by the Hague Code of Conduct, and that de facto international law will be made via the unilateral actions of states, as demonstrated by the US destruction of one of its own satellites. The US action to destroy its satellite and official responses by other governments may stand as precedents for procedures under which the use of force in outer space is legitimized, in the absence of specific treaty law.

TREND 2.2: COPUOS remains active, but the Conference on Disarmament has been unable to agree to an agenda since 1996 — A range of international institutions, such as the UN General Assembly, the UN COPUOS, the International Telecommunication Union (ITU), and the Conference on Disarmament (CD), have been mandated to address issues related to space security. But the CD has been deadlocked without an agreed plan of work since 1996 and there has been no progress on space issues in 30 years, despite efforts to move forward on the Prevention of an Arms Race in Outer Space (PAROS) mandate to develop an instrument relating to the weaponization of space. COPUOS remains active, with a focus on non-binding, technical approaches to security in space.

2008 Developments:

- CD continues without program of work; discusses draft treaty to prevent the weaponization of space
- Continued efforts toward a voluntary rules-based approach to space security

Space Security Impact

Activities surrounding the UN COPUOS in 2008 reinforced the continued focus on non-binding, technical approaches to international governance of outer space noted in Trend 2.1. Despite drawbacks, these are the only mechanisms that are garnering widespread support and leading to improvements in the security of outer space in the face of continued lack of consensus on new treaties in both the UN COPUOS and the CD. However, the increased interaction between these two organizations suggests that addressing security concerns in space more comprehensively may become possible in the future, although the stark division between civil and safety issues and military and weapons issues remains institutionalized.

TREND 2.3: National space policies consistently emphasize international cooperation and the peaceful uses of outer space — All spacefaring states emphasize the importance of cooperation and the peaceful uses of space, but with caveats based on national security concerns. The US has recently announced plans for peaceful space exploration of the Moon and Mars, while there is growing interest in manned space programs in countries such as India and Japan. The national space policies of many developing countries, such as Brazil and India, tend to focus on the utility of space cooperation for social and economic development.

2008 Development:

- South Africa approves a National Space Agency with focus on peaceful use

Space Security Impact

States continued to express commitment to international cooperation on the peaceful use of outer space in their civil space policies in 2008. Some peaceful uses of space are increasingly viewed as strategic, however, which could limit opportunities for cooperation and cause political tensions in space, depending on whether states pursue independent or collective measures to achieve the strategic goals set out in their space policies.

TREND 2.4: Growing focus within national policies on the security uses of outer space — Fueled by the technological revolution in military affairs, the military doctrine of a growing number of actors (led by China, Russia, the US, and key European states) increasingly emphasizes the use of space systems to support national security. Dependence on these systems has led several states to view space assets as critical national security infrastructure. US military space doctrine has focused on the need to ensure US freedom of action in space, through the use, when necessary, of "counterspace operations" that prevent adversaries from interfering with US space operations.

2008 Developments:

- Japan issues new space law lifting its ban on national security and military space activities
- China's 2008 White Paper on Defense highlights importance of "informationization"
- France's White Paper on Defense and National Security encompasses overhaul of space strategy
- New approach to space protection in the US may include international interdependence
- Space for security a renewed priority for Europe

Space Security Impact

In 2008 many states continued to emphasize the use of space for national security purposes in policy statements. A positive impact of this trend is increased transparency and clarity of intentions that allow states to better predict the behavior of others in space. However, a parallel trend, in which civilian and commercial space infrastructure is being used for national security purposes, may lead to added vulnerabilities in space if this infrastructure is viewed as a legitimate target during conflict, particularly given the absence of laws governing conflict in space.

Civil Space Programs and Global Utilities

TREND 3.1: Growth in the number of actors with access to space, including dual-use applications — The rate at which new states gain access to space increased dramatically in the past decade. By 2008 9 actors had demonstrated independent orbital launch capacity and 49 states had launched civil satellites, either independently or in collaboration with others. In 2003 China joined Russia and the US as the only space powers with demonstrated manned spaceflight capabilities.

2008 Developments:

- Space access continues to increase, with new states gaining satellites and developing space agencies
- Iran, North Korea, Brazil, and South Korea seek direct access to space through launch technology

Space Security Impact

Increased participation in space activities is a positive trend insofar as more actors gain access to space for peaceful purposes, extending the benefits of space applications, science, and security. On the other hand, the growth of space activities also creates challenges for security in space due to increased demand for limited space resources such as orbital slots and radio frequencies, particularly when new activities replicate rather than rely on or enhance the capabilities provided by other states. Because of the ability of space assets and technologies such as launch vehicles to be used for different purposes, the intentions of the many actors in space cannot be known.

TREND 3.2: Changing priorities and funding levels within civil space programs toward large-scale projects — Civil expenditures on space have continued to increase in India and China in recent years, while past decreases in the space budgets of the US, the EU countries, and Russia have begun to reverse. Increasingly, civil space programs include security and development applications. Several states, in particular Brazil, Nigeria, and South Africa, are placing a priority on satellites to support social and economic development. Such dual-use applications as satellite navigation and Earth imaging are a growing focus of almost every civil space program.

2008 Developments:

- NASA focuses on maintaining human access to space as retirement of the Space Shuttle looms
- Space programs in China and India continue to grow, with focus shifting to human spaceflight
- Russia significantly increases the budget for space, primarily to make its Global Navigation Satellite System (GLONASS) viable
- Space agencies continue to focus on robotic missions to the Moon

Space Security Impact

The use of outer space continues to be dominated by a few states, with activities in 2008 demonstrating renewed interest in lunar exploration and human spaceflight. Although developments in 2008 indicate some cooperation on these projects, historical trends indicate that competition may increase if such capabilities become strategic in the future. Nonetheless, it remains to be seen if large-scale projects will gain the necessary investment to come to fruition; only in India, Russia, and possibly China are resources growing significantly. Delays in construction of new human spacecraft in the US may adversely influence space security in the future by limiting human access to space, particularly to the International Space Station (ISS).

TREND 3.3: Continued international cooperation in civil space programs — International civil space cooperation efforts over the past decades have included the US-USSR Apollo-Soyuz docking of manned modules, Soviet flights to the MIR space station with foreign representatives and Space Shuttle flights to MIR, the Hubble Space Telescope, joint NASA-ESA projects such as Spacelab, and European cooperation with Chinese and Indian lunar probes. The most prominent example of international cooperation is the International Space Station, involving 16 states, 56 launches, and an estimated cost of over $100-billion to date. International civil space cooperation has played a key role in the proliferation of technical capabilities for states to access space.

2008 Developments:

- Continued international cooperation on space exploration as the International Space Station turns 10
- International cooperation provides access to space for developing countries

Space Security Impact

The continuation in international cooperation in space is a positive development, particularly if it helps to reduce potential tensions over large-scale, national space projects such as human spaceflight and lunar exploration, and enables more states to access the benefits of outer space through shared costs and technologies. Cooperation can also increase transparency of space activities, further reducing potential conflicts in a strategic environment. There is a risk, however, that sensitive military technologies may proliferate, and that greater access to dual-use space-based applications for military purposes may exacerbate regional tensions.

TREND 3.4: Growth in global utilities as states seek to expand applications and accessibility — The use of space-based global utilities, including navigation, weather, and search-and-rescue systems, has grown substantially over the last decade. These systems have spawned space applications that are almost indispensable to the civil, commercial, and military sectors. Advanced and developing economies alike are heavily dependent on these space-based systems. Currently Russia, the US, the EU, Japan, China, and India are developing satellite-based navigation capabilities. The strategic value of satellite navigation has been underscored by conflicts over use of radio frequencies.

2008 Developments:

- Continued development of independent satellite navigation capabilities
- Global access to remote sensing data improving

Space Security Impact

Ongoing development of space-based global utilities such as satellite navigation systems could have a positive impact on space security by providing redundancy of capabilities and increasing access to space through collaborative efforts, particularly if they are interoperable. However, such a result requires considerable international coordination and cooperation, which have not fully developed due to ongoing disputes over the use of frequency signals, the development of independent capabilities to guarantee service, and a lack of planning for the increased demand on orbits and radio frequencies created by duplicate systems. The growing use of remote sensing data to manage a range of global challenges, including disaster monitoring and response, is positive for space security insofar as it further links the security of Earth to the security of space, expands space applications to include additional users, and encourages international collaboration and cooperation on an important space capability.

Commercial Space

TREND 4.1: Continued overall growth in the global commercial space industry — Commercial space revenues have steadily increased since the industry first started to grow significantly in the mid-1990s. Global commercial space revenues, dominated by satellite services, have been estimated as totaling between $144-billion and $175-billion in 2008. Individual consumers are a growing source of demand for these services, particularly satellite television and personal GPS devices. In recent years Russia has dominated the space launch industry, having the most commercial launches, while US companies have led in the satellite manufacturing sector. However, international competition in both of these sectors is increasing.

2008 Developments:

- Continued industry growth driven by consumer services and a strong satellite replacement market
- Growing international competition from China, India, and Japan
- Growth opportunities for small, low-cost satellites may expand access to space

Space Security Impact

Although the strong commercial launch industry in 2008 was in part due to the ongoing replacement of satellites, continued growth is also seen in satellite services and ground equipment revenues, driven by consumer-oriented products. Ongoing growth of the industry suggests that there is overall confidence in the security of space and the ability of both companies and consumers to continue to rely on space resources. Further, individual consumers continue to become more significant stakeholders in space. Growing competition in the commercial launch market may contribute to space security by providing greater access to outer space, although tensions may arise if future demand for space resources such as orbital slots and radio frequencies exceeds supply. Currently, however, the positive gains in the sector's value and ubiquity outweigh the greater friction with respect to supply and demand.

TREND 4.2: Commercial sector supporting increased access to space — Commercial space launches have contributed to cheaper space access. The cost to launch a commercial satellite into GEO has declined from an average of about $40,000/kilogram in 1990 to $26,000/kilogram in 2000, with prices now stabilizing. The commercial space industry is also opening up access to Earth imaging data, which until a few years ago was only available to a select number of governments. Today any individual or organization with access to the Internet can use these services through Google Maps, Google Earth, and Yahoo Maps programs. An embryonic private spaceflight industry continues to emerge, seeking to capitalize on new concepts for advanced, reliable, reusable, and relatively affordable technologies for launch to suborbital trajectories and low Earth orbit.

2008 Developments:

- New launchers entering the market increase capacity, but no indication of further launch cost reductions
- Private human access to space slowly progressing
- Commercial actors continue to expand availability of Earth imagery

Space Security Impact

Sustained competition in commercial space launch may slightly reduce the cost of access to space in the near future, but in the absence of revolutionized technologies, there is not likely to be a significant impact on space access. Moreover, while efforts are being made to support private human access to space, such access may cause challenges to space security, both in terms of the sustainability of the space environment as well as the applicability of international laws, such as the Astronaut Rescue Agreement (see Laws, Policies, and Doctrines Trend 2.1). Finally, while the space industry is facilitating greater use of space applications, in particular remote sensing data, there are legitimate fears about the security implications on Earth of widely available imaging data.

TREND 4.3: Government's dependency on the commercial space sector means that subsidies and national security concerns continue to play an important role — The commercial space sector is significantly shaped by national governments with particular security concerns. The 1998 US Space Launch Cost Reduction Act and the 2003 European Guaranteed Access to Space program provide for considerable government subsidization of the space launch and manufacturing markets. The US and European space industry also receive important space contracts from government programs. In 1999 the US placed satellite export licensing on the State Department's US Munitions List, bringing satellite product export licensing under the International Traffic in Arms Regulations (ITAR) regime and significantly complicating participation by US companies in international collaborative satellite launch and manufacturing ventures.

2008 Developments:
- Military dependence on commercial space services continues to expand, deepen
- Relationships between governments and commercial sector continue to evolve toward more substantial partnerships
- Ongoing debate over how to apply trade restrictions for security purposes
- Commercial operators engage in space governance

Space Security Impact

The strong relationship between military and commercial uses of space and the security dimensions of many commercial services have complex impacts on space security. On the one hand, multiple-use spacecraft could become military targets in the future, resulting in an overall decrease in security. Alternatively, the proliferation of dual-use assets in space could make a military attack less useful and, therefore, less likely. This could increase overall space security. The focus of the year has been a constant discussion on changes that ought to be brought about in ITAR to increase the commercial competitiveness of the US satellite and launch industries, specifically in the light of the ITAR-free satellites manufactured by Europe for the Chinese market.

Space Support for Terrestrial Military Operations

TREND 5.1: US and Russia continue to lead in deploying military space systems — Estimated at $29-billion, almost half of all global spending on space is for defense-related programs that provide military attack warning, communications, weather forecasting, reconnaissance, surveillance, and intelligence, as well as navigation and weapons guidance applications. The US spends 95 percent of this amount, but spending on military space programs is increasing in other countries around the world. At the end of 2008 there were over 150 operational dedicated military satellites worldwide, with the US operating approximately 76, and Russia approximately 36.

2008 Developments:

- US faces increased demands for military satellite capabilities as it struggles to upgrade its systems
- Russia increases investment in GLONASS again, pursues other high-priority upgrades

Space Security Impact

Despite ongoing acquisition challenges in providing next-generation space capabilities for its military and intelligence communities, the US maintains the most capable and robust systems, which are one indication of secure and sustainable access to and use of space. While ongoing dependence on space systems for security makes the US particularly vulnerable in space, efforts are being made to mitigate this risk through the use of commercial capabilities and smaller satellites that can be launched quickly. Russian space efforts and funding are focused on finishing the GLONASS program and upgrading early warning capabilities, both of which could be positive for security in space by providing redundancy for US GPS and greater stability through more reliable early-warning data.

TREND 5.2: More states developing military and dual-use space capabilities — During the Cold War, states allied with either the US or the USSR benefited from their capabilities. Traditionally, military satellites outside of the US and Russia have been almost exclusively intended for telecommunications and imagery intelligence. Recently, however, states such as China, France, Germany, Japan, Israel, Italy, and Spain have been developing satellites with a wider range of functions. Security is a key driver of established government space programs, pushing spending higher. However, in the absence of dedicated military satellites, many actors use their civilian satellites for military purposes or purchase data and services from other satellite operators. While individual European states have pursued independent, national space capabilities for military support, in a unique twist, they also share many of these capabilities among European partners.

2008 Developments:

- European states continue to cooperate on military space projects
- The Council of the European Space Agency endorses military use of its dual-use space projects
- China continues to launch potential dual-use spacecraft
- India and Israel cooperate on space
- Japan plans new military uses of space
- Canada continues to develop dual-use space capabilities

Space Security Impact

The drive for more states to develop and deploy both dedicated military and dual-use space systems demonstrates the continued accessibility of the space environment and greater access to space technologies. In general, these systems are being developed independently of one another and, while in theory some, such as satellite navigation, could be interoperable to enhance security, such cooperation is not the rule. However, Europe is emerging as the one region where space-based capabilities are being developed cooperatively, thus providing access to more states and redundancy of capabilities. As more states become dependent on space systems for military operations and national security, greater vulnerability may provide incentives to enhance the security of outer space or to develop capabilities to quickly negate space systems. At the same time, increasing reliance on dual-use spacecraft will make intentions difficult to determine.

Space Systems Protection

TREND 6.1: US and Russia lead in ability to detect rocket launches, while US leads in development of technologies to detect direct attacks on satellites — The ability to distinguish space negation attacks from technical failures or environmental disruptions is critical to maintaining international stability in space. Early warning also enables defensive responses, but the type of protection available may be limited. Only the US and Russia can reliably detect rocket launches. The US Defense Support Program provides early warning of conventional and nuclear ballistic missile attacks; Russia began rebuilding its aging system in 2001 by upgrading its Oko series satellites. France is developing two experimental missile-launch early-warning satellites — Spirale-1 and -2. Most actors have a basic capability to detect a ground-based electronic attack, such as jamming, by sensing an interference signal or by noticing a loss of communications. It is very difficult to obtain advance warning of directed energy attacks that move at the speed of light.

2008 Developments:

- US and Russia continue to upgrade early warning systems, and Japan considers developing a national early warning capability
- US pursues on-orbit warning and attack detection capabilities to enable defensive responses
- Improvements in access to independent space surveillance data, and ongoing discussions about options to share such data

Space Security Impact

Efforts to improve missile early warning capabilities in the US and Russia contribute to space security by maintaining the foundation of capabilities to monitor compliance with international controls on missile and nuclear technology developments that could be used to threaten objects in space (see Space Systems Negation), and to warn of impending threats. Thus the loss of the US sensor to detect nuclear blasts weakens an important protection measure, while the potential for early warning capabilities to be developed by additional actors is a positive measure that could increase the robustness of these efforts. US interest in developing local, on-orbit capabilities to warn of possible attacks or detect interference with a satellite can enhance protection of specific space systems by enabling defensive responses and possibly deterring attempts to interfere with those satellites. More broadly these capabilities could contribute to increased stability if they were able to identify the source of interference and if it were intentional, accidental, or environmental. It is noted, however, that on-orbit surveillance and warning can potentially facilitate aggressive counteractions in space, which could be destabilizing and spiral into conflict.

TREND 6.2: Efforts to protect satellite communications links but ground stations remain vulnerable — Many space systems lack protection from determined attacks on ground stations and communications links. Because the vast majority of commercial space systems have only one operations center and one ground station, they are vulnerable to negation efforts. While many actors employ passive electronic protection capabilities, such as shielding and directional antennas, more advanced measures, such as burst transmissions, are generally unique to military systems and the capabilities of more technically advanced states. Laser communications still have the best potential to reduce vulnerabilities of satellite communications links, but are proving difficult to implement.

2008 Developments:

- Plans for US Cyber Command evolve; NATO opens Co-operative Cyber Defense Center
- US focuses on improved security of existing communications links, while efforts to develop future laser links continue, but face both technical and budgetary challenges

Space Security Impact

Efforts to secure the network safety of critical infrastructure, which includes satellite command and control stations, reflects the interdependence of security in space with other terrestrial security issues and the complexity of defending against potential threats. These efforts are positive insofar as they reduce the number and severity of network attacks; encourage international cooperation, currently limited to NATO members; and enable governments to keep pace with innovations in cyber attacks. Laser communication technologies continue to offer the promise of better protection for ground-to-satellite communications, which is one of the most prevalent sources of attacks on space system. But progress remains slow and is currently focused on satellite-to-satellite transmissions. Efforts to improve the security of both computer networks and communications links demonstrate the spiral effect of protection-negation dynamics in space, where capabilities to improve one lead actors to improve the other.

TREND 6.3: Protection of satellites against some direct threats is improving but remains limited — The primary source of protection for satellites stems from the difficulties associated with launching an attack into space. Passive satellite protection measures also include system redundancy and interoperability, which have become characteristic of satellite navigation systems. Most key US, European, and Russian military satellites are hardened against the effects of a high-altitude nuclear detonation. Nonetheless, physically protecting a satellite from a direct kinetic attack remains difficult.

2008 Developments:

- US, Canada, and Sweden experiment with formation flying, which could support dispersion techniques to reduce the vulnerability of satellite systems
- US pursues technology enablers for on-orbit repair

Space Security Impact

Capabilities that would enable actors to disperse the function of a single large satellite into a cluster of smaller satellites are progressing and would contribute to security in space by reducing the vulnerability of space-based components, which would no longer rely on a single spacecraft. However, other security challenges, such as the ability to safely manage traffic in space, could increase. While enabling technologies to repair damaged spacecraft on-orbit through new propulsion, maneuvering, docking, and grappling capabilities is progressing, it remains a longer-term potential. As capabilities to protect satellites on-orbit become more active, however, there is a potential for them to be used against non-cooperative spacecraft. The long-term impact on space security will depend greatly on how technologies are used and how transparent usage is. Moreover, space-based protection capabilities could still be defeated by a determined actor, raising the potential for a spiral of protection and negation capabilities in space.

TREND 6.4: Efforts to develop capacity to rapidly rebuild space systems following direct attacks, but no operational capabilities — The ability to rapidly rebuild space systems after an attack could reduce vulnerabilities in space. Although the US and Russia are developing elements of responsive space systems, no state currently has this capability. The key US responsive launch initiative is the Falcon program, which seeks to develop a rocket capable of placing 100 to 1,000 kilograms into LEO within 24 hours. It includes funding for the the AirLaunch LLC QuickReach rocket, which came to an end in 2008, and the SpaceX Falcon-1.

2008 Developments:

- US, China, and France developing more capable microsatellites and rapid launch technologies

Space Security Impact

The ability to quickly launch new satellite systems, reconstitute damaged or failed components, or upgrade existing capabilities contributes to space security by reducing the vulnerability of space systems to environmental threats and natural degradation of capabilities and deterring potential attacks on space components. When combined with microsatellite constellations that can replace a single satellite (Trend 6.3), the longevity of the constellation is increased immeasurably. Relatively inexpensive systems are being developed to launch smaller satellites. As with most space technology, however, they could be used for other purposes, including the covert launch of space-based anti-satellite systems.

Space Systems Negation

TREND 7.1: Capabilities to attack ground stations and communications links are widely spread — Ground segments, including command and control systems and communications links, remain the most vulnerable components of space systems, susceptible to attack by conventional military means, computer hacking, and electronic jamming. Several incidents of intentional jamming of communications satellites have been reported in recent years. Iraq's acquisition of GPS-jamming equipment during Operation Iraqi Freedom in 2003 suggested that jamming capabilities are proliferating. The US leads in developing doctrines and advanced technologies to temporarily negate space systems by disrupting or denying access to satellite communications, and has deployed a mobile system to disrupt satellite communications without inflicting permanent damage to the satellite.

2008 Developments:

- US and China pursuing cyber attack capabilities
- States are vulnerable to cyber attacks by individuals

Space Security Impact

Although cyber attacks in 2008 did not appear to target space systems, they nonetheless represent a growing threat to space security as capabilities to launch them are spreading and improving, in what is becoming a protection-negation spiral (see Space Systems Protection Trend 6.2). For now, cyber attacks are less damaging than kinetic or other physical attacks, since they are generally temporary and reversible. They can, however, seriously disrupt a nation's ability to respond to a more damaging attack, and so should not be taken lightly. Because there have been few known past events, data on the impact of cyber attacks is scarce and the full impact of such a breach is unknown. Moreover, because individuals, often anonymous, as well as states can interfere with this facet of space security, the consequences could be both more complex and destabilizing.

TREND 7.2: US leads in the development of space surveillance capabilities that can support negation — Space surveillance capabilities for debris monitoring and transparency can also support satellite tracking for space negation purposes. The US and Russia maintain the most extensive space surveillance capabilities and the US has explicitly linked its development of enhanced space surveillance systems to efforts to enable offensive counterspace operations. China and India also have satellite tracking, telemetry, and control assets essential to their civil space programs. France, Germany, Japan, and Europe are developing independnet space surveillance capabilities.

2008 Development:

- US space surveillance and tracking data enable destruction of a failed satellite, as global efforts to improve access to such data continue

Space Security Impact

Space surveillance capabilities can be used to both enhance and degrade security in outer space, but activities in 2008 seemed to favor positive impacts (see Space Environment Trend 1.3 and Space Systems Protection Trend 6.1). The US engagement of a de-orbiting satellite in 2008 demonstrates the applicability of surveillance data to negation, but also the fact that such capabilities are used far more extensively to support civil space efforts such as human spaceflight, mitigate the risk of collision with debris, and manage space traffic. Nonetheless, the potential for independent space surveillance capabilities to support deliberate attacks against satellites and other space objects, demonstrated through the centrality of space surveillance in identifying foreign satellites, space control efforts, and close proximity operations, is one of the obstacles preventing access to the more precise data that is needed for some of the more protection-oriented functions listed above.

TREND 7.3: Ongoing proliferation of ground-based capabilities to attack satellites — The development of ground-based anti-satellite weapons employing conventional, nuclear, and directed energy capabilities dates back to the Cold War, when a variety of US and USSR programs were initiated. Since then technologies have proliferated to more than 30 states. The capability to launch a payload into space to coincide with the passage of a satellite in orbit is a basic requirement for conventional satellite negation systems. Some 28 states have demonstrated suborbital launch capability that could enable a rudimentary attack in space and, of those, 10 have orbital launch capability. As many as 30 states may have low-power lasers to degrade unhardened satellite sensors. The US, China, and Russia lead in the development of more advanced ground-based kinetic-kill systems that have the capability to directly attack satellites. They have access to advanced laser programs, which have inherent satellite negation capabilities in LEO.

2008 Developments:

- US reconfigures anti-missile system to destroy a failed satellite as it de-orbits
- Ongoing efforts to improve missile technology globally may enable anti-satellite capabilities
- US laser program for missile defense continues, but feasibility not proven

Space Security Impact

The US engagement of the de-orbiting USA-193 satellite demonstrates the ability to reconfigure an interceptor missile, even if only for a one-time event, for use against a satellite, raising the prospect of greater insecurity in space as more actors research and develop anti-missile systems. Increased global interest in missile and anti-missile capabilities has an uncertain effect on the security of outer space. While it is potentially threatening and destabilizing and could trigger an arms race targeting space, some assess it as a valuable deterrent against the use of force in space because it creates mutual vulnerabilities. The development of high-energy lasers can have the same uncertain impact, but this uncertainty is aggravated by the fact that lasers can be used in a wide range of space activities, including tracking objects in space, and they can be much more easily used covertly or without warning.

TREND 7.4: Increased access to space-based negation enabling capabilities — Space-based negation efforts require sophisticated capabilities, such as precision on-orbit maneuverability and space tracking. Many of these capabilities have dual-use potential. For example, microsatellites provide an inexpensive option for many space applications, but could be modified to serve as kinetic-kill vehicles or aid in targeting for other kinetic-kill vehicles. The US leads in the development of most of these enabling capabilities, although none appear to be integrated into dedicated space-based negation systems.

2008 Developments:

- A broad range of dual-purpose space-based technologies continue to be developed
- US weapons technology programs developing proximity and maneuverability capabilities

Space Security Impact

The duality of many of the technologies outlined here is clear from their presence in both Space Systems Protection and Space Systems Negation chapters. While microsatellites were initially created to protect space systems, much of their development has been in a range between passive protection and active negation. The largest danger is in the capacity to conduct proximity maneuvers, since the size of such satellites implies that they are difficult to detect and track. However, these capabilities are still very much under development, and the ability of one satellite to approach an uncooperative satellite without notice to conduct an offensive operation is still several years away.

Space-Based Strike Capabilities

TREND 8.1: While no space-based strike systems have been tested or deployed, the US continues to develop technologies behind space-based interceptors for its missile defense system — Although the US and USSR developed and tested ground-based and airborne ASAT systems between the 1960s and 1980s, there has not yet been any deployment of space-to-Earth or space-to-missile strike systems. Under the Strategic Defense Initiative in the 1980s, the US invested several billion dollars in the development of a space-based interceptor concept called Brilliant Pebbles, and tested targeting and propulsion components required for such a system. The US and USSR were both developing space-based directed energy strike systems in the 1980s, although today these programs have largely been halted.

2008 Developments:

- Funding cut for US Space Test Bed, but feasibility study approved
- Experimental missile defense satellite conducts second successful test of rocket sensor technology
- Multiple Kill Vehicle contract awarded

Space Security Impact

The absence of space-based strike systems and infrastructure continued to support the security of outer space in 2008. While precursor technology development continued in the Near-Field Infrared Experiment Test and the Multiple Kill Vehicle program, restraint by US policymakers is positive and indicates concern for space security and the challenges of balancing terrestrial missile defense requirements with the need to maintain freedom from space-based threats.

TREND 8.2: More countries are developing advanced space-based strike-enabling technologies through civil, commercial, and military programs — The majority of advanced, space-based strike enabling technologies are dual-use and are developed through civil, commercial, or military space programs. While there is no evidence to suggest that states pursuing these enabling technologies intend to use them for space-based strike purposes, such development does bring these actors technologically closer to this capability. For example, China, India, and Israel are developing precision attitude control and large deployable optics for civil space telescope missions. Five states in addition to the European Union are developing independent, high-precision satellite navigation capabilities. China, India, and the EU are developing Earth reentry capabilities that provide a basis for the more advanced technologies required for the delivery of mass-to-target weapons from space to the Earth.

2008 Developments:

- US Prompt Global Strike program continues to develop, but its long-term implications are unclear
- Key actors continue to develop a range of space-based strike enabling capabilities

Space Security Impact

Space-based weapons designed to strike terrestrial targets will require sophisticated technological developments that, at present, few spacefaring states seem able or willing to exploit. The development of dual-use capabilities that also provide enabling technologies for space-based strike systems continued in 2008, although there is no evidence that states are developing such capabilities for strike purposes. Nonetheless, the potential for space-to-Earth strike systems will continue to pose a challenge to the international community as advanced space-based technologies continue to be developed. While some enabling technologies for space-based strike are discrete and include significant technology barriers, many are advanced technologies associated with other space applications and have been developed for a variety of purposes by several different actors. If one actor were to pursue a space-based strike capability, others could follow.

The Space Environment

This chapter assesses trends and developments related to the impact of human activity on the space environment, with an emphasis on space debris and space resource issues such as the registration of orbital slots and the allocation of radio frequencies.

Space debris, which is predominantly caused by manmade objects, represents a growing threat to spacecraft. The impact of space debris upon space security is related to a number of key issues examined by this chapter, including the amount of space debris in various orbits, space surveillance capabilities that track space debris to enable collision avoidance, and efforts to reduce new debris and to potentially remove existing space debris in the future.

All space missions inevitably create some amount of space debris, mainly as rocket booster stages are expended and released to drift in space along with bits of hardware. More serious fragmentations are usually caused by energetic events such as explosions. These can be both unintentional, as in case of unused fuel exploding, or intentional, as in the testing of weapons in space that utilize kinetic energy interceptors. Tests of this sort have created thousands of long-lasting pieces of space debris, some 300 of which are reportedly still in orbit from USSR activities in the 1970s and 1980s.[1]

A growing awareness of the impact of space debris on the security of space assets has encouraged space actors to take steps to mitigate the production of new debris through the development and implementation of national and international debris mitigation guidelines, also examined here.

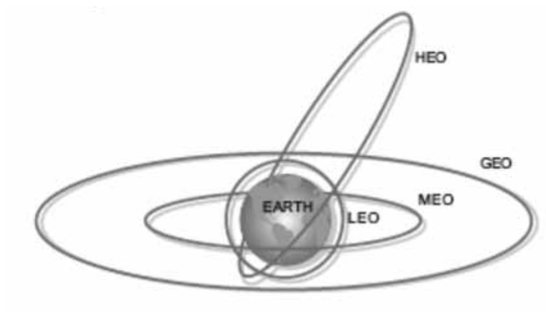
Geostationary orbits are limited natural resources. Actors who wish to place a satellite in this region must secure an appropriate orbital slot in which to do so and secure a portion of the radio spectrum to carry their satellite communications. Both radio frequencies and orbital slots are indispensable tools for all space operations and their national assignments are coordinated through the International Telecommunication Union (ITU). This chapter assesses the trends and developments related to the demand for orbital slots and radio frequencies, as well as the conflict and cooperation associated with the distribution and use of these key space environment resources. This includes compliance with existing norms and procedures developed through the ITU to manage the use and distribution of orbital slots and radio frequencies.

Because the focus of this report is on human activities affecting the security of space, this chapter does not address natural phenomena such as solar flares and near-Earth asteroids. In cases where these issues might relate to international law or institutions, they are covered under Space Laws, Policies, and Doctrines.

Space Security Impact

Space is a harsh environment and orbital debris represents a growing threat to the secure access to, and use of, space due to the potential for collisions with spacecraft. Due to very high orbital velocities of up to 7.8 kilometers per second (~30,000 kilometers per hour) in Low Earth Orbit (LEO), debris as small as 10 centimeters in diameter carries the kinetic energy of a 35,000-kilogram truck traveling at up to 190 kilometers per hour. While objects have lower relative velocities in Geostationary Orbit (GEO), debris at this altitude is still moving as fast as a bullet — about 1,800 kilometers per hour. No satellite can be reliably protected against this kind of destructive force and it is considered to be impractical to shield against objects bigger than one centimeter.

Figure 1.1: Types of Earth orbits*



* See Annex for a description of each orbit's attributes

The total amount of space debris in orbit is growing each year through human activities and is concentrated where these activities take place. LEO is the most highly congested area, especially the Sun-synchronous region. Some debris in LEO will reenter the Earth's atmosphere and disintegrate in a relatively short period of time due to atmospheric drag, but debris in orbits above 600 kilometers will remain a threat for decades and even centuries. There have already been a number of collisions between civil, commercial, and military spacecraft and pieces of space debris. Although a rare occurrence, the reentry of very large debris can also pose a threat to the Earth and infrastructure on Earth.

The development of surveillance capabilities to track space debris and avoid collisions clearly provides significant space security advantages. Efforts to mitigate the production of new debris through compliance with national and international rules, guidelines, standards, and practices can also have a positive impact on space security. Technical measures to efficiently remove debris, once developed and used, could have a positive impact in the future.

Resource distribution, including the assignment of orbital slots and radio frequencies to space actors, has a direct impact on the abilities and inabilities of actors to access and use space. Growing numbers of space actors, particularly in the communications sector, have led to more competition and sometimes friction over the use of orbital slots and frequencies.

New measures to increase the number of available orbital slots and frequency bands, such as technology to reduce interference between radio signals, can reduce competition and increase the availability of these scarce resources. Confidence in the sustainability of their use creates a strong incentive for space actors to cooperate in the coordination, registration and use of radio frequencies and orbital slots. Cooperation in this area can also strengthen support for the application of the rule of law to broader space security issues.

Key Trends

Trend 1.1: Growing risk to spacecraft as orbital debris continues to increase

The US Space Surveillance Network (SSN) is the system that most comprehensively tracks and catalogs space debris, although technological factors limit it to spot checking rather than continuous surveillance, and limit the size of tracked objects to those greater than 10 centimeters in LEO and much larger in GEO. According to the latest reports, the US Department of Defense (DOD) is using the SSN to track more than 19,000 objects approximately 10 centimeters or larger, of which fewer than 5 percent are operational satellites.[2] It is estimated that there are over 300,000 objects with a diameter larger than one centimeter, and millions smaller.[3]

Two key factors affecting the amount of space debris are the number of objects in orbit and the number of debris-creating launches each year. Growth in the debris population increases the probability of inter-debris collisions that have the potential to create even more debris. A recent study by NASA has shown that, in LEO, inter-debris-debris collisions will become the dominant source of debris production within the next 50 years. As debris collides and multiplies, it will eventually create a "cascade of collisions" that will spread debris to levels threatening sustainable space access.[4] As of 2003 it was estimated that 43 percent of tracked debris resulted mostly from explosions and collisions.[5] Additional space debris in LEO could be created by use of ground- and space-based midcourse missile defense systems currently under development, or other weapons testing in space.[6]

Between 1961 and 1996 an average of approximately 240 new pieces of debris were cataloged each year; these new pieces were the result, in large part, of fragmentation and the presence of new satellites. Between 8 October 1997 and 30 June 2004 only 603 new pieces of debris were cataloged — a noteworthy decrease, particularly given the increased ability of the system. This decline can be related in large part to international debris mitigation efforts, which increased significantly in the 1990s, combined with a lower number of launches per year. Since 2004 an increase in the annual rate of debris production has again been observed.

Today, collisions between space assets like the International Space Station and very small pieces of untracked debris are a frequent but manageable problem.[7] Collisions with larger objects remain rare. A 1995 US National Research Council study found that within the orbital altitude most congested with debris (900-1,000 kilometers), the chance of a typical spacecraft colliding with a large fragment was only about one in 1,000 over the spacecraft's 10-year functional lifetime.[8]

However, the same study noted that, "although the current hazard to most space activities from debris is low, growth in the amount of debris threatens to make some valuable orbital regions increasingly inhospitable to space operations over the next few decades."[9] Indeed, some experts at NASA believe that collisions between space assets and larger pieces of debris will remain rare only for the next decade, although there is ongoing discussion about this assessment.[10] While major collisions have so far been rare, there have been several incidents of varying severity as noted in Figure 1.2 below.

Figure 1.2: Unintentional collisions between space objects[11]

Year	Event
1991	Inactive Cosmos-1934 satellite hit by cataloged debris from Cosmos 296 satellite
1996	Active French Cerise satellite hit by cataloged debris from Ariane rocket stage
1997	Inactive NOAA-7 satellite hit by uncataloged debris large enough to change its orbit and create additional debris
2002	Inactive Cosmos-539 satellite hit by uncataloged debris large enough to change its orbit and create additional debris
2005	US rocket body hit by cataloged debris from Chinese rocket stage
2007	Active Meteosat-8 satellite hit by uncataloged debris large enough to change its orbit
2007	Inactive NASA UARS satellite believed hit by uncataloged debris large enough to create additional debris

2008 Development

Short-lived debris created by destruction of US-193 satellite to mitigate risk posed by reentry

On 20 February 2008, the United States Navy fired a modified Standard Missile 3 (SM-3) missile defense interceptor from an Aegis warship to intercept and destroy US-193 – a National Reconnaissance Office (NRO) satellite launched in 2006 that subsequently failed in orbit[12] and was posed to reenter Earth's atmosphere[13] (see Space System Negation Trend 7.3). The satellite was carrying a full tank of toxic hydrazine fuel (454 kilograms), believed to have frozen into a solid mass. Initial reports from US government officials and other experts indicated that the expected reentry of the satellite posed no risk to Earth (17,000 manmade objects have re-entered the Earth's atmosphere over the past 50 years), but the government later concluded that pieces of the satellite and fuel would survive reentry, posing a risk to human life.[14]

A decision was subsequently taken to 'engage' the satellite prior to reentry to mitigate the potential risk from debris and fuel landing on Earth.[15] Efforts were made to minimize as much as possible long-lasting debris from the event. The interception was planned to take place when the satellite was close to reentry and the angle of the impact was designed so that as few pieces as possible would be thrown into higher orbits. Consequently, only 360 pieces of trackable debris were created by the event. Of those, 174 stayed in orbit long enough to be entered into the US Space Surveillance Network (SSN) satellite catalog.[16] The majority of pieces decayed within a few months of the event, however at least one piece of trackable debris remains on orbit.[17]

Analyzing the potential threat to Earth posed by the satellite and its fuel after the receipt of several requests for information, the US government released a paper on the subject of spacecraft reentry survivability based on a significant amount of frozen hydrazine fuel. The paper indicated that 80 percent of the tank thickness would have ablated away during reentry.[18] Still, some believe that the analysis may be over simplified to favor survivability.[19]

Figure 1.3: Intentional collisions between space objects

Year	Event	# Debris Created*	Lifetime
1963 - 1982	Nine Soviet co-orbital ASAT test intercepts	700+	Decades
1985	US destruction of Solwind using F-15 launched ASAT	285	19 years
2007	Chinese destruction of FY-1C using direct ascent ASAT	2,300	Centuries
2008	US destruction of de-orbiting USa-193 satellite	360	Months

*trackable (greater than 10 centimeters) debris only

2008 Development

Growth rate of new space debris declines for first time in four years

For the first time since 2004, the annual rate of growth in new trackable space debris declined in 2008, with almost all fragmentation events generating relatively minor and short-lived debris. By the end of 2008, the total number of large and medium-sized objects (larger than 10 centimeters in diameter) in orbit cataloged by the US SSN stood at 12,743.[20] This number represents an increase of 287 objects or 2.2 percent over yearend data for 2007, which is less than in previous years.[21]

The most serious breakup of 2008 involved Russia's Cosmos-2421, a Russian Electronic Intelligence Ocean Reconnaissance Satellite (EORSAT). On 14 March 2008 the satellite fragmented into approximately 300 pieces of debris while in a 400 kilometer by 420 kilometer orbit at an inclination of 65°. Two additional fragmentations occurred on 28 April and 9 June 2008. In total, 508 pieces of debris from the satellite were cataloged. By 1 February 2009, 439 of these pieces had reentered the Earth's atmosphere. However, a significant number of other pieces had been projected into orbits with apogees as high as 900 kilometers and will stay in orbit for much longer. Fragmentation events are not new for this type of satellite. Twenty-two of the 50 EORSATs launched by Russia since 1974 have broken up.[22] Generally, this fragmentation occurs toward the end of the satellite's operational life.[23] It has been speculated that the EORSATs undergo an intentional destruction prior to reentry to protect the technology onboard and that an anomaly may have caused this system to trigger early.

In early July 2008, it was reported that Russia's Cosmos-1818 had released dozens of small particles.[24] These particles appear to be metallic in nature, which has led to the conclusion that they are droplets of NaK, a sodium potassium alloy that is liquid at room temperature. Historically, NaK has been used as coolant on Soviet nuclear-powered satellites, such as the Radar Ocean Reconnaissance Satellites (RORSATs). While not a RORSAT itself, Cosmos-1818 uses a new-generation nuclear thermionic nuclear power supply.[25] It is located in a relatively high nuclear safety orbit of 800 kilometers to prevent premature reentry of radioactive components, which happened when Cosmos-954 crashed in northern Canada in 1978.

On 14 March 2008 a Russian Briz-M upper stage failed during the launch of the SES Americom AMC-14 satellite.[26] Consequently, the Briz-M has a significant amount of fuel left onboard and is likely to experience a severe fragmentation event in the future, similar to the Briz-M explosion in 2007 that created over 1,000 pieces of debris. [27] An independent review board announced that the primary cause of the 2007 failure was a ruptured exhaust gas duct, and recommended that International Launch Services, which operates the booster, replace the duct to prevent future failures.[28]

A complete listing of the 2008 breakups can be found in Figure 1.4 below. While some types of breakup can be mitigated through use of best practices, others are more worrisome. These include the fragmentation events associated with Cosmos-1818 and Cosmos-2421, both of which were only the most recent examples of satellite models with a long history of creating debris on orbit.

Figure 1.4: Summary of 2008 debris events[29]

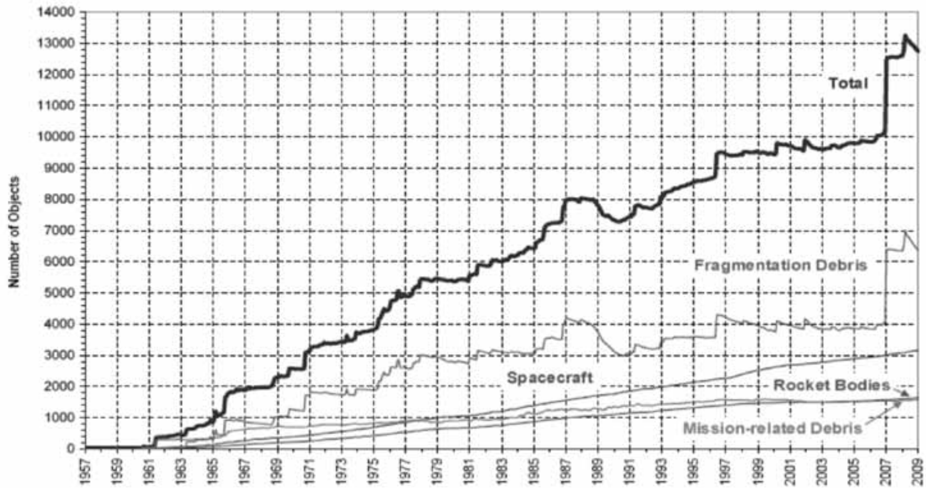
Parent Object	Country	Date	Estimated Number of Pieces*	Cataloged Number of Pieces**	Lifespan of Pieces
Cosmos-2125	CIS	16 January 2008	6	None	None
CZ-3A R/B	PRC	27 January 2008	30-40	None	None
SL-6 R/B	CIS	17 February 2008	2	None	None
USA-193	US	21 February 2008	360	173	8 months
Cosmos-2421	CIS	14 March 2008***	500+	507	Years
Atlas-5 R/B	US	21 March 2008	25	None	None
Cosmos-1818	CIS	Early July 2008	50+	None	Decades

* As initially reported by the US Space Surveillance Network

** As of 1 February 2009

*** Date of first breakup. Object experienced two additional breakups on 28 April and 9 June. Pieces displayed in table are totals for all three breakups

Figure 1.5: Growth of on-orbit population by type[30]



This chart displays a summary of all objects in Earth orbit officially cataloged by the SSN. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

2008 Development

Increased risk to spacecraft posed by debris

The International Space Station (ISS) conducted its first collision avoidance maneuver in five years on 27 August 2008, when it was moved to avoid a piece of debris from Russia's Cosmos-2421, which released debris three times in 2008 (see Trend 1.1 above). Located only 60 kilometers above the ISS, many of the 500 trackable pieces of debris released by Cosmos-2421 intersect the orbit of the ISS and could pose collision threats over the next few years. The US screens the ISS for potential collisions at least once daily. A collision avoidance maneuver is considered for any conjunction that has a probability of collision greater than one in 10,000.[31] The conjunction on 27 August was predicted to come within 1.6 kilometers of the ISS and had a collision probability of one in 72.[32]

In September 2008, NASA announced that a Shuttle repair mission to the Hubble Space Telescope planned for the following October had an increased probability of total loss, including risks posed by space debris.[33] The greatest source of risk from debris factoring into this probability was an impact on the inside of the open Shuttle bay doors, which contain critical components of the cooling system to help dissipate heat and regulate the temperature of the orbiter.

Debris caused by China's intentional destruction of the Fengyun-1C satellite in 2007 continued to pose threats to operational spacecraft in 2008. In November 2008 it was reported that the French microsatellite Parasol was forced to make a collision avoidance maneuver as the result of a potential conjunction with a piece of debris from that event.[34] The Parasol is part of NASA's A-Train, a Sun-synchronous constellation of several satellites that provide remote sensing of the Earth.[35] Another of the A-train satellites, NASA's Terra, had previously conducted a collision avoidance maneuver in June 2007 due to a conjunction with a piece of Fengyun-1C debris.

2008 Space Security Impact

With no major on-orbit fragmentations in 2008, there was minimal additional risk by new debris, but existing debris continues to pose hazards to operational spacecraft, particularly in Low Earth Orbit (LEO). Concerns are also raised by intentional satellite breakups, as well as the ongoing presence in orbit of satellites with a history of severe fragmentation. Although relatively little lasting debris was created, the US destruction of the failed USA-193 satellite prior to its reentry in Earth's atmosphere raises a challenge for space security in which the sustainability of the space environment can potentially conflict with security from threats posed by objects in space.

Trend 1.2: Continued efforts to develop and implement debris mitigation practices

Growing awareness of space debris threats has led to the development of a number of efforts to decrease the amount of new debris, beginning at the national level. NASA first issued guidelines on limiting orbital debris in the August 1995 *NASA Safety Standard 1740*. In December 2000 the US government issued formal orbital debris mitigation standards for space operators. These standards were developed by DOD and NASA. In 2004 the US Federal Communications Commission imposed requirements for satellite operators to move geostationary satellites at the end of their operating life into "graveyard orbits" some 200 to 300 kilometers above GEO, and in 2005 new rules went into effect requiring satellite system operators to submit orbital debris mitigation plans.[36] In 2008 NASA published the first edition of the *Handbook for Limiting Orbital Debris*, which presents the scientific background for debris mitigation procedures.[37]

The European Space Agency (ESA) initiated a space debris mitigation effort in 1998. The *ESA Space Debris Mitigation Handbook* was published in 1999 and revised in 2002.[38] Also in 2002 ESA issued the European Space Debris Safety and Mitigation Standard[39] and issued new debris mitigation guidelines in 2003. Japan and Russia also appear to strongly support the mitigation of space debris production. China, although a member of the Inter-Agency Space Debris Coordination Committee (IADC), has been slow to adopt debris mitigation measures.[40] (The IADC includes representatives of the space agencies of China, Europe [ESA], France, Germany, India, Italy, Japan, Russia, Ukraine, the UK, and the US.) At the 2003 annual meeting of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), China committed to "undertake the study and development of Chinese design norms to mitigate space debris, in conformity with the principles reflected in the space debris mitigation guidelines developed by the Coordination Committee."[41]

While there are differences among national debris mitigation guidelines, they are broadly consistent. For example, all national guidelines address issues related to the minimization of debris released during normal operations. Most states require residual propellants, batteries, flywheels, pressure vessels, and other instruments to be depleted or made passive at the end of their operational lifetime.[42] All major national debris mitigation guidelines address the disposal of GEO satellites, typically in graveyard orbits some 235 kilometers above the GEO orbit, and most seek the removal of dead spacecraft from LEO within 25 years. [43]

The Scientific and Technical Subcommittee of COPUOS began discussions of space debris issues in 1994 and published its Technical Report on Space Debris in 1999. In 2001 COPUOS asked IADC to develop a set of international debris mitigation guidelines, on which it based its own draft guidelines in 2005.[44] In 2007 these guidelines were adopted by UN COPOUS and endorsed by the UN General Assembly as voluntary measures with which all states are asked to comply.[45]

Figure 1.6: UN COPUOS Space Debris Mitigation Guidelines[46]

1. Limit debris released during normal operations.
2. Minimize the potential for breakups during operational phases.
3. Limit the probability of accidental collision in orbit.
4. Avoid intentional destruction and other harmful activities.
5. Minimize potential for post-mission breakups resulting from stored energy.
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission.
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission.

The progressive development of international and national debris mitigation guidelines has been complemented by research into technologies to physically remove debris, such as electromagnetic "tethers" that could help to safely de-orbit non-operational satellites or debris.[47] However, a 2006 IADC report concluded that, while "electrodynamic tethers have strong potential to become effective mitigation measures…various problems are still to be solved before this technique can be practically adopted."[48] Currently natural decay due to atmospheric drag remains the only technologically and economically feasible way to remove debris, although research into this area continues. The issue is also affected by security concerns, because many of the concepts being developed could also feasibly be used against uncooperative objects in space.

2008 Development

International recognition and adoption of UN Debris Mitigation Guidelines

One week prior to the US engagement of its failed US-193 satellite, the US government briefed the COPUOS Scientific and Technical Sub-Committee of its plans and the steps being taken to mitigate the creation of space debris (see Trend 1.1). The US presentation asserted that it was conducting the engagement within the parameters of the Debris Mitigation Guidelines drafted by COPOUS and endorsed by the UN, based on a situation where "intentional destruction and other harmful activities may be necessary." If the engagement attempt had failed, the US also pledged to provide advance notifications of tracking and impact predictions in accordance with the IADC Space Debris Mitigation Guidelines.[49] The engagement was successful, however, and a subsequent brief was presented to COPUOS on the resulting space debris.[50]

Throughout its 2008 session the Subcommittee also received technical presentations from Germany, Japan, Russia, and the ESA on their efforts to mitigate debris.[51]

2008 Development

NASA studies potential value of physically removing debris from orbit

In July 2008 NASA published a paper analyzing the value of actively removing a handful of debris objects from orbit each year.[52] In contrast to debris mitigation, which seeks to limit the amount of debris produced in space, the methods presented in the paper aim to reduce the amount of debris already in orbit through active removal. The paper concluded that since collisions between existing orbital debris will cause the population to increase even without additional launches, methods of actively removing debris are necessary for the sustainability of critical low Earth orbits. While actual methods of removing objects were not analyzed in the paper, calculations showed that removal of just five objects per year was enough to stabilize the debris population in low Earth orbit.[53] However, debate remains on the most technologically and economically feasible way to remove debris, as well as which objects should be targeted for removal.

2008 Space Security Impact
Reporting by some states on efforts to implement the Debris Mitigation Guidelines of the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and evidence that some states are factoring the guidelines into decision-making are positive signs that the Mitigation Guidelines are becoming part of state practice. However, responsible actions by a few spacefaring states will not guarantee progress in reducing the creation of space debris. In particular, efforts are needed to make emerging and developing space states aware of the consequences of space debris and their international responsibilities, and to help them develop the technical means to meet those responsibilities. Finally, while the US asserts that it adhered to the guidelines when destroying the de-orbiting USA-193 satellite, it is not clear how other states may engage in similar actions over the long term (see Laws, Policies, and Doctrines).

Trend 1.3: Space surveillance capabilities to support collision avoidance slowly improving

Space surveillance capabilities are vital to the mitigation of environmental hazards because they provide information about the locations of objects in Earth orbit. There is no international space surveillance mechanism, but efforts to create one date from the 1980s. In 1986 Canada presented the so-called PAXSAT study, which proposed a space-to-space remote sensing system (PAXSAT A) based on non-superpower technology available at the time. In 1989 France proposed the creation of an Earth-based space surveillance system consisting of radar and optical sensors to allow the international community to track the trajectory of space objects. Such an initiative could complement the US-Russian agreement to establish the Joint Center for the Exchange of Data from Early Warning Systems and Notification of Missile Launches and would be consistent with that agreement's anticipated multilateralization.[54] In the absence of an international system, countries are establishing independent space surveillance capabilities, with some limited degree of information exchange.

The US Space Surveillance Network (SSN) is comprised of approximately 30 radar and optical sensors at 16 sites worldwide.[55] The SSN can reliably track objects in LEO with a radar cross-section of ten centimeters in diameter or greater. It uses a tasked sensor approach, which means that not all orbital space is searched at all times; thus objects may be observed and then lost again. The entire SSN pulls in more than 500,000 observations daily on objects in orbit. The Air Force Space Surveillance System or Space Fence is the oldest US space surveillance system and consists of three transmitters and six receivers spread across the Southern US. It provides the greatest number of observations of any sensor in the network and is capable of making some five million detections each month of objects larger than a basketball to an altitude of 10,000 kilometers.[56] Many of the other SSN sensors also do double duty as missile warning radars.

Data from all the SSN sensors is used to maintain a satellite catalog of manmade objects in Earth orbit. Those objects that can be tracked repeatedly and whose source has been identified are placed in the satellite catalog, currently numbering almost 13,000 objects. A low accuracy version of this catalog is publicly available at the Space Track website, but the data is too inaccurate to adequately support collision avoidance. Using its own more precise, unpublished orbital data, the US Air Force screens about 300 satellites each day to warn primarily the operators of US government satellites, NASA, and spacecraft carrying humans of potential collisions. While other operators can request this information through the Commercial and Foreign Entities (CFE) program, but it is not always provided. More than 25,000 users from 149 countries have registered to use the CFE, and efforts are currently underway transform it into formal system. But while some operators would like direct access to orbital data, there is resistant to widely releasing it.[57] The US updated its regulations on redistribution of SSN data according to national security interests in 2004.[58]

The Center for Space Standards & Innovation (CSSI), a not-for-profit organization, runs conjunction analyses on all satellites in orbit (active and inactive), using the two-line element (TLE) data provided by the North American Aerospace Defense Command (NORAD) through a service called SOCRATES (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space), and provides free reports to satellite operators.[59] But the system is limited by the accuracy of the TLE data.

Russia is the only other state with a dedicated space surveillance system, which uses mainly Russia's early warning radars along with more than 20 optical and electro-optical facilities at 14 locations on Earth.[60] The main optical observation system, Okno (meaning "window"), located in the mountains near the Tajik city of Nurek, aims principally at objects from 2,000 to 40,000 kilometers in altitude.[61] The SSS has significant limitations due to its limited geographic distribution: it cannot track satellites at very low inclinations and the operation of Russian surveillance sensors is reportedly erratic.[62] The network as a whole is estimated to carry out some 50,000 observations daily, contributing to a catalog of approximately 5,000 objects, mostly in LEO.[63] While information from the system is not classified, Russia does not have a formal process to widely disseminate information about observations.[64]

France and Germany also use national space surveillance capabilities to monitor debris. France's Air Force operates the Grande Réseau Adapté à la Veille Spatiale (GRAVES) space surveillance system, which has been fully operational since 2005. The system is capable of monitoring approximately 2,000 space objects, including orbital debris, in LEO up to 1,000 kilometers in altitude, and follows more than a quarter of all satellites, particularly those that France considers threatening and those for which the US does not publish orbital information.[65] France has cited the necessity of developing this system to decrease reliance on US surveillance information, and to ensure the availability of data in the event of a data distribution blackout.[66] The German Defense Research Organization operates the FGAN Tracking and Imaging Radar. The 34-meter-diameter antenna carries out observations in the L- and Ku-bands and can see objects as small as two centimeters in diameter at altitudes of 1,000 kilometers.[67] Also, the British National Space Centre (BNSC) is developing a new space surveillance system to map large areas of the sky quickly and has existing optical telescope capabilities.[68]

The EU maintains information from the SSN in its own Database and Information System Characterising Objects in Space (DISCOS), which also takes inputs from Germany's FGAN Radar and ESA's Space Debris Telescope in Tenerife, Spain. The Space Debris Telescope, a one-meter Zeiss optical telescope, focuses on observations in GEO and can detect objects as small as approximately 15 centimeters in diameter in that orbit.[69] Other optical sensors, including three Passive Imaging Metric Sensor Telescopes operated by the UK Ministry of Defence, the Zimmerwald one-meter telescope at the Astronomical Institute of the University of Berne in Switzerland, and the French SPOC system and ROSACE telescope, contribute to debris surveillance in GEO.[70] Using data from DISCOS, ESA's Space Operations Centre in Germany has begun to provide a Space Debris Avoidance Service for satellite operators.[71] The ESA has defined space surveillance as one of three main security priorities.[72] Although there is still not an integrated European network, studies of options are ongoing and a formal proposal was made in 2008 (see below).

Since joining the IADC in 1995 China has also maintained its own catalog of space objects, using data from the SSN to perform avoidance maneuver calculations and debris modeling.[73] Space surveillance is an area of growth for China, which announced new investments in optical telescopes for debris monitoring in 2003. Prior to the launch of the Shenzhou V in 2003, it was revealed that the spacecraft had a debris "alarm system" to warn of potential collisions.[74] In 2005 the Chinese Academy of Sciences established a Space Object and Debris Monitoring and Research Center at Purple Mountain Observatory that employs researchers to develop a debris warning system for China's space assets.[75] To support its growing space program, China has established a tracking, telemetry, and command (TT&C) system consisting of six ground stations in China and one each in Namibia and Pakistan, as well as a fleet of four Yuan Wang satellite-tracking ships.[76] These assets provide the foundation for space surveillance, but are believed to have limited capacity to track uncooperative space objects.

Since 2004 Japan has operated a radar station in Okayama prefecture dedicated to the observation of space debris to support manned space missions. The Kamisaibara Spaceguard Center radar can detect objects as small as one meter in diameter to a distance of 600 kilometers, and track up to 10 objects at once.[77] Two optical telescopes at the Bisei Astronomical Observatory — a 0.5-meter tracking telescope and a 1.01-meter reflecting telescope capable of viewing objects as small as 30 centimeters[78] — are dedicated to space debris surveillance in GEO.

Canada's Microvariability and Oscillations of Stars microsatellite hosts a space telescope and was a technology demonstrator for future space surveillance efforts.[79] Canada is also developing the Sapphire system, which will feature a space-based sensor that will provide observations of objects in high Earth orbits (6,000 to 40,000 kilometers) for the US SSN, as will Canada's planned Near Earth Object Surveillance Satellite (NEOSsat) asteroid discovery and debris tracking mission, being developed by Defence Research and Development Canada and the Canadian Space Agency.[80]

Figure 1.7: Space surveillance capabilities[81]

Country	Optical Sensors	Radar Sensors	Orbital Sensors	Global Coverage	Centralized Tasking	Catalog	Public Data
Amateur observers	■			□	□	□	■
Bolivia*	■						
Canada	■		(□)				
China	■	■					
European Union	■	■			(□)	(□)	
France	■	■					
Georgia*	■						
Germany		■					
Great Britain	■	■					
Japan	■	■					
India	■						
Norway		■					
Russia	■	■				□	
South Africa	■						
Spain*	■						
Switzerland	■						
Tajikistan*	■						
Ukraine	■						
United States	■	■	□	□	■	■	□
Uzbekistan*	■						

Key
■ = Full capability
□ = Some capability
(□) = Under development
* Part of the International Scientific Optical Network (ISON)

2008 Development

The US, European Space Agency, and Russia take steps to improve access to independent space surveillance data

In March 2008 the US Air Force announced that it was exploring a program to place sensors on satellites to increase data available for space situational awareness.[82] Citing the large number of military, commercial, civil, and scientific satellites in orbit, the Air Force seeks to develop small optical sensors that can be mounted on any satellite that volunteers as a host. Key to this approach is the development of sensors that can be fitted to a wide variety of satellite buses in a standard way to minimize the impact on the manufacturing and requirements of the host satellite. In October 2008 the US Air Force awarded a $30-million contract to Lockheed Martin for the Self-Awareness Space Situational Awareness (SASSA) technology demonstrator program, which may be related to this project (see Space Systems Protection Trend 6.2).[83]

Efforts are also under way to improve the capabilities of the existing SSN. In July 2008 the US Air Force Space Command announced that it is planning to accelerate work to upgrade the Haystack radar so that it will be capable of imaging microsatellites. Space Command requested an extra $10-million in the 2008 defense budget to ensure that the work is completed by 2012.[84] This comes as the only on-orbit space surveillance satellite ceased operation on 16 July 2008.[85] The Mid-Course Space Experiment/Space Based Visible sensor was originally a Ballistic Missile Defense Organization experiment launched in 1996 and later turned over to US Space Command to provide data on deep space objects for the SSN.[86] Its replacement, the Space Based Space Surveillance (SBSS) satellite, is planned for launch in 2009 (see Space Systems Negation Trend 7.2).[87] An update on the planned S-Band Fence for the SSN was reported in October 2008, with the US Air Force projecting that the new Space Fence would be operational by 2015.[88] The upgrade would cost approximately $1-billion with a contract expected to be awarded in February 2009. The S-Band Fence would enable tracking of objects as small as 5 centimeters in diameter as far as 20,000 kilometers in orbit. It is currently planned to consist of three transmitter-receiver pairs spread across the globe.

After several years of discussions officials from the European Space Agency agreed in November 2008 to spend $62.8-million over three years to initiate a European space situational awareness program, beginning with development of a data security and data release policy, a study of space weather and near-Earth objects, work on a ground-based tracking radar, and the design of space surveillance data centers.[89] Continuation of the program will be addressed again in 2011.[90] In the meantime, member states with data from national military systems will be exploring limited agreements to combine data from complementary sensors such as the French GRAVES radar and the German Tracking & Imaging Radar (TIRA).[91]

Russia secured permanent access to its space surveillance radar in July 2008 in a deal with Tajikistan to turn over control of the Okno space tracking facility to Russia in exchange for debt forgiveness of $242-million.[92]

2008 Development

Efforts to better coordinate international space surveillance data increase

In early 2008, the Center for Space Standards & Innovation began offering SOCRATES-GEO, an enhanced version of its service that focuses on monitoring satellites in GEO through cooperation with the commercial operators.[93] In exchange for providing very accurate data on their satellites' positions and upcoming maneuvers, participating companies receive conjunction assessment and collision avoidance assistance from CSSI. Six major service providers participated in 2008: Intelsat, Inmarsat, EchoStar, SES, NOAA, and Star One, which together include over 100 satellites. Like the regular SOCRATES service, however, it is limited by the inaccuracies of the public two-line elements provided by NORAD for all the non-participating satellites and debris, as well as the timeliness with which participants provide data.

Some of the major satellite companies have joined together to examine a new concept for data sharing known as the "data center," which would create a shared repository of orbital data from both operators and the CFE. Still others are considering a global database that would include data from countries in addition to the US, and industry.[94]

In October 2008, details of the International Space Observation Network (ISON) space tracking network were presented at the third annual International Association for the Advancement of Space Safety Conference. ISON comprises 18 scientific institutions that operate 25 optical telescopes in nine different countries, mostly in Europe and Asia.[95] Working in partnership with the ESA's European Space Operations Centre, the data collected by ISON was used to publish the tenth edition of the *Classification of Geosynchronous Objects* in February 2008.[96] This document provides a complete listing of all objects near geosynchronous orbits that are currently tracked by both ISON and the US SSN, including those that are under active control and those that are drifting through the GEO belt. The classification includes orbits for 146 objects not included in the satellite catalog published by the US military.[97] At the end of 2008 there was discussion of a potential partnership between ISON and CSSI's SOCRATES-GEO service, particularly of the ability for ISON to provide very accurate positional data on space debris, which would further improve the accuracy of the conjunction assessments provided by SOCRATES.

In June 2008 experts from US Air Force Space Command, Department of Defense, and State Department met with representatives from the ESA and "key European allies" to discuss future cooperation on space surveillance.[98]

2008 Space Security Impact

The various national efforts to improve independent space surveillance capabilities in 2008 are positive for space security because they provide better and redundant tracking of space objects and greater transparency of space activities. However, ongoing challenges to greater cooperation and collaboration include hesitancy to share information on satellites that are deemed sensitive, particularly since space surveillance information can be used to support space negation efforts; and technical difficulties associated with combining information in various formats and from different types of sensors. Consequently, the use of orbital data to adequately support collision avoidance remains limited, but events in 2008 indicate that such use may increase in the near future.

Trend 1.4: Growing demand for radio frequency spectrum and orbital slots

Radio frequencies

The radio frequency spectrum is the part of the electromagnetic spectrum that allows the transmission of radio signals. It is divided into portions known as frequency bands. Frequency is generally measured in hertz, defined as cycles per second. Radio signals can also be characterized by their wavelength. Higher frequencies (shorter wavelengths) are capable of transmitting more information than lower frequencies (longer wavelengths), but require more power to travel longer distances.

Certain widely used frequency ranges have been given alphabetical band names in the US. Communications satellites tend to use the L-band (1-2 gigahertz) and S-band (2-4 gigahertz) for mobile phones, ship communications, and messaging. The C-band (4-8 gigahertz) is widely used by commercial satellite operators to provide services such as roving telephone services, and the Ku-band (12-18 gigahertz) is used to provide connections between satellite users. The Ka-band (27-40 gigahertz) is now being used for broadband communications. It is US policy to reserve the Ultra-High Frequency, X-, and K-bands (240-340 megahertz, 8-12 gigahertz, and 18-27 gigahertz, respectively) for the US military.[99]

Most satellite communication falls below 60 gigahertz; thus actors are competing for a relatively small portion of the radio spectrum, with competition particularly intense for the segment of the spectrum below 3 gigahertz.[100] Additionally, the number of satellites operating in the 7-8 gigahertz band, commonly used by GEO satellites, has grown rapidly over the past two decades.[101] Since many satellites vie for this advantageous frequency and ever closer orbit slots, there is an increased risk of accidental signal jamming.

Originally adopted in 1994, the current version of the International Telecommunication Union (ITU) Constitution[102] governs international sharing of the finite radio spectrum and orbital slots used to communicate with and house satellites in GEO. Article 45 of the Constitution stipulates that "all stations…must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other members."[103] Military communications are exempt from the ITU Constitution, though they must observe measures to prevent harmful interference. It is aptly observed that "interferences from the military communication and tracking systems into satellite communications is on the rise"[104] as military demand for bandwidth grows. During the US-led invasion of Afghanistan in 2001, when the US military used some 700 megabytes per second of bandwidth, up from about 99 megabytes per second used during the 1991 US operations in Iraq.[105]

While crowded orbits can result in signal interference, new technologies are being developed to manage the need for greater frequency usage, allowing more satellites to operate in closer proximity without interference. Frequency hopping, lower power output, digital signal processing, frequency-agile transceivers, and software-managed spectrum have the potential to significantly improve bandwidth use and alleviate conflicts over bandwidth allocation. Current receivers have a higher tolerance for interference than those created decades ago, reflecting the need for increased frequency usage and sharing.[106] Significant research is also being conducted on the use of lasers for communications, particularly by the military (see Space Systems Protection Trend 6.2). Lasers transmit information at very high bit rates and have very tight beams, which could allow for tighter placement of satellites, thus alleviating some of the current congestion and concern about interference.

Today, issues of interference arise primarily when two spacecraft require the same frequencies at the same time, and their fields of view overlap or they are transmitting in close proximity to each other. While interference is not epidemic, it is a growing concern for satellite operators, particularly in "crowded space segments" in Asia.[107] For example, a general manager of engineering at AsiaSat has noted that "frequency coordination is a full-time occupation for about five percent of our staff, and that's about right for most other satellite companies."[108] An official at New Skies Satellites noted, however, that while interference is common, "satellite operators monitor their systems around the clock and can pinpoint interference and its source fairly easily in most cases."[109]

The simplest way to reduce such interference is to ensure that all actors have access to reasonable and sufficient bandwidth. To this end the US DOD is releasing a portion of the military-reserved spectrum from 1,710-1,755 megahertz to the commercial sector for third-generation wireless communications.[110] India, however, has the world's fastest growing telecoms market, and there is an ongoing struggle between the commercial sector and the Indian Department of Defence over spectrum use.[111]

Bilateral efforts are also under way to harmonize radio frequency utilization. In 2004 the US and EU agreed to major principles over frequency allocation and interoperability between the US GPS and the EU Galileo navigational system;[112] details were finalized in 2007 for a common GPS-Galileo civilian signal allowing for interoperability of the two systems while also maintaining the integrity of the US military signal.[113] But added conflict has arisen from China's announcement that it too will build a global satellite navigation system; it has filed with the ITU to transmit on signals that would overlay both Galileo and the US M code.[114]Chinese sources indicate that it is willing to cooperate with the other systems, but there is no sign of efforts to reach an agreement.[115]

Orbital slots

Today's satellites operate mainly in three basic orbital regions: LEO, MEO, and GEO (see Figure 1.1). There are approximately 860 operational spacecraft, approximately 36 percent of which are in LEO, six percent in MEO, 48 percent in GEO, and about 10 percent in either Highly Elliptical Orbit (HEO) or planetary trajectories.[116] HEO is increasingly being used for specific applications, such as early warning satellites and polar communications coverage. LEO is often used for remote sensing and earth observation, and MEO is home to space-based navigation systems such as the GPS. Most communications and weather satellites are in GEO, as orbital movement at this altitude is synchronized with the Earth's 24-hour rotation, meaning that a satellite in GEO appears to "hang" over one spot on Earth.

GEO slots are located above or very close to the Earth's equato. Low inclinations are also desired to maximize the reliability of the satellite footprint. The orbital arc of interest to the US lies between 60 and 135 degrees west longitude because satellites in this area can serve the entire continental US;[117] these desirable slots are also optimal for the rest of the Americas. Similar desirable spots exist over Africa for Europe and over Indonesia for Asia.

GEO satellites must generate high-power transmissions to deliver a strong signal to Earth, due to distance and the use of high bandwidth signals for television or broadband applications.[118] To avoid radio frequency interference, GEO satellites are required to maintain a minimum of two and up to nine degrees of orbital separation, depending on the band they are using to transmit and receive signals, the service they provide, and the field of view of their ground antennas.[119] Thus, only a limited number of satellites can occupy the prime equator (0 degree inclination) orbital path. In the equatorial arc around the continental US, there is room for only an extremely limited number of satellites. To deal with the limited availability of orbital slots, the ITU Constitution states that radio frequencies and associate orbits, including those in GEO, "must be used rationally, efficiently and economically…so that countries or groups of countries may have equitable access" to both.[120] However in practice the orbital slots in GEO are secured on a first-come, first-served basis.

Equitable treatment has been further compromised by a rash of early registrations with the ITU, often of so-called "paper satellites," combined with ITU revenue shortfalls and disputes over satellite network filing fees. "At one time there were about 1300 filings (applications) for satellite networks before the ITU and about 1200 of them were for paper satellites."[121] Filing fees for ITU cost recovery grew from about $1,126 in 2000 to $31,277 in 2003, resulting in patterns of non-payment and tensions between satellite operators and the ITU. A fee schedule implemented in January 2006 links charges to the complexity and size of a filing. While most incur a flat fee of $500, they can reach almost $60,000 for complex requests requiring extensive coordination.[122] Additional measures to reduce unnecessary registrations include a requirement for satellites to be brought online within seven years of a request, a requirement for the provision of advanced publication information at the time of filing to verify the seriousness of intention, and payment of filing fees within six months.[123] Still, by May 2007 157 satellite network filings had been cancelled for non-payment of cost recovery fees.[124]

Originally, crowding in the MEO region was not a concern, as the only major users were the US and Russia with their GPS and GLONASS navigation satellite constellations. However, concern is increasing that problems could develop in this area when Russia adds more satellites and if both China and the EU make good on plans for constellations of their own. The ITU does require that these constellations all have their operational frequencies registered but, does not stipulate specific orbital slots. All four of these systems use multiple orbits in different inclinations and each system has a different operational altitude. While not necessarily a problem for daily operations, the failure to properly dispose of MEO satellites at the end of their operational life is likely to cause future problems. To date there is no consistent planning and cooperation among the four operators in the constellation design of these systems.

2008 Development

Continued uncertainty surrounding future satellite navigation signals

In March 2008 it was reported that the EU had demanded that China reveal more information on its planned Beidou navigation system.[125] These demands stemmed from concerns that the frequencies to be used by the Beidou satellites could interfere with the European Galileo navigation system, as well as the US Global Positioning System. Although Chinese officials have claimed that its system will be fully compatible with the US GPS, European Galileo, and Russian GLONASS systems, China has not yet coordinated its frequencies with these states.[126] This is particularly a challenge for Europe, because China has filed with the ITU to use the same frequencies as Galileo. Japan is also developing a regional satellite navigation system, the Quazi Zenith Satellite System, but the two states have had few talks to coordinate their systems.

2008 Development

Efforts to overcome the costs of unintentional signal interference

Unintentional interference by other broadcasters with satellite signals costs operators millions of dollars each year. A report published in June 2008 conservatively quantified the costs of electromagnetic interference on a fleet of three geostationary satellites at $2-million per year.[127] And as the demand for limited orbital slots and frequency spectrum continues to grow, the problem is becoming worse. At a meeting of the World Broadcasting Unions International Satellite Operations Group in June 2008, Intelsat's Vice-President for Network Operations explained that "interference is coming in all shapes and sizes," particularly due to growing global demand for the Internet, including services for ships and aircraft.[128] In July, the Satellite Users Interference Reduction Group (SUIRG) filed a position paper with the US Federal Communications Commission (FCC) on the recent petition to the FCC by terrestrial communications providers to use the Ku-band spectrum.[129] SUIRG contends that terrestrial broadcasts in this 14.0- to 14.5-gigahertz band will cause significant interference on satellites services. Testing with existing C-band satellite communications and certain terrestrial WiMax services concluded that significant interference was present.[130]

Several efforts are under way to combat the problem. The International Satellite Operations Group "is campaigning for all encoders to include data that would identify the source of the signal, to help pinpoint where interference is coming from."[131] A different approach involves new technologies that are being developed to minimize or prevent interference. The most promising are Digital Spectrum Analyzers, which can analyze the entire carrier signal to determine if there is any interference present before it starts to disrupt the signal.[132] This in turn can allow operators to reconfigure the transponder or otherwise work to remove the interference.

For the first time, in 2008 several geostationary satellites registered with the ITU were deregistered, freeing up valuable spectrum and orbital slots. In November, the ITU received a request to deregister EUTELSAT 3-44E, EUTELSAT 3-48E, and EUTELSAT E-48E.[133]

2008 Space Security Impact

Developments in 2008 further highlight both the scarcity of available slots in the radio frequency spectrum and the challenges with the existing governance mechanisms. In particular, the Chinese plan for Beidou appears to be consistent with current ITU regulations, and efforts to resolve the issue of frequency coordination were complicated by untimely release of technical details about Galileo. Moreover, as military and economic interests drive the growth of competing systems for similar services, additional demands are also made on their related orbits — in this case, highly elliptical orbit. Determining the nature of solutions to satellite signal interference, both accidental and hostile, will continue to be a challenge for the foreseeable future and is a significant deterrent to space security.

Space Laws, Policies, and Doctrines

This chapter assesses trends and developments related to national and international space laws, multilateral institutions, national space security policies, and military space doctrines.

International space law has gradually expanded to include, among others, the 1967 Outer Space Treaty, the 1968 Astronaut Rescue Agreement, the 1972 Liability Convention, the 1975 Registration Convention, and the 1979 Moon Agreement. These treaties establish the fundamental right of all states to access space, as well as state responsibility to use space for peaceful purposes. They also prohibit space from national appropriation and restrict certain military space activities, such as placing nuclear weapons or weapons of mass destruction in outer space.

This chapter also assesses trends and developments related to multilateral institutions mandated to address uses of space, such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS), the Conference on Disarmament (CD), and the UN General Assembly. While COPUOS tends to focus on commercial and civil space issues, the CD primarily addresses military space challenges through its work on the Prevention of an Arms Race in Outer Space (PAROS). The International Telecommunication Union (ITU) and the Inter-Agency Space Debris Coordination Committee (IADC) are examined in the Space Environment chapter.

National space policies include authoritative national policy statements regarding the principles and objectives of space actors with respect to the access to and use of space. Such policies provide the context within which national civil, commercial, and military space actors operate. For the most part, states continue to emphasize international cooperation and the peaceful uses of space in their national space policies.

This chapter also examines the interplay between national space policies and military space programs. Reflecting the fact that space is increasingly being used to support military operations, some space actors also have designated national military space doctrines that support the development of military space applications such as navigation, communications, intelligence, surveillance, reconnaissance, or meteorological capabilities.

Space Security Impact

National and international laws have a direct impact on space security since they establish key parameters such as the common access to space, prohibitions against the national appropriation of space and the placement of certain weapons in space, and the obligation to ensure that space is used for peaceful purposes. International law can improve space security by restricting activities that infringe upon actors' secure and sustainable access to and use of space, or that result in space-based threats. International law, when followed, promotes predictability and transparency among space actors and helps to overcome collective action problems. National legislation and international space law also play an important role in establishing the framework necessary for the sustainable commercial use of space.

Multilateral institutions play an essential role in space security, providing a venue to discuss issues of collective concern, negotiate solutions to potential disagreements over the allocation of scarce space resources in a peaceful manner, and develop new international law as and when necessary. Ongoing discussion and negotiation within these institutions also help to build a degree of transparency and therefore confidence among spacefaring states. Multilateral institutions also help to provide the technical support that is needed to ensure access to and use of space by all nations.

National space policies and doctrines both reflect and inform space actors' use of space, as well as their broad civil, commercial, and military priorities. Thus the relationship between policy and space security varies, depending on whether or not a specific policy or doctrine promotes the secure and sustainable use of space by all space actors. Some space actors maintain explicit policies on international cooperation in space with the potential to enhance transparency and exert a related positive influence upon space security considerations. Such international cooperation frequently supports the diffusion of space capabilities, not only increasing the number of space actors with space assets, but also creating a greater interest in maintaining the peaceful and equitable use of space.

National space policies and military doctrines may have adverse effects on space security if they promote policies and practices designed to constrain the secure use of space by other actors or advocate space-based weapons. States that remain ambiguous on these points could also stimulate the development of policies, doctrines, and capabilities to counterbalance what a peer may, with a lack of evidence to the contrary, perceive as a threat. Furthermore, military doctrines that rely heavily on space can push other states to develop protection and negation capabilities to protect valuable space systems. At the same time, making these doctrines and policies public also promotes transparency and can help to make behavior more predictable.

Trend 2.1: Gradual development of legal framework for outer space activities shifting away from adoption of multilateral treaties

The international legal framework that governs the use of outer space includes UN treaties, customary international law, bilateral treaties, and other space-related international agreements, which have gradually become more extensive since 1967. What began as a focus on multilateral treaties, however, has transitioned to a focus on what some describe as 'soft law,' which refers to a range of non-binding governance tools including principles, resolutions, confidence-building measures, and policy and technical guidelines.

The UN Charter establishes the fundamental objective of peaceful relations among states, including their interactions in space. Article 2(4) of the Charter prohibits the threat or use of force in international relations, while Article 51 codifies the right of self-defense in cases of aggression involving the illegal use of force.[1]

Outer Space Treaty (OST)

Often referred to as the Magna Carta of outer space, the OST represents the primary basis for legal order in the space environment, establishing outer space as a domain to be used by all humankind for peaceful purposes (see Figure 2.1).

Lack of definitional clarity in the OST presents several challenges for space security. The OST does not specify where airspace ends and outer space begins. This issue has been on the agenda of both the Legal and the Scientific and Technical Subcommittees of COPUOS since 1959 and remains unresolved.[2] The dominant view is that space begins at 100 kilometers above the Earth, but some states continue to disclaim the need for the establishment of such a boundary.[3]

There has also been debate regarding the expression "peaceful purposes." The interpretation initially favored by Soviet officials viewed peaceful purposes as wholly non-military.[4] The position maintained by the US, that the OST's references to "peaceful purposes" mean "non-aggressive" purposes, has generally been supported by state practice.[5] Thus while space assets have been used extensively to support terrestrial military operations, actors have stopped short of actually deploying weapons in space. However, ground-based weapons have been tested against satellites in orbit — most recently by China in 2007[6] and the US in 2008 (see below) and previously by the US and USSR (see Space Systems Negation Trend 7.3). Japan was the only state to declare China's test illegal. Article IV of the OST has been cited by some in arguments that all military activities in outer space are permissible, unless specifically prohibited by another treaty or customary international law.[7] However, others contest this interpretation of the OST.[8]

There is no widely accepted definition of the term "space weapon." Various definitions have been advanced around the nature, place of deployment, location of targets, and scientific principle of weapons; and there have been debates about whether anti-satellite and anti-ballistic missile weapons constitute space weapons.[9]

Figure 2.1: Key provisions of the Outer Space Treaty[10]

Article	Key provisions
Preamble	Mankind has an interest in maintaining the exploration of space for peaceful purposes.
Article I	Outer space, including the Moon and other celestial bodies, is "the province of all mankind" and "shall be free for the exploration and use by all states without discrimination of any kind, on a basis of equality."
Article II	Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, use, occupation, or any other means.
Article III	The UN Charter and general principles of terrestrial international law are applicable to outer space.
Article IV	It is prohibited to place in outer space objects carrying nuclear weapons or any other kinds of weapons of mass destruction. The Moon and other celestial bodies are to be used exclusively for peaceful purposes. Military fortifications and the testing of any other kind of weapons on the Moon are prohibited. However, the use of military personnel and hardware are permitted, but for scientific purposes only.
Article VI	States are internationally responsible for national activities in outer space, including activities carried on by nongovernmental entities.
Article VII	States Parties that launch, procure a launch, or from whose territory an object is launched are internationally liable for damage to another State Party
Article IX	In the exploration and use of outer space, States shall be guided by the principles of cooperation and mutual assistance and shall conduct all their activities in outer space with due regard to the corresponding interests of all other States. States Parties are to undertake international consultations before proceeding with any activity that would cause potentially harmful interference with the peaceful exploration and use of outer space.
Article XI	States Parties are to inform the UN Secretary-General, the public, and the international scientific community of the nature, conduct, location, and results of outer space activities.

Liability Convention

This Convention establishes a liability system for activities in outer space, which is instrumental in addressing threats from space debris and other spacecraft. The Convention specifies that a launching state "is absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight."[11] If a launching state causes damage to another space object, it is liable only if it is at fault for causing the damage. The Convention has been instrumental in , only one settlement. Canada received $3-million in compensation from the Soviet Union for cleanup following the 1978 crash of Cosmos-954, which scattered radioactive debris over a remote part of the country.[12] Liability for damage caused in space is more difficult to establish. Moreover, the Convention reiterates that states parties remain responsible for the activities of their national and nongovernmental entities. The commercialization and growing military uses of space are challenging the structure of the Liability Convention. For example, the growing number of private and international actors undertaking space launches is confusing the current definition of the term "launching state," which under the provisions of the OST and the Liability Convention means the state that launches or procures the launching of an object into outer space and the state from whose territory or facility an object is launched.

Registration Convention

This Convention requires states to maintain national registries of objects launched into space. Also mandatory is reporting to the Secretary-General of the UN on several data points, such as the date and location of the launch, changes in orbital parameters after the launch, and the recovery date of the spacecraft. This data is maintained in a public "Convention Register," the benefits of which include effective management of space traffic, enforcement of safety standards, and attribution of liability for damage. Furthermore, it acts as a space security confidence-building measure by promoting transparency. As of 2006, only 21 of 51 parties had submitted notice to the UN of a national registry.[13] The UN also maintains a separate register with information provided by states not party to the Convention (the Resolution Register), based on UNGA Resolution 1721 B of 20 December 1961.[14]

The lack of timelines for UN registration remains a shortcoming of the Registration Convention. While information is to be provided "as soon as practicable," it might not be provided for weeks or months, if at all. Part of the challenge is the growing number of private and international actors. For example, from 1980 to 1991 registration of space objects at both the national and international levels slipped from 99 percent to 91 percent, and between 2001 and 2003 it was only 75 percent.[15] Moreover, no satellite has ever been registered as having a military function.[16] Nor does the Convention require a launching state to provide appropriate identification markings for its spacecraft and its component parts. Various proposals have been advanced at the CD to resolve the shortcomings of the Registration Convention. In 2007 the UNGA adopted a resolution to improve state practice in registering space objects and adhering to the Registration Convention that included wider ratification of the Convention by states and international organizations, efforts to attain uniformity of information submitted to the UN registry, and efforts to address gaps caused by the ambiguity of the term "launching state" based on recommendations by the Legal Subcommittee of COPUOS.[17]

Moon Agreement

This Agreement generally echoes the language and spirit of the OST in terms of the prohibitions on aggressive behavior on and around the Moon, including the installation of weapons and military bases, as well as other non-peaceful activities.[18] However, it is not widely ratified due to contentious issues surrounding lunar exploration.[19] States continue to object to its provisions for an international regime to govern the exploitation of the Moon's natural resources and differences exist over the interpretation of the Moon's natural resources as the "common heritage of mankind" and the right to inspect all space vehicles, equipment, facilities, stations, and installations belonging to any other party.

Astronaut Rescue Agreement

This Agreement requires that assistance be rendered to astronauts in distress, whether on sovereign or foreign territory. The Agreement also requires that astronauts and their spacecraft are to be returned promptly to the responsible launching authority should they land within the jurisdiction of another state party.

Figure 2.2: Signature and ratification of major space treaties as of 2008

Treaty	Date	Ratifications	Signatures
Outer Space Treaty	1967	98	27
Rescue Agreement	1968	91	25
Liability Convention	1972	87	25
Registration Convention	1975	51	4
Moon Agreement	1979	13	4

UN space principles

In addition to treaties, five UN resolutions known as UN principles have been adopted by the General Assembly for the regulation of special categories of space activities (see Figure 2.4). Though these principles are not legally binding, they establish a code of conduct reflecting the conviction of the international community on these issues.

Figure 2.3: Key UN space principles

Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (1963)
Space exploration should be carried out for the benefit of all countries. Outer space and celestial bodies are free for exploration and use by all states and are not subject to national appropriation by claim of sovereignty. States are liable for damage caused by spacecraft and bear international responsibility for national and nongovernmental activities in outer space.
Principles on Direct Broadcasting by Satellite (1982)
All states have the right to carry out direct television broadcasting and to access its technology, but states must take responsibility for the signals broadcasted by them or actors under their jurisdiction.
Principles on Remote Sensing (1986)
Remote sensing should be carried out for the benefit of all states, and remote sensing data should not be used against the legitimate rights and interests of the sensed state.
Principles on Nuclear Power Sources (1992)
Nuclear power may be necessary for certain space missions, but safety and liability guidelines apply to its use.
Declaration on Outer Space Benefits (1996)
International cooperation in space should be carried out for the benefit and in the interest of all states, with particular attention to the needs of developing states.
UN Space Debris Mitigation Guidelines (2007)
Voluntary guidelines for the mission planning, design, manufacture, and operational phases of spacecraft and launch vehicle orbital stages to minimize the amount of debris created.

PAROS resolution

Since 1981 the UNGA has passed an annual resolution asking all states to refrain from actions contrary to the peaceful use of outer space and calling for negotiations in the CD on a multilateral agreement to support PAROS.[20] PAROS resolutions have had overwhelming support in the UNGA, demonstrating a widespread desire on the part of the international community to prohibit weapons in space.[21] Starting in 1995, however, the US and Israel consistently abstained from voting on the resolution, and they cast the first negative votes in 2005.[22] Israel has since reverted to abstaining.

Multilateral and bilateral arms control and outer space agreements

Since space issues have long been a topic of concern, there are a range of other legal agreements that have attempted to provide predictability and transparency in the peacetime deployment or testing of weapons that either travel through space or can be used in space. For example, one of the key provisions of some arms control treaties, beginning with the 1972 Strategic Arms Limitation Treaty I, has been recognition of the legitimacy of space-based reconnaissance, or National Technical Means (NTMs), as a mechanism of treaty verification, and agreement not to interfere with them.[23] A claim can be made, therefore, that a norm of noninterference with NTMs, early warning satellites, and certain military communications satellites has been accepted as conforming to the OST's spirit of populating space with systems "in the interest of maintaining peace and international security."[24] A summary of the key space provisions of these agreements is provided in Figure 2.5.

Figure 2.4: Multilateral and bilateral arms control and outer space agreements

Agreement	Space security provisions
Limited Test Ban Treaty (1963)	Prohibition of nuclear weapons tests or any other nuclear explosion in outer space
Strategic Arms Limitation Treaty I (1972)*	Acceptance of, and prohibition of interference with, national technical means of verification Freezes the number of intercontinental ballistic missile launchers
Hotline Modernization Agreement (1973)*	Sets up direct satellite communication between the US/USSR
Anti-Ballistic Missile Treaty (1972)*†	Prohibition of space-based anti-ballistic missile systems and interference with national technical means of verification
Environmental Modification Convention (1977)	Bans using as weapons modification techniques that have widespread, long-lasting, or severe effects on space
Strategic Arms Limitation Treaty II (1979)*	Acceptance of, and prohibition of interference with, national technical means of verification Prohibits fractional orbital bombardment systems (FOBS)
Launch Notification Agreement (1988)*	Notification and sharing of parameters in advance of any launch of a strategic ballistic missile
Conventional Armed Forces in Europe Treaty (1990)	Acceptance of, and prohibition of interference with, national and multinational technical means of verification
Strategic Arms Reduction Treaty I (1991)*	Acceptance of, and prohibition of interference with, national technical means of verification
Intermediate-Range Nuclear Forces Treaty (1997)	Acceptance of, and prohibition of interference with, national technical means of verification
Memorandum of Understanding establishing a Joint Data Exchange Center (2000)*	Exchange of information obtained from respective early warning systems
Memorandum of Understanding establishing a Pre- and Post-Missile Launch Notification System (2000)*	Exchange of information on missile launches
* Indicates a bilateral treaty between US and USSR/Russia † US withdrew according to the terms of the treaty in 2002	

Other laws and regimes

Coordination among participating states in the Missile Technology Control Regime (MTCR) adds another layer to the international regulatory framework.[36] The MTCR is a voluntary arrangement among 34 states to apply common export control policy on an agreed list of technologies, such as launch vehicles that could also be used for missile deployment (see Commercial Space Trend 4.3).[37] Another related effort is the International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct), which calls for greater restraint in developing, testing, using, and proliferating ballistic missiles.[38] To increase transparency and reduce mistrust among subscribing states, it introduces confidence-building measures such as the obligation to announce missile launches in advance; however, implementation of this practice is inconsistent.

Finally, the treaties that have an impact on space during times of armed conflict include the body of international humanitarian law composed primarily of the Hague and Geneva Conventions — also known as the Laws of Armed Conflict. Through the concepts of proportionality and distinction, they restrict the application of military force to legitimate military targets and establish that the harm to civilian populations and objects resulting from specific weapons and means of warfare should not be greater than that required to achieve legitimate military objectives.[39] It is not clear how these laws apply to spacecraft and other space objects.

The emergence of space commerce and the potential for space tourism has led at least 20 states to develop national laws to regulate these space activities in accordance with the OST, which establishes state responsibility for the activities of national and nongovernmental entities.[40] While the proliferation of national legislation may increase compliance with international obligations and reinforce responsible use of space, in practice it has occasionally led to divergent interpretations of treaties.[41]

The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in 1999, adopted the Vienna Declaration on Space and Human Development. It established an action plan calling for the use of space applications for environmental protection, resource management, human security, and development and welfare. The Vienna Declaration also called for increasing space access for developing countries and the promotion of international space cooperation.[42] A concrete outcome of UNISPACE III is the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), adopted by the UNGA under Resolution 61/110 on 14 December 2006. It is the first program aimed specifically at ensuring access to and use of space-based information for all countries and organizations during all phases of a disaster.

Space Security Proposals

The last 25 years have seen a number of proposals to address gaps in the space security regime, primarily within the context of the CD. At the 1981 UN General Assembly the USSR first proposed a "Draft Treaty on the Prohibition of the Stationing of Weapons of Any Kind in Outer Space" to ban the orbiting of objects carrying weapons of any kind and the installation of such weapons on celestial bodies or in outer space and to prevent actions to destroy, damage, or disturb the normal functioning of unarmed space objects of other states. A revised version of the draft treaty was introduced to the CD in 1983 with a broader mandate that included a ban on anti-satellite testing or deployment as well as verification measures.[43] Subsequent drafts were submitted for consideration in 2002 and 2007 (see Trend 2.2 below).

During the 1980s several states tabled working papers in the CD proposing arms control frameworks for outer space, including the 1985 Chinese proposal to ban all military uses of space. India, Pakistan, and Sri Lanka made proposals to restrict the testing and deployment of anti-satellite weapons. Canada, France, and Germany explored definitional issues and verification measures.[44] In 1989 France proposed the creation of a shared space surveillance system consisting of radar and optical sensors for the international community to track the trajectory of space objects. The proposal presented in the CD became known as the International Trajectography Centre (UNITRACE).

After the CD agenda crisis led to the collapse of the PAROS ad hoc committee in the late 1990s, Canada, China, and Russia contributed several working papers on options to prohibit space weapons. In 2002, in conjunction with Vietnam, Indonesia, Belarus, Zimbabwe, and Syria, Russia and China submitted to the CD a joint working paper called “Possible Elements for a Future International Legal Agreement on the Prevention of Deployment of Weapons in Outer Space.”[45] The paper proposed that states parties to such an agreement undertake not to place in orbit any object carrying any kind of weapon and not to resort to the threat or use of force against outer space objects. Parties would also declare the locations and scopes of launching sites and the properties and parameters of objects being launched into outer space, and would notify others of launching activities. Efforts to clarify or strengthen international law regarding the use of weapons or force in outer space have incurred greater urgency following renewed use of weapons against space objects by China in 2007 and the US in 2008.

In 2005 the UNGA first adopted what has become and annual resolution sponsored by Russia entitled “Transparency and confidence-building in outer space activities,” inviting states to inform the UN Secretary-General of transparency and confidence-building measures, and reaffirming that “the prevention of an arms race in outer space would avert a grave danger to international peace and security.”[46] The United States consistently registers the only vote against the resolution and Israel the only abstention because the text links such measures with negotiation of a treaty on arms control.

Nongovernmental organizations (NGOs) have also contributed to this dialogue on gaps in the international legal framework. For example, the Union of Concerned Scientists drafted a model treaty banning anti-satellite weapons (1983).[47] In 2003 and 2007 the Henry L. Stimson Center proposed a code of conduct on dangerous military practices in space.[48] The concept of a Code of Conduct or rules of the road for space operations has since been supported by multiple stakeholders including government and military officials, commercial representatives, and nongovernmental organizations.[49] Since 2002 the UN Institute for Disarmament Research has periodically convened expert meetings to examine space security issues and options to address them.[50]

2008 Developments

US reiterates its rejection of legally binding approaches to security in space at UN General Assembly

During the 63rd session of the UN General Assembly in 2008, the US maintained its longstanding opposition to any legally binding efforts that would restrict its freedom of action in space. Member States adopted the Resolution “Prevention of an arms race in outer space” (document A/C.1/63/L.4) by a vote of 177 in favor and one negative vote from the US and one abstention from Israel.[51] During debate in the First Committee of the General Assembly, the US explained that its longstanding opposition to any restrictions on US activities in space is based on its belief that a ‘space weapon’ cannot be defined, that such a regime cannot be verified, and that the existing regime is sufficient to guarantee all states access to and operations in space.[52]

However, the US indicated support for voluntary measures to enhance security in space, including international cooperation and transparency and confidence-building measures (TCBMs). The US cast the only vote against the UN General Assembly Resolution "Transparency and confidence-building measures in outer space activities" (UN Doc. A/C.1/63/L.44/Rev.1),[53] claiming that it "makes an unacceptable linkage between proposals for voluntary pragmatic TCBMs and the commencement of futile negotiations on unnecessary and unverifiable space arms control agreements."[54] But the US also stated that "the growing use of outer space increases the need for greater transparency and better information on the part of the international community" and reminded Members of "the importance of confidence building measures as a means conducive to ensuring attainment of the objective of the prevention of an arms race in outer space."[55]

2008 Developments

US says destruction of a failed satellite consistent with the Outer Space Treaty

In what it called an engagement, on 20 February 2008 the US destroyed one of its failed intelligence satellites (USA-193) with a modified Standard Missile-3 (SM-3) missile defense interceptor as the satellite approached the Earth's atmosphere in a decaying orbit. The stated goal was to prevent the satellite's 454 kilograms of toxic hydrazine fuel from falling on populated areas (see The Space Environment Trend 1.1). This is the second time in two years that a state has intentionally used force against a satellite in outer space.

Prior to the event, the US government advised relevant international bodies of its intentions, citing consistency with international law. The US briefed the Scientific and Technical Subcommittee of the UN COPUOS one week before the event, informing Member States of how much debris it expected from the event and how it met the parameters of the debris mitigation guidelines of both COPUOS and the Inter-Agency Space Debris Coordination Committee (see The Space Environment Trend 1.2).[56] A subsequent brief was presented to COPUOS on the resulting space debris.[57] On 15 February 2008, the US Representative to the CD provided a statement indicating that the US would be liable for any damage to Earth or aircraft in flight, according to the provisions of the Liability Convention, and that it may seek to recover any debris or component parts that land on Earth, according to the provisions of the Rescue Agreement.[58] The statement also indicated that all actions would be consistent with the Outer Space Treaty, that the process of notifying foreign governments was consistent with a commitment to "safe and responsible space operations," and that the event was not part of an anti-satellite development and testing program.[59]

A survey of international responses to the event indicates that foreign experts and media around the world expressed some skepticism regarding the stated goal of protecting populations on Earth, and criticism regarding the use of force in space,[60] but official reactions from foreign governments were relatively muted. The Russian Defense Ministry stated that "the impression arises that the United States is trying to use the accident with its satellite to test its national anti-missile defense system as a means of destroying satellites," but the head of the Russian Space Agency approved of the interception.[61] China initially protested the planned action, stating that it feared a space-based arms race and debris, but subsequently focused on the need for the US to fulfill its international obligations.[62] The non-armament provisions of the Outer Space Treaty are limited to the prohibition of the placement of nuclear weapons or other weapons of mass destruction in space and the testing of weapons or military maneuvers on the Moon and other celestial bodies (Article IV).

2008 Developments

European Commission issues draft Code of Conduct for Outer Space Activities

After an initial phase of consultations, the General Affairs and External Relations Council of the EC released its draft Code of Conduct for Outer Space Activities in December 2008. The preamble of the code recognizes "that a comprehensive approach to safety and security in outer space should be guided by the following principles: (i) freedom of access to space for all for peaceful purposes, (ii) preservation of the security and integrity of space objects in orbit, (iii) due consideration for the legitimate defence interests of States."[63]

Although the Code of Conduct would be voluntary, it is intended to apply to civilian, military, and commercial uses of space. Among the provisions included are measures to:

- Implement policies to minimize the possibility of accidents in space, including *any form of harmful interference* against another spacecraft engaged in peaceful uses of outer space
- Refrain from actions that might damage or destroy outer space objects
- Minimize the risk of a collision
- Promote the development of guidelines to protect the safety of space operations and long-term sustainability of outer space activities
- Refrain from intentional activities that may generate long-lived debris
- Notify all potentially affected Subscribing States of activities in space including maneuvers, orbital changes, and reentries
- Share information on space activities, including national policies and procedures.

The draft Code also includes a mechanism for consultations and highlights the key principles of the Outer Space Treaty for peaceful uses of outer space and the obligation to abide by the existing legal framework for outer space.[64]

The EU is expected to hold bilateral consultations with spacefaring nations throughout 2009 to revise the Code of Conduct text, in an effort to make it accepted by more interested countries.[65]

2008 Developments

Implementation issues impede Hague Code of Conduct against Ballistic Missile Proliferation

As of October 2008, the International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct or HCOC) had been signed by 130 states, but implementation of its voluntary measures remains a challenge.[66] On 1 January 2008 Russia stopped providing pre-launch notification of its ballistic missile and space launches as prescribed under the Code,[67] thus, some argue, undermining the Code's fundamental transparency measures.[68] Observers have noted that other participating members of the Code "also are not fully implementing their commitments."[69] However, some non-subscribing states, such as Iran, assert that the Hague Code of Conduct is discriminatory in that it "was drafted and endorsed outside the United Nations in an opaque manner and without participation of all interested countries. Moreover a selective, unbalanced and incomprehensive approach was pursued in devising the content of the HCOC." India has stated that the HCOC is a "claim made by some states for the exclusive rights for the possession of advanced weapon systems and their continued modernization.[70] Non-subscribing states instead argue that a more inclusive and comprehensive approach to the issue of missiles is required, as has been proposed in the resolutions that they regularly put forward at the First Committee meetings of the UN General Assembly.[71] These resolutions have created three Groups of Governmental Experts, the most recent in 2008, on "the issue of missiles in all its aspects," but none has been able to reach any meaningful recommendations or conclusions.[72] The HCOC and "Missiles" resolutions are thus a source of ongoing disagreement in the UN First Committee on Disarmament and International Security.[73]

2008 Space Security Impact

International legal events in 2008 suggest a continued focus on non-binding governance tools, which some refer to as 'soft law', such as transparency and confidence-building measures and codes of conduct. Support for these measures indicates a growing commitment on the part of some leading spacefaring countries to better regulate activities in outer space by codifying generally accepted behaviors. However, the potential risk with this approach is that implementation will be arbitrary and selective, as demonstrated by the ongoing challenges faced by the Hague Code of Conduct, and that de facto international law will be made via the unilateral actions of states, as demonstrated by the US destruction of one of its own satellites. The US action to destroy its satellite and official responses by other governments may stand as precedents for procedures under which the use of force in outer space is legitimized, in the absence of specific treaty law.

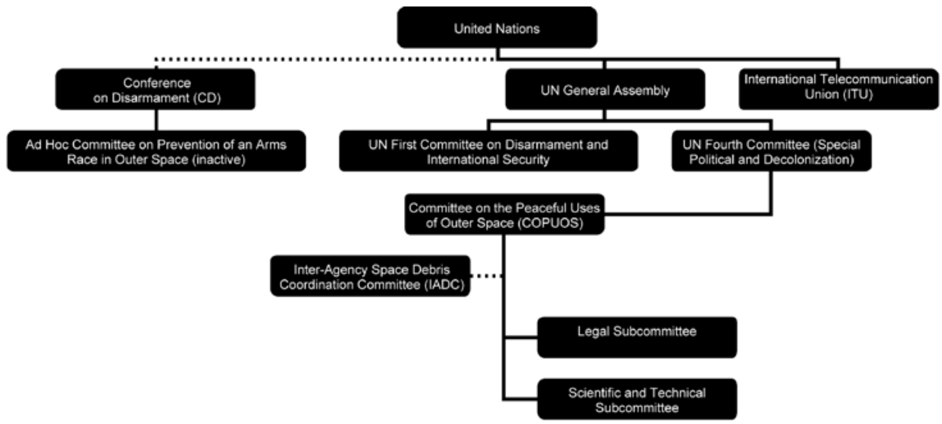
Trend 2.2: COPUOS remains active, but the Conference on Disarmament has been unable to agree on an agenda since 1996

An overview of the relationships among key institutions is provided in Figure 2.6. The UN General Assembly is the main deliberative organ of the United Nations and issues of space security are often debated within the Assembly's First Committee (Disarmament and International Security). While the decisions of the Assembly are not legally binding, they are considered to carry the weight of world opinion. The General Assembly has long held that the prevention of an arms race in outer space would make a significant contribution to international peace and security.

The UN General Assembly created COPUOS in 1958 to review the scope of international cooperation in the peaceful uses of outer space, develop UN programs in this area, encourage research and information exchanges on outer space matters, and study legal problems arising from the exploration of outer space. COPUOS and its two standing committees — the Scientific and Technical Subcommittee and the Legal Subcommittee — develop recommendations based on questions and issues put before them by the General Assembly and Member States. There are currently 67 Member States of COPUOS, which works by consensus. Debate on revisiting the mandate of COPUOS to include all issues affecting the peaceful uses of outer space — namely those pertaining to militarization — has not reached consensus. The US in particular maintains a strong distinction between peaceful uses and non-armament.[74]

The IADC was established in 1993 as a standalone agency comprising the space agencies of major space actors, and played a key role in developing and promoting space debris mitigation guidelines, which provided the basis for those drafted by the COPUOS Scientific and Technical Subcommittee in 2005.[75]

Figure 2.5: International space security-relevant institutions



The CD was first established in 1962 as the Eighteen Nation Disarmament Committee. It went through several name changes as its membership grew, receiving its present name in 1979 as the primary multilateral disarmament negotiating forum. The CD, with 66 current Member States plus observers, works by consensus under the chair of a rotating Presidency. The CD has repeatedly attempted to address the issue of the weaponization of space, driven by perceived gaps in the OST that include its lack of verification or enforcement provisions and failure to expressly prohibit conventional weapons in outer space or ground-based ASATs. In 1982 The Mongolian People's Republic put forward a proposal to create a committee to negotiate a treaty to that effect.[76] After three years of deliberation, the CD Committee on PAROS was created and given a mandate "to examine, as a first step … the prevention of an arms race in outer space."[77] From 1985 to 1994 the PAROS committee met, despite wide disparity among the views of key states, and in that time made several recommendations for space-related confidence-building measures.[78]

Efforts to extend the PAROS committee mandate faltered in 1995 over an agenda dispute that linked PAROS with other agenda items, in particular a Fissile Material Cut-off Treaty (FMCT). Since 1996 CD agenda negotiations have been stalled and the CD has remained without a formal plan of work. In 2000 then President of the CD Ambassador Amorim of Brazil attempted to break the deadlock by proposing the creation of four subcommittees, including one to "deal with" PAROS and another to "negotiate" the FMCT. The 2002 "Five Ambassadors' Initiative" again attempted to resolve the blockage, proposing an agenda that decoupled the establishment of an ad hoc PAROS committee from any eventual treaty on the non-weaponization of space; this initiative received support from China in 2003, leaving only the US in disagreement. In 2004 several states called for the establishment of a CD expert group to discuss the broader technical questions surrounding space weapons, but there was still no consensus on a program of work. Since 2005 the CD has been advancing discussions on space security through informal sessions hosted by delegates. There is no consensus on negotiation of a PAROS treaty.

2008 Developments

CD continues without program of work; discusses draft treaty to prevent the weaponization of space

The 2008 sessions marked another year in which the CD failed to agree to a program of work. A draft program (CD/1840) was issued on 13 March 2008, under which the Conference would appoint Coordinators to oversee discussions on nuclear disarmament and prevention of a nuclear war, prevention of an arms race in outer space, negative security assurances for non-nuclear weapon States, and negotiations on a fissile material cut-off treaty.[79] Although this program was widely supported, the longstanding stalemate continued, due primarily to formal opposition from Pakistan and Iran.[80] In the absence of an agreed program, informal discussions took place on a variety of subjects, including prevention of an arms race in outer space, and on 12 February 2008 China and Russia submitted a draft treaty "Prevention of Placement of Weapons in Outer Space, the Threat of Use of Force Against Outer Space Objects" (PPWT).[81]

The draft treaty is intended to close existing gaps in the international legal framework for space activities, and is based on elements proposed in a working paper to the CD in June 2002 by Russia, China, Viet Nam, Indonesia, Belarus, Zimbabwe, and Syria.[82] Following extensive international consultations in 2007, the draft would prevent military confrontation in outer space, with Article II specifically stating that "States Parties undertake not to place in orbit around the Earth any objects carrying any kind of weapons, not to install such weapons on celestial bodies, and not to station such weapons in outer space in any other manner; not to resort to the threat or use of force against outer space objects; not to assist or encourage other states, groups of states or international organizations to participate in activities prohibited by the Treaty."[83] The draft defines a weapon as "any device placed in outer space, based on any physical principle, specially produced or converted to eliminate, damage or disrupt normal function of objects in outer space, on the Earth or in its air, as well as to eliminate population, components of biosphere critical to human existence or inflict damage to them" and the use of force as "any hostile actions against outer space objects including, inter alia, those aimed at their destruction, damage, temporarily or permanently injuring normal functioning, deliberate alteration of the parameters of their orbit, or the threat of these actions."[84]

Statements on space and the Russian/Chinese draft treaty indicate a division between those who favor a legally binding treaty immediately, and those who favor the development of further voluntary measures such as a code of conduct.[85] Regarding the draft treaty, Canada's Ambassador to the CD stated that "the nature of the issues involved will require considerable detailed and complex discussion of a technical, legal, and political nature on which no consensus currently exists."[86] The US, however, reiterated its longstanding opposition to legally binding arms control regimes and detailed specific concerns with the PPWT in a letter to the CD on 19 August 2008.[87] In it the US claims, for example, that the draft treaty leaves out several critical issues, particularly the research, development, and production of space-based weapons short of deployment; ground-based anti-satellite weapons; the use of force against one's own satellites; and a verification process.[88]

2008 Developments

Continued efforts toward a voluntary rules-based approach to space security

Informal consultations held by the Chairman of COPUOS from July 2006 to April 2007 resulted in a working paper submitted to the COPUOS plenary session in June 2007 on the future role and activities of the Committee on the Peaceful Uses of Outer Space.[89] A key proposal by then Chairman Gerard Brachet was to develop rules for long-term sustainability of space activities based on a bottom-up approach that draws on existing best practices. In February 2008 this proposal became concrete when France, under the leadership of Brachet, convened an informal working group in Paris consisting of 20 states and four large commercial operators to begin articulating technical guidelines. A subsequent meeting was held in

October 2008.[90] The results of this informal working group are expected to be presented to the COPUOS plenary session in June 2009, with the objective of adopting the issue of long-term sustainability of space activities as a new item on the COPUOS Science and Technical Subcommittee agenda in 2010.

In response to calls for greater cooperation between the CD and COPUOS, Brachet addressed the Conference for the first time on 20 February 2008. His presentation focused on the ongoing work of COPUOS and how it is related to space security, in particular the long-term sustainability of outer space. Brachet indicated that, as with the CD, there is no consensus within COPUOS on negotiation of new space security treaties, but suggested that the development of technical guidelines based on existing best practices can be a successful model, as demonstrated by the space debris mitigation guidelines adopted by COPUOS.[91]

Indicating a shift in US policy toward international regulation of space activities, the NASA Authorization Act for fiscal year 2009 included a provision directing NASA to initiate discussions on space traffic management rules with other countries.[92]

2008 Space Security Impact

Activities surrounding the UN COPUOS in 2008 reinforced the continued focus on non-binding, technical approaches to international governance of outer space noted in Trend 2.1. Despite drawbacks, these are the only mechanisms that are garnering widespread support and leading to improvements in the security of outer space in the face of continued lack of consensus on new treaties in both the UN COPUOS and the CD. However, the increased interaction between these two organizations suggests that addressing security concerns in space more comprehensively may become possible in the future, although the stark division between civil and safety issues and military and weapons issues remains institutionalized.

Trend 2.3: National space policies consistently emphasize international cooperation and the peaceful uses of outer space

The national space policies of all spacefaring states explicitly support the principles of peaceful and equitable use of space. Similarly, almost all emphasize the goals of using space to promote national commercial, scientific, and technological progress, while countries such as China, Brazil, and India also emphasize economic development. Virtually all space actors underscore the importance of international cooperation in their space policies; however, it is often delineated by national security concerns.

The US has the most to offer to international cooperative space efforts. While the US is perhaps the least dependent upon such efforts to achieve its national space policy objectives, the 2006 US National Space Policy nonetheless sets a goal to "encourage international cooperation with foreign nations and/or consortia on space activities that are of mutual benefit and that further the peaceful exploration and use of space," as well as to "advance national security, homeland security, and foreign policy objectives."[93] Such cooperation is particularly linked to space exploration, space surveillance, and Earth observation. The US also aims to build an understanding of, and support for, US national space policies and programs and to encourage the use of US space capabilities and systems by friends and allies.[94]

Russia is deeply engaged in cooperative international space activities, asserting that international cooperation in space exploration is more efficient than breakthroughs by individual states.[95] Russia is a major partner of the European Space Agency (ESA)[96] with other key partners in space cooperation including China and India (see Civil Space and Global Utilities Trend 3.3 and 3.4).[97] Russia has also undertaken cooperative space ventures with Bulgaria, Canada, France, Germany, Hungary, Israel, Pakistan, and Portugal on various occasions.[98] Similar to those of the US, Russian space cooperation activities have tended to support broader access and use of space. But Russian policy also aims to maintain Russia's status as a leading space power, as indicated in the Federal Space Program for 2006-2015, which significantly increased the resources of the Russian Federal Space Agency (Roscosmos).[99]

China's 2006 White Paper on space declares a commitment to the peaceful use of outer space in the interests of all mankind, linking this commitment to national development and security goals, including protecting China's national interest and building the state's "comprehensive and national strength."[100] While China actively promotes international exchanges and cooperation, it has stated that such efforts must encourage independence and self-reliance in space capabilities.[101] China has emphasized Asia-Pacific regional space cooperation, which in 1998 led to the signing of the Memorandum of Understanding on Cooperation in Small Multi-Mission Satellite and Related Activities with Iran, Mongolia, Pakistan, South Korea, and Thailand, thus supporting broader access to space.[102] China has pursued space cooperation with more than 13 states.[103]

India is a growing space power that has pursued international cooperation from the inception of the Indian Space Research Organisation (ISRO), although its mandate remains focused on national priorities. India has signed MOUs with almost 30 states in addition to the ESA. India also provides international training on civil space applications through the Indian Institute of Remote Sensing (IIRS) and the Centre for Space Science and Technology Education in the Asia Pacific Region to support broader use of space data.[104]

The ESA facilitates European space cooperation by providing a platform for discussion and policymaking for the European scientific and industrial community.[105] Many see this cooperation as one of the most visible achievements of European cooperation in science and technology. Historically Europe lacked the resources to meet its stated space policy, leading it to establish strong links of cooperation with larger space powers, specifically the US and Russia. In addition France, Germany, Italy, and the UK all have extensive cooperative ventures with the US, Russia, and, to a lesser extent, Japan and others.

In 2007 the first European Space Policy was adopted jointly by the ESA and the European Union. While stressing the peaceful use of outer space, the policy notes that "the economy and security of Europe and its citizens are increasingly dependent on space-based capabilities which must be protected against disruption" and emphasizes the need for European states to maintain independent access to space.[106] The European Parliament has noted that "freedom from space-based threats and secure sustainable access to, and use of, space must be the guiding principles of the European Space Policy."[107] Autonomy is a longstanding goal of European national space policies, as exemplified by the Ariane launch and Galileo navigation programs.

In 2007, 14 national space agencies jointly released the document *The Global Exploration Strategy: The Framework for Coordination*.[108] The document marked the culmination of efforts toward international collaboration in outer space exploration initiated by NASA in 2006 and sets out an action plan to share strategies and efforts for exploration. According to the document, "this new era of space exploration is intended to strengthen international partnerships through the sharing of challenging and peaceful goals."[109]

2008 Developments

South Africa approves a National Space Agency with focus on peaceful use

Following adoption by the government in December 2008, the president of South Africa signed into law the South African National Space Agency Act in January 2009 and creation of the Agency is expected in 2009. The Agency's purpose is to "provide for the promotion and use of space and cooperation in space-related activities, foster research in space science, advance scientific engineering through human capital, [and] support the creation of an environment conducive to industrial development in space technologies within the framework of national government…."[110] Additionally, the Agency is responsible for implementing the National Space Strategy adopted on 15 December 2008 to establish South Africa as a leading nation in the use of space science and technology.[111] Launch of a National Space Policy is expected for 2009.

2008 Space Security Impact

States continued to express commitment to international cooperation on the peaceful use of outer space in their civil space policies in 2008. Some peaceful uses of space are increasingly viewed as strategic, however, which could limit opportunities for cooperation and cause political tensions in space, depending on whether states pursue independent or collective measures to achieve the strategic goals set out in their space policies.

Trend 2.4: Growing focus within national policies on the security uses of outer space

Fueled by the revolution in military affairs, the national policies and military doctrine of a number of states increasingly reflect a growing focus on space-based applications to support military functions (see Space Support for Terrestrial Military Operations). Related to this trend is a tendency among major space powers and several emerging space powers to view their space assets as an integral element of their national security infrastructure.

While there is a specific hierarchy in US military space doctrine documents, some emphasize space control, defined as the "freedom of action in space for friendly forces while, when directed, denying it to an adversary."[112] It is US policy, under *Joint Publication 3-14* and Department of Defense (DOD) *Space Control Policy*, to emphasize tactical denial, meaning that denial should have localized, reversible, and temporary effects.[113] There is currently an active debate within the US on how best to assure the security of vulnerable national space assets. Some advocate the development of space control capabilities, including enhanced protection, active defense systems, and space-based counterspace weapons. The 2003 US Air Force *Transformation Flight Plan* in particular calls for onboard protection capabilities for space assets, coupled with offensive counterspace systems to ensure space control for US forces.[114] The 2004 Air Force document on *Counterspace Operations* doctrine makes explicit mention of military operations conceived "to deceive, disrupt, deny, degrade, or destroy adversary space capabilities."[115] It also describes the planning for and execution of such operations, including legal considerations and targets, which include third-party providers of satellite services. This has implications for the growing use of commercial and civilian satellites for military purposes (see Civil Space and Global Utilities and Commercial Space).

Others in this debate advocate enhanced protection measures, but oppose the deployment of weapons in space.[116] Much official US military space doctrine has remained focused primarily on force enhancement, as reflected in the US DOD 1999 S*pace Policy.*[117] The authoritative US joint doctrine on such matters, *Joint Publication 3-14,* as well as the *2004*

USAF Posture Statement reflect a continuing emphasis on using space assets for traditional force enhancement or combat support operations, as well as other passive measures such as space systems protection and responsive space access.[118]

Development of an antiballistic missile system in the US has fuelled discussion and plans for space-based interceptors. The National Missile Defense Act of 1999 makes it the policy of the US to "deploy as soon as is technologically possible an effective National Missile Defense… against limited ballistic missile attack."[119] While not explicitly mentioning particular space-based systems, the 2006 *National Space Policy* calls on the Secretary of Defense to provide space capabilities to support "multi-layered and integrated missile defenses."[120]

In all military doctrine documents since 1992, Russia has expressed concern that attacks on its early warning and space surveillance systems would represent a direct threat to its security.[121] Therefore a basic Russian national security objective is the protection of Russian space systems, including ground stations on its territory.[122] These concerns derive from Russia's assessment that modern warfare is becoming increasingly dependent on space-based force enhancement capabilities.[123] In practical terms, Russian military space policy appears to have two main priorities. The first is transferring to a new generation of space equipment capabilities, including cheaper and more efficient information technology systems.[124] The second is upgrading its nuclear missile attack warning system. Together, these recent developments are seen as having a critical role in guaranteeing Russia's secure access to space.[125] Russia has expressed concern about the potential weaponization of space and the extension of the arms race to outer space, especially in light of the development of US missile defense systems.[126] Russia has actively argued for a treaty prohibiting the deployment of weapons in space. In the interim Russia has pledged not to be the first to deploy any weapons in outer space and has encouraged other spacefaring nations to do the same, but various Russian officials have also threatened retaliatory measures against any country that attempts to deploy weapons in space.[127]

China's military space doctrine, should it exist, is not made public. China's 2006 White Paper on Space Activities identifies national security as a principle of China's space program.[128] The 2004 National Defense White Paper describes China's plans to develop technologies as part of the modernization of its armed forces, including "dual purpose technology" in space, for civil and military use.[129] A subsequent White Paper in 2006 describes "informationization" as a key strategy of its military modernization, although there is no express mention of the use of outer space for national defense, and asserts an international security strategy based on developing cooperative, non-confrontational, and nonaligned military relations with other states.[130] Nonetheless, in contemporary Chinese military science, the military use of space is inextricably linked to attaining comprehensive national military power.[131] China demonstrated significant space negation capabilities via the destruction of an orbiting satellite with a missile on 11 January 2007, but maintains that the test was "not targeted at any country and will not threaten any country," and has remained publicly committed to the non-weaponization of space.[132]

Space is important for the European Security and Defence Policy (ESDP). The space policies of EU member states recognize that efforts to assume a larger role in international affairs will require the development of space assets such as global communications, positioning, and observation systems.[133] The paper "European Space Policy: ESDP and Space," adopted by the European Council in 2004, was the first council strategy paper on the use of space for ESDP purposes, and was followed by a roadmap for implementation in 2005.[134] While most European space capabilities have focused on civil applications, there is an increasing awareness of the need to strengthen dual-use and dedicated military capabilities.[135] The EU/ESA European Space Policy adopted in 2007 highlights implementation of the space dimension of the ESDP and seeks to develop synergies between defense and civil space programs and also to guarantee EU independent access to space.[136] While military space capabilities remain within the exclusive purview of member states, the new policy urges them to increase coordination to achieve the highest levels of interoperability between military and civilian space systems. The policy envisages that "sharing and pooling of the resources of European civilian and military space programmes, drawing on multiple use technology and common standards, would allow more cost-effective solutions."[137]

At the national level, French military space doctrine recognizes the essential role of space support for terrestrial military operations and the Ministry of Defense has emphasized the role of space power in maintaining sovereignty.[138] UK military space doctrine calls for greater satellite use for communications and intelligence. For its part, the ESA has traditionally focused on civil uses of space; its statute refers to "exclusively peaceful purposes."[139]

Emerging spacefaring powers have also begun to emphasize the security dimension of outer space. Israel's space program is based on national security needs and tightly linked to its military. In 2006 the Israeli Air Force was renamed the Air and Space Force and was given sole responsibility for all military activities in space as well as for designing and operating the nation's future satellites. Its mission is to operate in the air and space arena for purposes of defense and deterrence.[140]

India is establishing a tri-force Aerospace Command, intended to make "effective use of space-based assets for military needs."[141] In 2007 India revised its defense doctrine to exploit the use of space to enhance the functional effectiveness of its armed forces. Indian Army Commanders also adopted *Space Vision 2020* — "its philosophy for using space in future warfare"—that reportedly emphasizes aspects of force modernization.[142] This follows a space policy reportedly developed by the Indian Air Force in 2007, as well as a new Air Force defense doctrine that is supposed to feature the utilization of "space for real-time military communications and reconnaissance missions, ballistic missile defence and delivery of precision guided munitions through satellite signals."[143]

Recent Canadian Air Force documents have highlighted the importance of space systems in support of terrestrial military operations, space situational awareness, and space systems protection.[144]

2008 Developments

Japan issues new space law lifting its ban on national security and military space activities

Japan's government adopted the landmark Basic Space Law on 21 May 2008, which lifts a longstanding ban on national security and military space activities, and is based on the common interpretation of the Outer Space Treaty that allows for military use of space for peaceful purposes.[145] The law entered into force on 27 August 2008[146] and allows the deployment of satellites by the Ministry of Defense for non-aggressive purposes, including surveillance and military support functions, with possible early applications being missile warning, signals intelligence, and communications. However, the law "does not permit the deployment of offensive capabilities…in space"[147] and is subject to limitation by Article 9 of Japan's Constitution prohibiting acts of war by the state.[148] Moreover, on 1 July 2008 the Space and Maritime Security Policy Office was established within the Ministry of Defense to take a central role in considering various policies related to outer space. Japan's Strategic Headquarters for Space Policy, chaired by the Prime Minister, is currently developing the first Basic Space Plan, with a projected release in May 2009. The Basic Space Plan has five objectives: building prosperity, contributing to national security, promoting diplomacy, developing industries, and investing in the next generation through space exploration and space activity.[149] (See also Space Support for Terrestrial Military Operations Trend 5.2.)

Japan also released its annual white paper “Defense of Japan” on 5 September 2008, which highlights concerns about the modernization of China’s armed forces and its lack of transparency, as well as North Korea’s ballistic missile and nuclear weapon program. The paper describes North Korea as posing a serious threat “to the peace and stability of East Asia and the international community.”[150] Japan’s response is focused on ballistic missile defense and closer defense cooperation with the US.[151]

2008 Developments

China’s 2008 White Paper on Defense highlights importance of “informationization”

China issued a white paper titled “China’s National Defense in 2008” on 21 January 2009. The paper included a pledge with respect to the peaceful development and advancement of its military modernization.[152] The paper states “that China is actively adapting itself to new trends in world military development and advancing the modernization of its national defense and armed forces from a higher starting point.”[153] Regarding space, the paper states that China’s national defense strategy is based on “active defense” that “aims at winning local wars in conditions of informationization” and includes maintaining “space and electromagnetic space security.”[154] The paper also addresses the “existing legal instruments concerning outer space” as insufficient “to effectively prevent the spread of weapons to outer space”[155] and cites as its support for the development of new measures the draft treat “Prevention of Placement of Weapons in Outer Space, the Threat of Use of Force Against Outer Space Objects” introduced to the CD by China and Russia (see Trend 2.2 above). China stresses both military and civilian uses of science, technology, and industry as important for national defense.[156]

2008 Developments

France’s White Paper on Defense and National Security encompasses overhaul of space strategy

France’s White Paper on Defense and National Security, released in 2008, indicates an overhaul of French defense and security policy since the previous White Paper of 1994. The Paper identifies improving the military’s capacity to act as a key goal, stating that France will invest in modernizing the armed forces’ equipment, including implementation of a new space program.[157] The Paper includes a section dedicated to “the Strategic Use of Outer Space,”[158] which states that “France does not intend to deploy weapons in space and will continue its diplomatic efforts in favor of the demilitarization of space.”[159] However, the White Paper also emphasizes the increased importance of satellites in various applications and the intention to utilize them in line with France’s national security strategy.[160] Specifically, a speech by President Sarkozy that set out five strategic areas of focus emphasized the need for France to maintain autonomous sources of surveillance and intelligence; budgets for satellite imaging and electromagnetic surveillance are intended to double.[161] The paper states that France is the only European country to have developed ballistic missiles and that it will continue to maintain the “competencies it developed in the field of ballistic missiles.”[162] Finally, a significant reorganization is described, placing “space related doctrine, operations and programmes…under the responsibility of a specific…Joint Space Command, under the authority of the Chief of Defence Staff.”[163]

2008 Developments

New approach to space protection in the US may include international interdependence

In 2008 the US Department of Defense submitted its Space Protection Strategy as ordered by Congress in the 2008 National Defense Authorization Act and created a new Space Protection Program, jointly funded by the Air Force and National Reconnaissance Office to "provide decision-makers with strategic recommendations on how best to protect our space systems and stay ahead of the threat."[164] Although details are classified, a more cooperative international approach to space protection may unfold, according to the head of the Program, Andrew Palowitch: "We would like to get to an international cooperative position that involves every country in the world…. If everybody was cooperating, then we wouldn't have to spend billions of dollars developing defensive mechanisms that just perpetuate conflict."[165] Palowitch has indicated that an alliance-based approach to space protection has been rejected in favor of a more inclusive, multilateral arrangement that would emphasize interdependence, although it would not rule out the development of new hardware to protect satellites when needed.

2008 Developments

Space for security a renewed priority in Europe

The European Parliament passed a resolution on 10 July 2008 titled "Space and security" (2008/2010(INI)) that focused on advancing the use of space for security and defense purposes in Europe.[166] The resolution noted, among other things, that Europe lacks a comprehensive space-based architecture for such purposes, the importance of space to the security of the European Union, and the need for a common approach to defend European interests in space. It also calls for common capabilities needed to implement the European Space and Defence Policy, including telecommunication, information management, observation, and navigation. The resolution "Taking forward the European Space Policy," adopted by the European Council and approved by the European Space Agency council of ministers, also highlighted the need for better cooperation between civil and military users to meet Europe's security and defense needs.[167] The resolution identified the need to set up a "mechanism to improve synergies between civil and defence space programs." "Space and Security" were identified as one of four priorities of the European Space Policy, highlighting "the important contribution of space to the CFS/ESDP" and recognizing that Galileo and GMES may be used by military users.

The European Space Agency formally accepted the dual-use by militaries of its space assets at its Ministerial Conference in November 2008 when it approved its planned Galileo satellite navigation system and Global Monitoring for Environment and Security program for use by European military and defense organizations (see Space Support for Terrestrial Military Use Trend 5.2).[168]

2008 Space Security Impact

In 2008 many states continued to emphasize the use of space for national security purposes in policy statements. A positive impact of this trend is increased transparency and clarity of intentions that allow states to better predict the behavior of others in space. However, a parallel trend, in which civilian and commercial space infrastructure is being used for national security purposes, may lead to added vulnerabilities in space if this infrastructure is viewed as a legitimate target during conflict, particularly given the absence of laws governing conflict in space.

Civil Space Programs and Global Utilities

CHAPTER THREE

This chapter assesses trends and developments associated with civil space programs and global space-based utilities. The civil space sector comprises those organizations engaged in the exploration of space, or scientific research in or related to space, for non-commercial and non-military purposes. This sector includes national space agencies such as the US National Aeronautics and Space Administration (NASA), the Russian Federal Space Agency (Roscosmos), and the European Space Agency (ESA); and missions such as Soyuz, Apollo, the Hubble Space Telescope, and the International Space Station (ISS). Key capabilities associated with launch vehicles related to civil programs that enable actors to access space are also addressed. Finally, the sector includes international collaborations that facilitate space access for countries without launch or other technical capabilities.

The chapter examines trends and developments among civil space actors and reviews the number of actors with either independent access to space or access via the launch capabilities of other actors; the number, scope, and priorities of civil programs, including the number of human and civil satellite launches made by each actor; and the funding trends of civil programs. It also assesses the degree and scope of international civil space collaboration, often seen as the hallmark of civil space programs.

Finally, this chapter examines trends and developments in space-based global utilities, including trends in conflict and cooperation between actors in their development and use. Global utilities are space-based applications provided by civil, military, or commercial actors, which can be freely used by anyone equipped to receive their data, either directly or indirectly. Some global utilities include remote sensing satellites that monitor the Earth's changing environment using various sensors, such as weather satellites. Satellite navigation systems that provide geographic position (latitude, longitude, altitude) and velocity information to users on the ground, at sea, or in the air such as the US Global Positioning System (GPS) are perhaps the most well-known global utilities.

Space Security Impact

Civil space programs can affect space security in several positive ways. First, they are one of the primary drivers behind the development of capabilities to access and use space, in particular space launch capabilities, increasing the number of actors with secure access to space. Second, civil space programs and their technological spin-offs on Earth underscore the vast scientific, commercial, and social benefits of secure and sustainable uses of space, thereby increasing global interest in the maintenance of space security. Third, civil space programs develop and shape public interest in and awareness of the peaceful uses of space.

Conversely, civil space programs can have a negative impact on space security by enabling the development of dual-use technologies for space systems negation or space-based strike capabilities, and by contributing to the overcrowding of scarce space resources such as orbital slots and radio frequencies.

Many civil space programs are dual-use and also support military functions. Civil-military cooperation can have a mixed impact on space security. On the one hand, it helps to advance the capabilities of civil space programs to access and use space. On the other hand, it may encourage adversaries to target dual-use civil-military satellites during conflict or make such targeting too costly depending on how other space actors react.

Millions of individuals rely on global utilities on a daily basis for weather, navigation, communications, and search-and-rescue functions. Consequently, global utilities are important for space security because they broaden the community of actors who have access to space data and an investment in the security of space for peaceful uses. Global utilities are an example of dual-use functions that can also support military operations.

International cooperation remains a key aspect of both civil space programs and global utilities. It can benefit space security by enhancing transparency regarding the nature and purpose of certain civil programs that can have military purposes. Furthermore, international cooperation in civil space programs can assist in the transfer of skills, material, and technology for the access to, and use of space, by emerging space actors. Finally, international cooperation in civil space programs can serve to highlight areas of mutual benefit in achieving space security and reinforce the practice of using space for peaceful purposes. On the other hand, competition for access to and use of space resources in the longer term, particularly on the Moon, could generate tensions between space powers.

Trend 3.1: Growth in the number of actors with access to space, including dual-use applications

Civil space programs, in collaboration with military space programs and the commercial sector, contribute to growth in the number of actors with access to space. By the end of 2008, 8 states in addition to the European Space Agency had demonstrated an independent orbital launch capability (see Figure 3.1). This total does not include private actors such as Sea Launch and International Launch Services — two consortia that provide commercial orbital launch services using rockets developed by state actors. Ukraine has not yet conducted an independent launch but builds the Zenit launch vehicle used by Sea Launch. Brazil, Iran, Kazakhstan, North Korea, and South Korea are also developing launch vehicles, some of which are based on ballistic missile designs.

There are a further 17 actors that have suborbital capability, which is required for a rocket to enter space in its trajectory, but not to achieve an orbit around the Earth. These actors are Argentina, Australia, Brazil, Canada, Germany, Iran, Iraq, Italy, Libya, North Korea, Pakistan, Saudi Arabia, South Africa, South Korea, Spain, Sweden, Switzerland, and Syria.[2]

The rate at which new states gain access to space increased dramatically in the past decade. By the end of 2008 a total of 49 civil actors had accessed space, either with their own launchers or those of others. This number is expected to continue to grow as more states seek the socio-economic benefits that space provides through the efforts of the commercial sector and countries like China, which are helping states to develop affordable small satellites. Companies, such as the former Surrey Satellite Technologies Limited, and China have assisted states including Algeria, Egypt, Malaysia, Nigeria, Portugal, South Korea, Thailand, Turkey, and South Africa in efforts to build their first civil satellites.[3]

Many civilian spacecraft are also used for military purposes, a trend that is increasing as more states with fewer resources to spend seek to maximize the use of data derived from space programs. High resolution remote sensing satellites used to image the Earth's surface are a prime example. While some systems are suspected of unofficially providing data to military users, such as India's Cartosat-2 and the Technology Experiment Satellite — both suitable for reconnaissance with resolutions up to one meter[4] — others are drawn on by militaries during times of increased demand due to conflicts, such as the US Landsat program, while some are purposefully designed for dual-use, such as Italy's Cosmos-Skymed constellation.[5] Many civilian communications satellites and global utilities such as navigation systems are similarly used.

Figure 3.1: Independent orbital launch capability and current launch sites of states (2008)[1]

State/actor	Year of first orbital launch	Launch vehicle
USSR/Russia	1957	R-7 rocket
USA	1958	Juniper-C
France*	1965	Diamant
Japan	1970	Lambda
China	1970	Long March
UK*	1971	Black Arrow
ESA	1979	Ariane
India	1980	SLV
Israel	1988	Shavit

* France and the UK no longer conduct independent launches, but France's CNES manufactures the Ariane launcher used by Arianespace/ESA.

The trend toward miniaturization in electronics has helped to reduce the size and weight of satellites, which can now perform the same functions as their bulkier predecessors but at a decreased cost. One of the first microsatellites to implement this technology was the US Clementine lunar mission in 1994. The ongoing enhancement of microsatellite capabilities is driving increased access to space at reduced cost because these satellites are cheaper to produce and to launch. In 2007 the Indian Space Research Organisation (ISRO) announced plans to launch satellites weighing less than 100 kilograms to meet the needs of developing countries and the domestic scientific community.[6] Although they are generally less capable than larger spacecraft, microsatellites such as the multinational Disaster Monitoring Constellation are increasingly used for more traditional functions, including communications and remote sensing.

Figure 3.2: Growth in the number of civil actors accessing space[7]

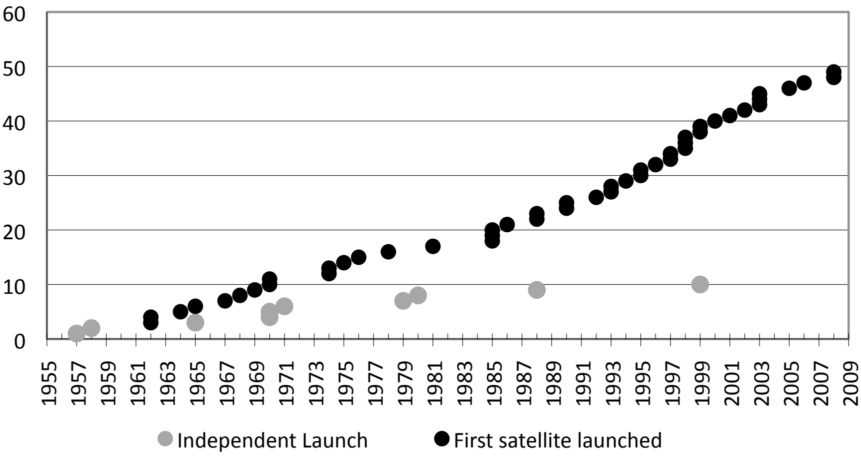
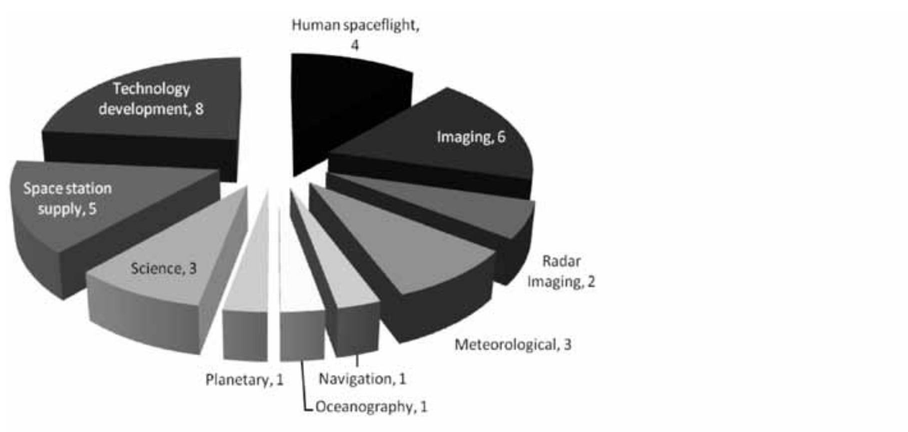


Figure 3.3: Civil spacecraft launched in 2008 by application[8]



2008 Developments

Space access continues to increase, with new states gaining satellites and developing space agencies

The number of states that have gained access to space reached 49 in 2008. After 13 years of preparation Vietnam's first satellite was successfully launched into geostationary orbit on 19 April 2008 by the Ariane-5 launcher.[9] At a total cost of $300-million, the Vinasat-1 communications satellite will be used to provide both commercial and non-commercial communications, eliminating a yearly $15-million charge to rent satellite capacity from others. Venezuela also acquired its first communications satellite in 2008, through cooperation with China. On 29 October 2008 China launched the Venesat-1 communications satellite, which cost $250-million and is part of a cooperative agreement between the two countries (see Trend 3.3 below).[10]

The South African National Space Agency Act was approved by the government in 2008 and signed by the President in January 2009;[11] it will consolidate all space-related activities in a single organization.[12] In December 2008 the Cabinet also approved a National Space Strategy (see Laws, Policies, and Doctrines Trend 2.3). South Africa will receive technical assistance from Russia and efforts are under way to create a Russia-South Africa Permanent Working Group on Space.[13] In 2008 the Mexican Space Agency was under development.[14] In September 2008 Russia and Cuba discussed the possibility of Russian assistance to develop a Cuban space agency, including joint use of space equipment.[15] The creation of an Arab Space Agency was encouraged by the United Arab Emirates, and discussions were held with Arab League member governments.[16]

2008 Developments

Iran, North Korea, Brazil, and South Korea seek direct access to space through launch technology

Iran attempted three rocket launches in 2008 using the Safir expendable launch vehicle, with the aim of placing a satellite in orbit by 2009.[17] Details on the rocket technology and launch results are covered in Space Systems Negation Trend 7.3. There are concerns that Iran's civilian space launch program is a cover for its long-range ballistic missile program, which would use similar technology, particularly since the two likely share the same launch site.[18] Iran and North Korea have long cooperated on missile technology, and in 2008 staff at Jane's Intelligence Group analyzed commercial satellite imagery to reveal that North Korea has continued to pursue a ballistic missile and space launch program, despite what was thought to have been a declining indigenous capability. Imagery revealed a second, previously unknown launch facility on North Korea's west coast, which is believed to have been under construction over the past eight years.[19] According to Jane's, the site will be able to support launches of both the Taepodong-2 ballistic missile and the Taepodong-2 space launch vehicle.

Brazil plans to launch a basic version of a space rocket in 2011, after successful tests of the second stage of its four-stage VLS-1 in October 2008.[20] South Korea's first experimental rocket launch, scheduled for 2007, was postponed again to 2009 due to delays in the delivery of the main booster rocket and other key parts from Russia and the construction of the launch pad at the Naro Space Centre.[21] This KSLV-1 project costs $377-million, including $198-million for at least two launching contracts with Russia; it is designed to launch a 100-kilogram satellite into LEO.[22] The KSLV-2 will be a larger, indigenously developed multi-stage rocket that will launch an operational satellite; it has a launch date of 2017.[23]

Ongoing technology developments in 2008 by existing launching states included:

- Russia's heavy-launch Angara rocket, to be launched from the Plesetsk space center, thus reducing Russia's dependency on Kazakhstan.[24]
- Another successful engine test of Europe's Vega small launcher; a full test is scheduled for 2009.[25]
- China's next-generation heavy lift rocket, the Long March 5, is scheduled for use in 2014.[26]
- On 25 December 2008 the Japan Aerospace Exploration Agency (JAXA) revealed its H-II Transfer Vehicle, designed primarily for the transportation of food, water, and project materials to the ISS.[27]
- ESA's Jules Vernes ATV was used for the first time to resupply the ISS on 19 June 2008.[28]
- NASA's Commercial Orbital Transportation Services (COTS) contenders SpaceX's Falcon 9 (first launch in 2009) and Orbital Sciences Taurus II (first launch in 2010) were awarded contracts for a total of 20 launches under the ISS Commercial Resupply Services program (see Commercial Space Trend 4.2).

2008 Space Security Impact
Increased participation in space activities is a positive trend insofar as more actors gain access to space for peaceful purposes, extending the benefits of space applications, science, and security. On the other hand, the growth of space activities also creates challenges for security in space due to increased demand for limited space resources such as orbital slots and radio frequencies, particularly when new activities replicate rather than rely on or enhance the capabilities provided by other states. Because of the ability of space assets and technologies such as launch vehicles to be used for different purposes, the intentions of the many actors in space cannot be known.

Trend 3.2: Changing priorities and funding levels within civil space programs toward large-scale projects

Space agencies
Different states and regions have varying civil space institutions. The US has two main civil agencies: NASA and the National Oceanic and Atmospheric Administration (NOAA). While much of the work is done by major contractors such as the Boeing Company and the Lockheed-Martin Corporation, mission design, integration, launch, and operations are undertaken by the agencies themselves.

In the Soviet Union during the Cold War civil space efforts were largely decentralized and led by "design bureaus" — state-owned companies headed by top scientists. Russian launch capabilities were developed by Strategic Rocket Forces, and cosmonaut training was managed by the Russian Air Force. Formal coordination of efforts came through the Ministry for General Machine Building.[29] A Russian space agency (Rossiyskoe Kosmicheskoye Agentstvo) was established in 1992, and has since been reshaped into Roscosmos. While this new agency has more centralized powers than previous organizations, most work is still completed by design bureaus, now integrated into "Science and Production Associations" (NPOs) such as NPO Energia, NPO Energomash, and NPO Lavochkin. This continued decentralization of civil activities makes obtaining accurate comprehensive budget figures for Russian civil space programs difficult.[30]

In 1961 France established its national space agency, the Centre National d'Études Spatiales (CNES), which remains the largest of the EU national-level agencies. Italy established a national space agency (ASI) in 1989, followed by Germany in 1990 (DLR). The European Space Research Organisation and the European Launch Development Organisation, both formed in 1962, were merged in 1975 into ESA, which is now the principal space agency for the region. Although ESA has 17 member states, most of its funding is provided by a few states with active national space programs. Germany and France regularly provide between 40 and 50 percent of the ESA budget.[31]

In China, civil space activities began to grow when they were allocated to the China Great Wall Industry Corporation in 1986. The China Aerospace Corporation was established in 1993, followed by the development of the Chinese National Space Administration (CNSA). The CNSA remains the central civil space agency in China and reports through the Commission of Science, Technology and Industry for National Defense to the State Council.

In Japan civil space was initially coordinated by the National Space Activities Council formed in 1960. Most of the work was performed by the Institute of Space and Aeronautical Science of the University of Tokyo, the National Aerospace Laboratory, and, most importantly, the

National Space Development Agency. In 2003 these efforts were merged into the Japanese Aerospace Exploration Agency (JAXA).[32] India's civil space agency ISRO was founded in 1969. Israel's space agency was formed in 1982, Canada's in 1989, and the Brazilian Agência Espacial Brasileira was formed in 1994.

For a complete list of civil space agencies please visit www.spacesecurity.org.

Expenditures

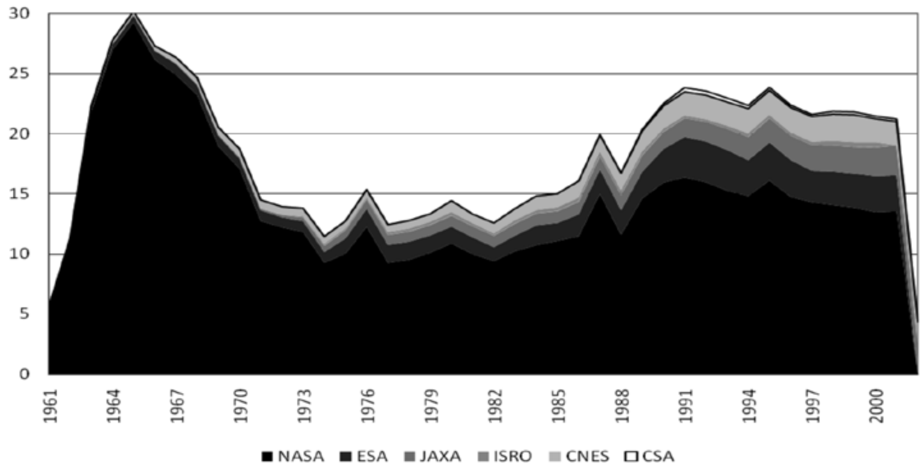
Although still dwarfing the civil space budgets of all other actors put together, the NASA budget dropped 25 percent in real terms between 1992 and 2001.[33] The ESA budget dropped nine percent in the same period. This follows a long period of growth for both NASA and ESA from 1970 to 1991, in which the NASA budget grew 60 percent in real terms and the ESA budget grew 165 percent in real terms.[34] The NASA budget has increased annually at a rate of three–four percent since 2004 when President George W. Bush released the *Vision for Space Exploration,* which contains a renewed focus on human space flight.[35] NASA's budget is now approaching $20-billion. The ESA budget was increased by 10 percent in 2005[36] and is now steady at approximately $3.5-billion per year.

The USSR/Russia was the most active civil space actor from 1970 to the early 1990s, when sharp funding decreases led to a reduction in the number of civil missions. By 2001 the number of Russian military, civil, and commercial satellites in space had decreased from over 180 during the Soviet era to approximately 90. The budget had been reduced to $309-million — about 20 percent of the 1989 expenditure and less than the cost of a single launch of the US space shuttle.[37] This steady decline was reversed in 2005, however, when Russia approved a 10-year program with a budget of approximately $11-billion.[38] The annual budget reached $1.5-billion in 2008, not including funds for the GLONASS satellite navigation system.[39]

Civil expenditures on space continue to increase considerably in India and China, due in large part to the growth of civil program activities, including large satellites and human spaceflight programs. Since 2005 India's space budget has dramatically increased and is currently over $800-million.[40] The Chinese space budget is complex. Officials have been quoted as saying that the Chinese civil space budget is as low as $500-million. Media sources place the budget closer to $2-billion. It is safe to speculate that it falls somewhere between these two figures.[41] Nonetheless, China now has the "fourth largest satellite space program" and the "fastest growing launch rate of any space-faring power," launching 39 satellites (eight of which were military) between 1996 and 2006, 75 percent in the latter five years.[42]

Expenditures are not the sole indicator of capabilities, however, because of the differences in production cost from one country to another, as well as local standards of living and purchasing power.[43] For example, Russia, which has a significantly lower budget than NASA, has historically launched more satellites than any other state.

Figure 3.4: Historic annual civil space agency budgets of major space agencies (billion 2001 dollars)[44]



Human spaceflight

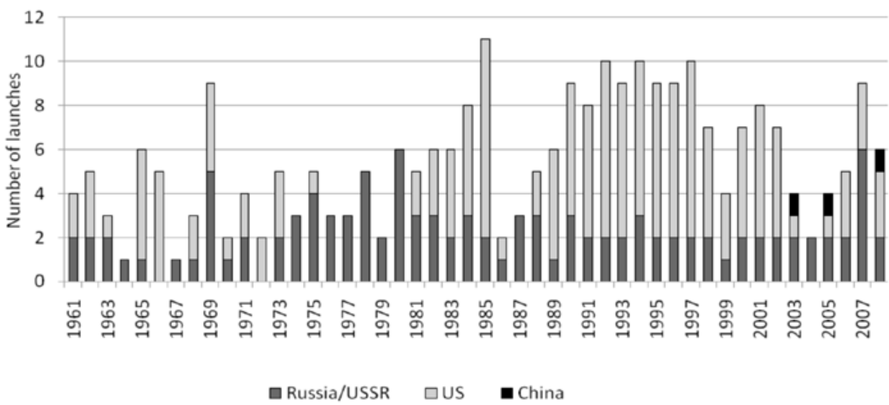
On 12 April 1961 Yuri Gagarin became the first human to travel into space onboard a Soviet Vostok 1 spacecraft. The early years of human spaceflight were dominated by the USSR, which succeeded in fielding the first woman in space, the first human spacewalk, the first multiple-person space flights, and the longest-duration space flight. Following the Vostok series rockets, the Soyuz became the workhorse of the Soviet and then Russian human spaceflight program, and has since carried out over 100 missions, with a capacity of three humans on each flight. The 2006-2015 Federal Space Program maintains an emphasis on human spaceflight, featuring ongoing development of a reusable spacecraft to replace the Soyuz vehicle, and completion of the Russian segment of the ISS.[45]

The first US human mission was completed on 5 May 1961, with the suborbital flight of the Mercury capsule launched on an Atlas-Mercury rocket. This was followed by the Gemini flight series and then the Apollo flight series, which ultimately took humans to the Moon. The US went on to develop the Skylab human space laboratories in 1973, and the USSR developed the MIR space station, which operated from 1986 to 2001. In the 1970s, the US initiated the Space Shuttle, which is capable of launching up to seven people to low Earth orbit (LEO). The first Space Shuttle, Columbia, was launched in 1981. By the end of 2008 the program had completed 124 launches and is currently the only human spaceflight capability for the US.[46] For a time after the 2003 Space Shuttle Columbia disaster, Russia was the only actor performing regular human missions, and its Soyuz spacecraft provided the only lifeline to the ISS (see Figure 3.5). This situation may recur, with the Space Shuttle scheduled for retirement in 2010 and the follow-on Orion/Ares system not anticipated before 2015.[47] In 2004 the US announced a new NASA plan that includes returning humans to the Moon by 2020 and a human mission to Mars thereafter. A new strategy for lunar exploration was announced in 2006.[48] Future plans include a permanent human presence on the lunar surface.[49]

China began developing the Shenzhou human spaceflight system in the late 1990s and completed a successful human mission in 2003, becoming the third state to develop an independent human spaceflight capability.[50] A second mission was successfully completed in 2005 and a third in 2008 (see below).

Other civil programs are also turning to human spaceflight and the Moon. In 2005 JAXA released its 20-year vision statement, which includes expanding its knowledge of human space activities aboard the ISS as well as developing a human space shuttle by 2025.[51] The ESA also has a long-term plan to send humans to the Moon and Mars through the Aurora program. India approved a human spaceflight program in 2006.[52] In 2007 both Japan and China launched robotic lunar missions: Kaguya and Change'e-1.[53] Germany, India, and South Korea are also planning lunar missions.[54]

Figure 3.5: Human spaceflight 1961 – 2008



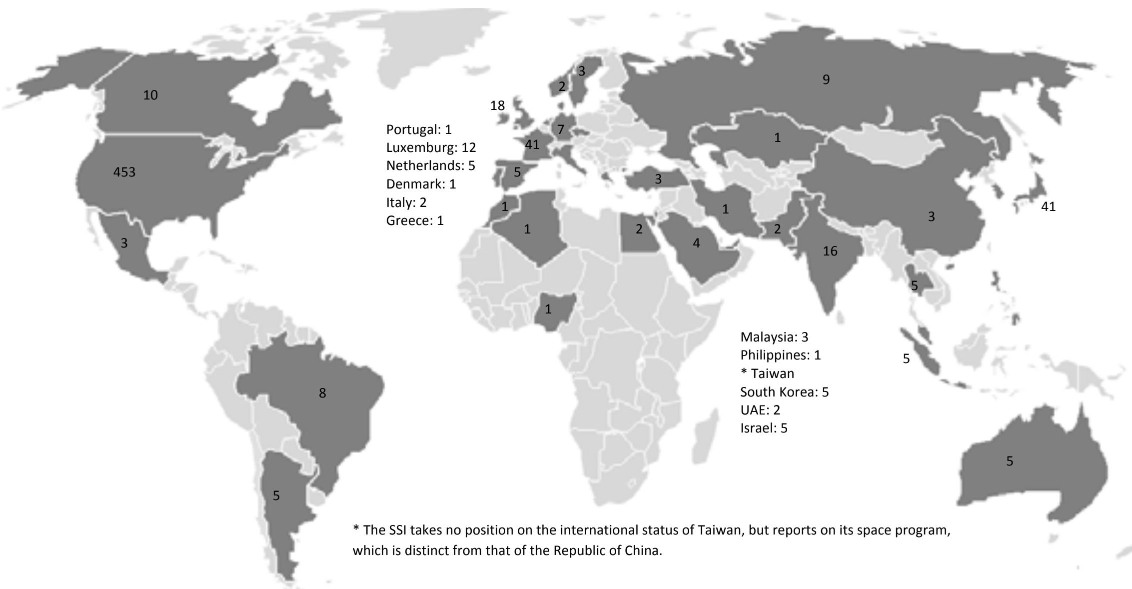
New directions for civil programs

More civil space projects are now explicitly focused on social and economic development objectives. ISRO was established on this basis in 1969 and has since developed a series of communications satellites that provide tele-education and telehealth applications and remote sensing satellites to enhance agriculture, land, and water resource management and disaster monitoring.[55] In 2000 Malaysia launched Tiungsat-1, a microsatellite that included several remote sensing instruments for environmental monitoring. In 1998 Thailand and Chile together launched TMSat, the world's first 50-kilogram microsatellite to produce high-resolution, full-color, multispectral images for monitoring the Earth, and FASat-Bravo, a microsatellite to study depletion of the ozone layer.[56] African states such as Algeria, Egypt, Nigeria, and South Africa have built or are in the process of building satellites to support socioeconomic development. A part of the 2007 EU/ESA Space Policy's mission is to serve the public in the area of "environment, development, and global climate change."[57]

Efforts are also being made to expand the reach of such programs. China and Brazil have agreed to provide free land images to African and Asian countries from their joint optical remote sensing satellite CBERS-2B (China-Brazil Earth Resource Satellite-2B), launched in September 2007.[58] They will also provide the software needed to read the data, which is intended to help respond to threats such as deforestation, desertification, and drought.[59] India has also committed to sharing remote sensing data for disaster management in the Asia-Pacific region and provides data analysis and training to countries without independent access.[60]

Civil space programs, particularly meteorology and Earth observation science, are increasingly used for national security missions. For example, the objective of the EU/ESA Global Monitoring for Environment and Security (GMES) program is to "support Europe's goals regarding sustainable development and global governance, in support of environmental and security policies, by facilitating and fostering the timely provision of quality data, information, and knowledge."[61]

Figure 3.6: Number of satellites by actor, December 2006[62]



2008 Developments

NASA focused on maintaining human access to space as retirement of the Space Shuttle looms

The US continues to spend more on space than all other states combined. The US Congress authorized funds for NASA of just over $20.2-billion for fiscal year 2009 — almost $3-billion higher than the budget of the previous year and $2.6-billion over what was requested[63] (although the amount used may be lower).

Lessening the impending gap in human access to space after the retirement of the Space Shuttle in 2010 was a significant concern for the US in 2008.[64] Spurred on by congressional efforts to extend the Space Shuttle program and concerns expressed during the presidential campaign, in August 2008 NASA initiated a study of requirements to extend Shuttle flights until 2015. The study revealed significant costs and risks to extending the program.[65] It is estimated that adding three additional flights to maintain operations until 2012 would cost $4.5-billion, and closing the capability gap through 2015 would cost $11-billion and would cause setbacks to a planned return to the Moon by 2020. The study also raised safety concerns.[66] The NASA Authorization Act of 2008 mandated the Agency to add one additional flight to the ISS beyond the 10 currently planned through 2010.[67]

Faced with potential delays in developing the Orion space capsule and Ares-1 launcher, NASA is reportedly adjusting the budget, schedule, and technical milestones for the first Orion/Ares-1 flight to meet an internal target date of 2014 and an absolute deadline of March 2015.[68] Without an extension of the Shuttle the US would be dependent on the Russian Soyuz for access to the ISS, but that arrangement came under stress in 2008 from disagreements over Georgia and Iran. A waiver for NASA on a US arms control law banning payments to Russia for space station activities until actions are taken on the flow of weapons technology to Iran, North Korea, and Syria was set to expire in 2011. Congress threatened to deny the waiver following tensions between the US and Russia over renewed conflict in Georgia, but finally granted it.[69] NASA and Russia are now negotiating the terms of continued Soyuz use beyond 2011.

2008 Developments

Space programs in China and India continue to grow, with focus shifting to human spaceflight

China successfully completed its third human spaceflight and its first extra-vehicular space walk in October 2008 using the Shenzhou-7, which also released a microsatellite to examine the space vehicle (see Space Systems Negation Trend 7.4).[70] This launch is part of a wider program to build a space station by 2020 and perhaps eventually go to the Moon.[71] Plans for the mass production of the Shenzhou-8, which could be used to support a space station, were announced in September 2008.[72] China is expected to launch three Shenzhou spacecraft in 2010-11 as part of a program to build a small laboratory in space.[73] China's space program is expected to grow steadily in coming years, as China's economy continues to expand and it pursues further human spaceflight and lunar programs.[74]

In 2008 ISRO asked the Indian government to approve a $2.5-billion human spaceflight program, with its Chairman claiming that India "cannot be left behind in the space race."[75] ISRO is working on a project to send two astronauts into space by 2015 without international cooperation: design of its human spacecraft began in October 2006.[76] The space budget for 2008-2009 is approximately $830-million, a significant increase over 2006-2007 expenditures of $607-million.[77] Major programs include launch vehicle development,[78] Earth observation systems, satellite communications and navigation, space science, atmospheric science, and disaster management. Increasingly, however, ISRO is shifting toward larger-scale, more prestigious human spaceflight and lunar projects (see below).

2008 Developments

Russia significantly increases the budget for space, primarily to make GLONASS viable

In Russia, the expenditure on civil space is roughly $2.2-billion, and includes the Federal Space Agency (Roscosmos) operational budget of $15-million and $2.19-billion for the programs that it operates.[79] In mid-February 2008 the Audit Chamber's board assessed the operations of Roscosmos and reported that its GLONASS navigation system was unlikely to offer serious competition to the US Global Positioning System (GPS).[80] Funding for GLONASS was substantially increased in the planned budgets for 2010 and 2011.[81]

Figure 3.7: Russia civil space spending 2009-2011

Organ/program	2009	2010	2011
Roscosmos	79 billion roubles ($2.2 billion)	52 billion ($1.4 billion)	56 billion ($1.5 billion)
Federal space program 2006-2015	58 billion ($1.6 billion)	36 billion ($1 billion)	43 billion ($1.2 billion)
Federal program on the development of cosmodromes 2006-2015	7 billion ($194 million)	9 billion ($253 million)	9 billion ($249 million)
Federal program GLONASS	526 million ($15 million)	28 billion ($771 million)	19 billion ($533 million)

2008 Developments

Space agencies continue to focus on robotic missions to the Moon

Following the Chinese and Japanese lunar probes launched in 2007, on 22 October 2008, India successfully launched its Moon orbiter the Chandrayaan-1, which will create a three-dimensional map of the lunar surface.[82] The probe carried five Indian scientific instruments and six built by other countries. At $79-million, the mission is considerably less expensive than China's and Japan's missions, at approximating $185-million and $470-million respectively.[83]

Additional testing took place for NASA's Lunar Reconnaissance Orbiter and Lunar Crater Observation and Sensing Satellite, which are to be launched together in 2009 to map the Moon and search for water ice or vapor respectively as the first step of the Vision for Space Exploration, intended to return humans to the Moon.[84] In addition, NASA's Constellation Program released a broad agency announcement for study proposals to evaluate human landing craft concepts to explore the Moon.[85] NASA also continued its focus on exploration of Mars, but additional funding is required for its planned 2009 rover mission, which has been postponed until 2011 and increased in cost to $1.9-billion from $1.6-billion.[86]

China's Chang'e-1 spacecraft continued to orbit the Moon in 2008 pending an intentional crash onto the surface scheduled for 2009.[87] The follow-on Chang'e-2 lunar orbiter satellite is scheduled for launch in 2010 or 2011.[88] China's Moon program is divided into three stages: orbiting the Moon; landing an unmanned vehicle on the Moon to study its surface; and collecting and returning samples of lunar soil.[89] It is anticipated that in the long term this will lead to manned missions to the Moon.[90] ISRO, the ESA, and JAXA have all announced informal interest for human Moon missions within the next two decades, although India's intentions are more concrete.[91]

Despite the growing number of independent lunar programs under development and talk of a new space race, these programs still involve strong elements of international cooperation (see Trend 3.3 below).

2008 Space Security Impact

The use of outer space continues to be dominated by a few states, with activities in 2008 demonstrating renewed interest in lunar exploration and human spaceflight. Although developments in 2008 indicate some cooperation on these projects, historical trends indicate that competition may increase if such capabilities become strategic in the future. Nonetheless, it remains to be seen if large-scale projects will gain the necessary investment to come to fruition; only in India, Russia, and possibly China are resources growing significantly. Delays in construction of new human spacecraft in the US may adversely influence space security in the future by limiting human access to space, particularly to the International Space Station (ISS).

Trend 3.3: Continued international cooperation in civil space programs

Due to the huge costs and technical challenges associated with access to and use of space, international cooperation has been a defining feature of civil space programs throughout the space age. Scientific satellites in particular have been a driver of cooperation.[92] One of the first scientific satellites, Ariel-1, was launched in 1962 and was the world's first international satellite, built by NASA to carry UK experiments. The earliest large international cooperation program was the Apollo-Soyuz Test Project, which saw two Cold War rivals working collaboratively on programs that culminated in a joint docking in space of US/USSR human modules in July 1975. However, "collaboration has worked most smoothly when the science or technology concerned is not of direct strategic (used here to mean commercial or military) importance," and when projects have "no practical application in at least the short to medium term."[93] Moreover, if government support for space science decreases, such cooperative efforts may also decline. A March 2006 report indicates that $3-billion will be cut from NASA's space science budget over the course of three years as priority shifts toward human space flight.[94]

The 1980s saw a myriad of international collaborative projects involving the USSR and other countries — including the US, Afghanistan, Austria, Bulgaria, Canada, France, Germany, Japan, Slovenia, Syria, and the UK — to enable those states to send astronauts to conduct experiments onboard the MIR space station.[95] From 1995 to 1998 there were nine dockings of the US Space Shuttle to the MIR space station, with various crew exchanges.[96] The ESA and NASA have collaborated on many scientific missions, including the Hubble Space Telescope, the Galileo Jupiter probe, and the Cassini-Huygens Saturn probe.

The most prominent example of international civil space cooperation is the ISS, the largest international engineering project ever undertaken. The project partners are NASA, Roscosmos, ESA, JAXA, and the Canadian Space Agency (CSA). Brazil participates through a separate agreement with NASA. The first module was launched in 1998. By 2008, 79 launches, including the first mission by the ESA, had carried components, equipment, and astronauts to the station, but it remains unfinished.[97] The ISS is projected to cost $129-billion over 30 years of operations.[98]

Space-based global utilities, discussed in more detail in Trend 3.4, represent another area of international cooperation. The EU Galileo satellite navigation system is a partnership between the EU and the ESA and includes several international partners.[99] Algeria, China, Nigeria, Spain, Thailand, Turkey, Vietnam, and the UK are collaborating on the Disaster Monitoring Constellation. The project, initiated by China, foresees the deployment of 10 dedicated microsatellites, seven of which have been deployed to date. International cooperation on Earth observation is also discussed below.

The nature of international space cooperation has changed since the end of the Cold War, as many barriers to partnership have been overcome. Examples include the EU-Russia collaboration on launcher development and uses, and EU-China cooperation on Galileo. There were some indications of future cooperation between the civil space activities of China and the US following an agreement signed in 2006,[100] but this faltered following the Chinese intercept and destruction of one of its own satellites in 2007.

Cooperation is also increasing among developed and developing countries, with new, unprecedented partnerships such as the Sino-Brazilian Earth observation satellite effort.[101] A 2006 Chinese white paper indicated that China had signed 16 international space cooperation agreements with 13 different countries, space agencies, and international organizations over the course of five years.[102] Pakistan, Nigeria, and Venezuela were identified as future partners in efforts to develop and launch satellites.

Despite signs of a new space race to the Moon, significant international cooperation is developing for Moon and Mars missions. In 2007 the 14 largest space agencies agreed to coordinate future space missions in the document "The Global Exploration Strategy: The Framework for Coordination," which highlights a shared vision of space exploration, focused on solar system destinations such as the Moon and Mars. It calls for a voluntary forum to assist coordination and collaboration for sustainable space exploration, although it does not establish a global space program.[103] Chinese authorities have also indicated that a mechanism for cooperation is being developed in Asia among countries pursuing lunar exploration programs.[104] Significant bilateral cooperation on Moon and Mars missions is also taking place. For example, ESA provided technical support and knowledge-sharing for both China's Chang'e-1 lunar orbiter and India's Chandrayaan-1 lunar orbiter. However, export controls remain a hindrance to increased cooperation, particularly in the US (see Commercial Space Trend 4.3).

2008 Developments

Continued international cooperation on space exploration as the International Space Station turns 10

The ISS marked its tenth anniversary in 2008 with the successful addition of European and Japanese laboratory modules and its first visit by the European Jules Verne Automated Transfer Vehicle.[105] The NASA budget approved in 2008 reserved $2.06-billion for the ISS program, including crew and cargo services — an increase of $247-million from the previous year — and funding for an additional flight beyond 2010 to deliver the Alpha Magnetic Spectrometer.[106] The ISS was originally scheduled to be completed in 2003, but the target date continues to be pushed back. Russia announced that it needs an additional $5-billion to finish the construction of its segment by 2015.[107]

Although several independent Moon and Mars missions are under way, they involve significant levels of international cooperation. In 2008 both the ESA and NASA cooperated with ISRO in its Chandrayaan-1 mission, which carried five instruments on their behalf. Europe is also assisting ISRO in the operations, data handling, and flight dynamics.[108] The US signed an agreement with what it referred to as eight "emerging" space states in July 2008 to cooperate on lunar exploration by building and operating an International Lunar Network of robotic probes to analyze the Moon's surface. The cooperating states include Canada, Germany, India, Italy, France, Japan, South Korea, Germany, and the UK.[109] In January 2008 Japan and Europe signed a cooperation agreement for a robotic mission (ESA's Mercury Planetary Orbiter [MPO] and JAXA's Mercury Magnetospheric Orbiter [MMO]) to Mercury. Its overall cost for ESA is €665-million ($970-million).[110]

There are signs that international cooperation on space exploration will continue to grow in the near future. In July 2008 the Canadian Space Agency hosted a meeting of the International Space Exploration Coordination Group, a mechanism for coordinating space exploration efforts laid out in the 2007 "Global Exploration Strategy." The meeting resulted in a continued commitment to cooperation as well as the establishment of a secretariat, which will initially be hosted by the ESA.[111]

Amidst speculation of a space race between the US and China, the two resumed talks on potential areas of space cooperation and agreed to establish working groups on space and

Earth science, the first of which met in June 2008.[112] While cooperation on exploration may remain remote, in the past China has expressed interest in participating in the ISS.[113]

2008 Developments

International cooperation provides access to space for developing countries

International government-to-government cooperation has been a driving force behind the increase in the number of states with access to outer space, and this trend continued in 2008. Plans progressed to launch a fourth China-Brazil Earth Remote Sensing satellite in 2009.[114] Brazil also signed an agreement with Germany to develop a night-vision radar satellite to observe the Amazon region.[115] Moreover, Brazil and Argentina agreed to collaborate on the construction and launch of a hyperspectral remote sensing satellite for environmental monitoring and oceanography.[116]

On 29 October 2008 China launched the Venesat-1 communications satellite for Venezuela, as part of a $406-million agreement signed in 2004 to provide training and technological expertise.[117] China is also providing the headquarters for the Asia-Pacific Space Cooperation Organization, which officially began operations in December 2008. Its seven members include China, Bangladesh, Iran, Mongolia, Pakistan, Peru, and Thailand; Indonesia, and Turkey have also signed the charter but are not yet members. Members will work together in development and research, space technology application, and training of space experts.[118]

Ukraine and Indonesia agreed to cooperate on space in 2008, including “space research, rocket technology, satellite launches, earth remote sensing and other uses of space for peaceful purposes.”[119] Moreover, several initiatives were under way in 2008 to provide better access to Earth Observation data to developing countries and the United Nations (see Trend 3.4 below).

2008 Space Security Impact

The continuation in international cooperation in space is a positive development, particularly if it helps to reduce potential tensions over large-scale, national space projects such as human spaceflight and lunar exploration, and enables more states to access the benefits of outer space through shared costs and technologies. Cooperation can also increase transparency of space activities, further reducing potential conflicts in a strategic environment. There is a risk, however, that sensitive military technologies may proliferate, and that greater access to dual-use space-based applications for military purposes may exacerbate regional tensions.

Trend 3.4: Growth in global utilities as states seek to expand applications and accessibility

The use of space-based global utilities, including navigation, weather, and search-and-rescue systems, has grown dramatically over the last decade. For example, GPS unit consumption grew by approximately 25 percent per year between 1996 and 1999; sales revenue increased from $6.2-billion in 1999[120] to $21.8-billion in 2005.[121] Key global utilities such as GPS and weather satellites were initially developed by military actors. Today these systems have grown into space applications that are almost indispensable to the civil and commercial sectors as well.

Satellite navigation systems

There are currently two global satellite navigation systems: the US GPS and the Russian GLONASS system. Work on GPS began in 1978 and it was declared operational in 1993, with a minimum of 24 satellites that orbit in six different planes at an altitude of approximately 20,000 kilometers in Medium Earth Orbit (MEO). A GPS receiver must receive signals from four satellites to determine its location, with an accuracy within 20 meters, depending on the precision of available signals. GPS operates a Standard Positioning Service for civilian use and a Precise Positioning Service that is intended for use by the US Department of Defense and its military allies.

Begun as a military system, GPS diversified and grew to the point that, in 2001, military uses of the GPS accounted for only about two percent of its total market. The commercial air transportation industry, which carries over two billion passengers a year, relies heavily on GPS.[122] US companies receive about half of GPS product revenues, but US customers account for only about one-third of the revenue base. The growth rate of GPS units in use continues to increase, particularly outside the US.[123] Demonstrating the growing importance of satellite navigation for civilian uses, former US President George W. Bush announced in 2007 that next-generation GPS Block III satellites will not have the selective availability capability to degrade the civilian signal. The "decision reflects the United States strong commitment to users of GPS that this free global utility can be counted on to support peaceful civil activities around the world."[124]

The Russian GLONASS system uses principles similar to those used in the GPS. It is designed to comprise a minimum of 24 satellites in three orbital planes, with eight satellites equally spaced in each plane, in a circular orbit with an altitude of 19,100 kilometers.[125] The first GLONASS satellite was orbited in 1982 and the system became operational in 1996. Satellites soon malfunctioned, however, and the system remains below operational levels, retaining only some capability, although efforts are again under way to complete the system.[126] GLONASS operates a Standard Precision service available to all civilian users on a continuous, worldwide basis and a High Precision service available to all commercial users since 2007.[127] However, the inadequacies of the GLONASS system, including inaccuracy and instability, are becoming more apparent.[128] Russia has extended cooperation on GLONASS to China and India.[129]

Two additional independent, global satellite navigation systems are being developed: the EU/ESA Galileo Navigation System and China's Beidou Navigation System. Galileo is designed to operate 30 satellites in MEO in a constellation similar to that of the GPS to provide Europe with independent capabilities. Significant effort on Galileo began in 2002, with the allocation of $577-million in development funds by the European Council of Transport Ministers under a public-private partnership.[130] After a delay of five years, European governments agreed in 2007 to provide the necessary $5-billion to continue work on what is now a public system not set to be deployed until 2013.[131] Galileo will offer open service; commercial service; safety-of-life service; search-and-rescue service; and an encrypted, jam-resistant, publicly regulated service reserved for public authorities that are responsible for civil protection, national security, and law enforcement.[132]

The current Chinese Beidou system is experimental and limited to regional uses. It uses a different principle than that of the GPS or GLONASS, operating four satellites in geostationary orbit.[133] In 2006 China announced that it will extend Beidou into a global system called Compass or Beidou-2 for military, civilian, and commercial use.[134] The global system is planned to include five satellites in GEO and 30 in MEO. India has also proposed an independent, regional system, the Indian Regional Navigation Satellite System (IRNSS), intended to consist of a seven-satellite constellation.[135] Similarly, Japan is developing the Quazi-Zenith Satellite System (QZSS), which is to consist of a few satellites interoperable with GPS in Highly Elliptical Orbit to enhance regional navigation over Japan, but will operate separately from GPS, providing guaranteed service.[136] Launch of the first satellite is expected for 2010, with initial services beginning in 2013.[137]

The development of competing independent satellite navigation systems, although conceivably interoperable and able to extend the reliability of this global utility, is not being coordinated internationally and has led to several conflicts, most notably over the use of signal frequencies. Another concern, however, is orbital crowding, as states seek to duplicate global services, particularly in MEO (see The Space Environment Trend 1.4). More troubling from the perspective of global satellite utilities, however, is the underlying drive for independent systems based on a concern that existing global satellite navigation signals such as GPS are not assured, particularly during times of conflict. Nonetheless, almost all states remain dependent on GPS service, and many of the proposed global and regional systems require cooperation with the US system.

Remote sensing

Remote sensing satellites are used extensively for a variety of Earth observation functions, including weather forecasting; surveillance of borders and coastal waters; monitoring crops, fisheries, and forests; as well as monitoring natural disasters such as hurricanes, droughts, floods, volcanic eruptions, earthquakes, tsunamis, and avalanches. Access to EO data is spreading worldwide, although not without difficulties.[138] To ensure truly broad access to data, agencies across the globe must cooperate more in exchanging data; this is now being realized by some participants.[139]

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) provides meteorological data for Europeans. The US NOAA, founded in 1970, provides the US with meteorological services.[140] Satellite operators from China, Europe, India, Japan, Russia, and the US, together with the World Meteorological Organization, make up the Co-ordination Group for Meteorological Satellites, a forum for the exchange of technical information on geostationary and polar-orbiting meteorological satellite systems.[141]

The Global Earth Observation System of Systems (GEOSS) has the goal of "establishing an international, comprehensive, coordinated and sustained Earth Observation System."[142] It is coordinated by the Group on Earth Observation, whose members currently include 77 states and the European Commission.[143] Begun in 2005, GEOSS has a 10-year implementation plan. Benefits will include reduction of the impact of disasters, resource monitoring and management, sustainable land use and management, better development of energy resources, and adaptation to climate variability and change.[144] The European GMES initiative is another example of a centralized database of Earth observation data made available to users around the world.[145]

Disaster relief

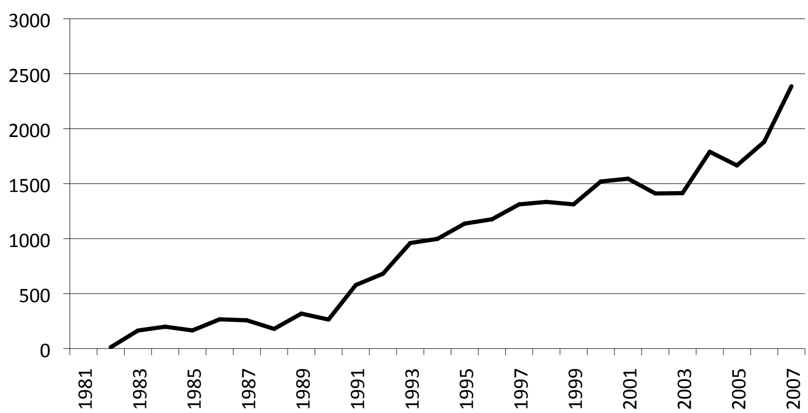
Space has also become critical for disaster relief. The International Charter "Space and Major Disasters" was initiated by ESA and CNES in 1999 to provide "a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users."[146] Other member organizations include the CSA, NOAA, ISRO, the Argentine Space Agency, the US Geological Survey, the British National Space Centre, CNSA, and DMC International Imaging, which bring together resources from over 20 spacecraft.[147] DMC International Imaging operates satellites for the Disaster Monitoring Constellation, which is a collaboration of Algeria, China, Nigeria, Spain, Thailand, Turkey, the UK, and Vietnam. The constellation is intended to deploy 10 Earth imaging microsatellites and seven are currently in operation.[148] Although it is used for international disaster relief purposes, its main function is to provide daily imaging capabilities to partner states.[149]

Search and rescue

In 1979 COSPAS-SARSAT, the International Satellite System for Search and Rescue, was founded by Canada, France, the USSR, and the US to coordinate satellite-based search-and-rescue. Since 2001 COSPAS-SARSAT has provided emergency communications for people in distress and has been credited with saving the lives of over 1,500 people per year, or more than 24,000 (see Figure 3.8). Currently the system operates 10 satellites.[150]

Recently states including Canada and Norway have begun to develop satellite systems to better collect and track Automated Identification System signals for collision avoidance. Satellite receivers for such signals could improve search-and-rescue efforts, as well as ship surveillance for security purposes (see Space Support for Terrestrial Military Operations Trend 5.2).[151]

Figure 3.8: Lives saved annually by COSPAS-SARSAT[152]



2008 Developments

Continued development of independent satellite navigation capabilities

Following restructuring of Europe's Galileo satellite navigation system in 2007 from a failed private-public partnership to a fully public system, the program made significant progress in 2008. The procurement process was launched in 2008, with an invitation to 11 companies to compete; between €2-billion and €3-billion is to be spent on 26 satellites, launches, and ground control stations.[153] Moreover, the second Galileo In-Orbit Validation Element satellite built by SSTL was tested successfully in 2008.[154] Galileo is scheduled for full deployment in 2013.

In an effort to get the GLONASS satellite navigation system back to full operational capability, Russian Prime Minister Vladimir Putin boosted financing for the project by $2.61-billion for 2008.[155] Russia launched six GLONASS-M satellites in 2008,[156] bringing the number of satellites in the constellation up to 20, "of which 16 are operational, two are undergoing maintenance, and one is due to be withdrawn. The system requires 18 satellites for continuous navigation services covering the entire territory of the Russian Federation, and 24 satellites to provide services worldwide."[157] Russia is also considering extending participation in the program to Cuba and Venezuela.[158]

China continues to develop its regional satellite navigation system Beidou (Compass), which covers Asia and is intended to be operational by 2010[159] and to eventually develop into a global system. Although Chinese officials have claimed that this system will be fully compatible with the US GPS, European Galileo, and Russian GLONASS systems, China has not yet completed frequency coordination with these states.[160] This is particularly a challenge for Europe, because China has filed with the International Telecommunication Union to use the same frequencies as those used by Galileo.

2008 Developments

Global access to remote sensing data improving

The GMES is an EU-led initiative in partnership with the ESA to combine ground- and space-based remote sensing data to develop an integrated environmental and security monitoring capability. It is one of the first examples of a service based on Earth imagery to be used for climate change, sustainable development, environmental policies and agreement verification, European civil protection, development aid, humanitarian aid, and implementation of the European Common Foreign and Security Policy. In 2008 Thales Alenia Space signed a €305-million contract to provide the system's first Sentinel-3 satellite, which will be devoted to oceanography and land-vegetation monitoring.[161] Phase two of the space component of the program was approved at the ESA Ministerial meeting in November 2008, with €830-million pledged by member states for the period 2009-2018.[162]

Under the auspices of the International Charter "Space and Major Disasters," the UN Office for the Coordination of Humanitarian Affairs asked for support to provide maps of affected areas following the cyclone that hit Myanmar on 3 May 2008. More than 10 different radar and optical sensors provided more than 60 satellite images, which were used by the UN Institute for Training and Research Operational Satellite Applications Programme (UNOSAT) to develop 29 maps showing the impact of the cyclone.[163] Satellite data was also requested by China through the Charter[164] and other channels[165] following the earthquakes in May 2008. In total, the Charter was activated 40 times in 2008 in response to floods, hurricanes, volcanic eruptions, and earthquakes around the world.[166] Two new satellites were added to the Disaster Monitoring Constellation in 2008 — Deimos-1 of Spain and the UK's UK-DMC2. They will offer improved images with a resolution of 22 meters and will provide free data for research to 10 selected projects.[167]

To help provide remote sensing data more systematically, NASA is working with the US Agency for International Development (USAID) and other international partners on a program called SERVIR-Africa in Nairobi, Kenya, officially launched in November 2008.[168] The system integrates the satellite resources of the United States and other countries into a Web-based Earth information system and makes relevant information accessible to local scientists, government leaders, and communities to help address such concerns as natural disasters, disease outbreaks, biodiversity, and climate change. Similarly, in July 2008 India and France adopted a data policy that will enable the global scientific community to have free access to data from the planned Megha Tropiques collaborative satellite that will monitor tropical weather.[169] Finally China launched its first two optical Huanjing disaster monitoring satellites, which are intended to be reinforced by 2010 by eight additional satellites that combine radar and optical capabilities. It is not clear if they will contribute to the "Space and Disasters" Charter.[170] China is also cooperating with the ESA on a second phase of the Dragon Program that should "encourage increased use of ESA and Chinese EO satellite data within China."[171]

2008 Space Security Impact

Ongoing development of space-based global utilities such as satellite navigation systems could have a positive impact on space security by providing redundancy of capabilities and increasing access to space through collaborative efforts, particularly if they are interoperable. However, such a result requires considerable international coordination and cooperation, which have not fully developed due to ongoing disputes over the use of frequency signals, the development of independent capabilities to guarantee service, and a lack of planning for the increased demand on orbits and radio frequencies created by duplicate systems. The growing use of remote sensing data to manage a range of global challenges, including disaster monitoring and response, is positive for space security insofar as it further links the security of Earth to the security of space, expands space applications to include additional users, and encourages international collaboration and cooperation on an important space capability.

CHAPTER FOUR

Commercial Space

This chapter assesses trends and developments in the commercial space sector, which includes the builders of space hardware such as rockets and satellite components, providers of space information such as telecommunications and remote sensing, and service operators for space launches, in the global market.

The commercial space sector has experienced dramatic growth over the past decade, largely related to rapidly increasing revenues associated with satellite services. These services are provided by companies that own and operate satellites, as well as the ground support centers that control them. The bulk of the revenue in the satellite services sector is generated by telecommunications.[1] The commercial sector has been instrumental in providing broader access to services that were once the exclusive perview of governments, including remote sensing and satellite-based navigation.

The second largest contribution to the growth of the commercial space sector has been made by satellite and ground equipment manufacturing. This includes both direct contractors that design and build large systems and vehicles, smaller subcontractors responsible for system components, and software providers.

This chapter also assesses trends and developments associated with access to space via commercial launch services. In the early 2000s, overcapacity in the launch market and a reduction in commercial demand combined to depress the cost of commercial space launches. More recently, an energized satellite communication market and launch industry consolidation have resulted in stabilization and an increase in launch pricing.

Finally, this chapter examines the relationships between governments and the commercial space sector, including the government as partner and the government as regulator, and the growing dependency of militaries on commercial services. Governments play a central role in commercial space activities by supporting research and development, subsidizing certain space industries, and adopting enabling policies and regulations. Indeed the space launch and manufacturing sectors rely heavily on government contracts. Conversely, because space technology is often dual-use, governments have sometimes taken actions such as the imposition of export controls, which have constrained the growth of the commercial market. There is also evidence that commercial actors are engaging governments on space governance issues, in particular space traffic management and best practices, and space situational awareness.

Space Security Impact

The pervasive role that the commercial space sector plays in launch, communications, imagery, and manufacturing, in addition to its role of supporting government civil and military programs, means that the commercial space sector both affects and is affected by changes in space security. A healthy space industry can lead to decreasing costs for space access and use, and increase the accessibility of space technology. Of the 49 states that have accessed space to date (see Civil Space Trend 3.1), almost all have been assisted in some way by the commercial space industry. This has a positive impact on space security by increasing the number of actors that can access and use space or space products, thereby increasing the number of stakeholders in the maintenance of space security. Increased competition can also lead to the further diversification of capabilities to access and use space. Conversely, an active space industry is also evidence of the *secure and sustainable access to space* needed to provide a viable business to investors.

Commercial space efforts have the potential to increase the level of transnational cooperation and interdependence in the space sector, building transparency and trust through international collaboration. Additionally, the development of the space industry could influence international space governance. To thrive, sustainable commercial markets must have the freedom to innovate, but they also require a framework of laws and regulations on issues of property, standards, and liabilities.

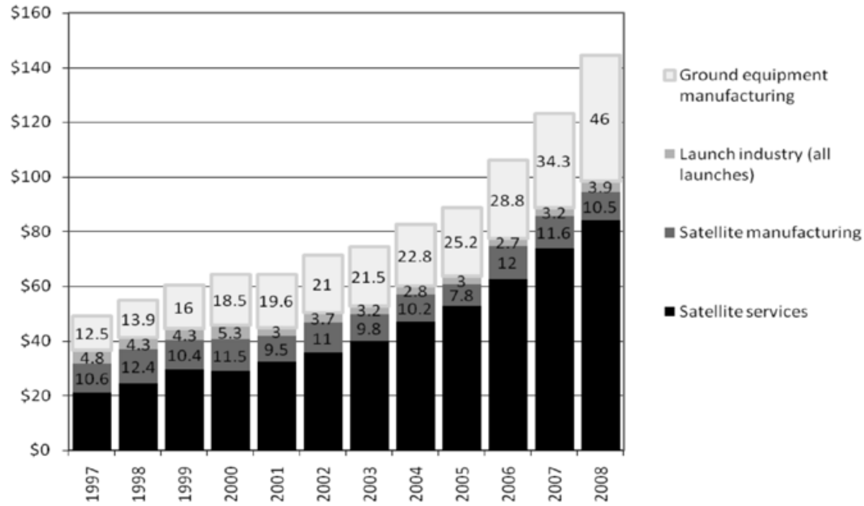
Some commercial space actors also note that issues of ownership and property pose an increasing challenge to the growth of the industry. For example, while the non-appropriation clause of the Outer Space Treaty is generally understood to prohibit ownership claims in space, this clause also raises questions about the allocation and use of space resources. There is concern that the clause could stifle entrepreneurship and growth in the commercial space industry. As well, future conflicts over the issue could decrease space security if not addressed in a timely manner.

Growth in space commerce has already led to greater competition for scarce space resources such as orbital slots and radio frequencies. To date, the International Telecommunication Union (ITU) and national regulators have been able to manage inter- and intraindustry tensions (see The Space Environment Trend 1.4). However, strong terrestrial demand for additional frequency allocations and demands of emerging nations for new orbital slots will provide new challenges for domestic and international regulators. The dependence of certain segments of the commercial space industry on military clients or, conversely, the reliance of militaries on commercial space assets could also have an adverse impact on space security by making the industry overly dependent on one client, or by making commercial space assets the potential target of military attacks.

Trend 4.1: Continued overall growth in the global commercial space industry

Commercial space revenues have steadily increased since the mid-1990s, when the industry first started to grow significantly. Global commercial space revenues, dominated by satellite services, have been estimated as totaling between $144-billion and $175-billion in 2008.[2] In the decade between 1996 and 2006 the satellite services sector more than tripled in size, generating up to 60 percent of the commercial satellite sector's total revenues (see Figure 4.1).[3] Unlike the manufacturing and launch industry, satellite services such as telecommunications have seen growth that has been largely driven by commercial rather than government demand. However, this trend is rapidly being mirrored in other sectors.

Figure 4.1: World satellite industry revenues by sector (billion)[4]



The telecommunications industry has long been a driver of commercial uses of space. The first commercial satellite was the Telstar-1, launched by NASA in July 1962 for the telecommunications giant AT&T.[5] Satellite industry revenues were first reported in 1978, when *US Industrial Outlook* reported 1976 Communication Satellite Corporation operating revenues of almost $154-million.[6] By 1980 it is estimated that the worldwide commercial space sector already accounted for $2.1-billion.[7] Individual consumers are becoming important stakeholders in space through their demand for telecommunications services, particularly Direct Broadcasting Services but also their use of global satellite positioning and commercial remote sensing images.

Today's space telecommunications sector emerged from what were previously government-operated bodies that were deregulated and privatized in the 1990s. For example, the International Maritime Satellite Organisation (Inmarsat, 1999) and International Telecommunications Satellite Organization (Intelsat, 2001) were privatized in 1999 and 2001 respectively.[8] PanAmSat, New Skies, GE Americom, Loral Skynet, Eutelsat, Iridium, EchoStar, and Globalstar were some of the prominent companies to emerge during this time. Hughes also entered the market with DirecTV, a new satellite television broadcast system. Major companies today include SES Global, Intelsat, Eutelsat, Telesat, and Inmarsat.[9]

The 2000 downturn in the technology and communications sectors affected the commercial space sector, reducing market take-up of satellite telephony and creating overcapacity in the launch sector. The number of commercial satellite launches dropped from a peak of 38 in 1999 to 16 in 2001, but are beginning to recover.[10] The trend in the commercial launch market has shifted away from low demand and high capacity, causing prices to rise recently.[11] In 2006 commercial launch revenues hit their highest point since 2002, with an increase of 20 percent over 2005, reflecting the joint trends of higher demand for launches to Geostationary Orbit (GEO) and higher launch costs. These figures are only beginning to reflect the rising costs to access space, however, as most launches in 2006 were ordered prior to price increases.[12] As in the satellite services industry, commercial customers represent a growing share of launch revenues and now match government payloads.[13] This is also a reflection of the growing demand for telecommunication services. Of the 21 commercial launches in 2006, 16 — the highest number since 2002 — went to GEO.[14] However, 2007 was a record year for non-geostationary launches, reflecting a strong replacement market, but not necessarily overall industry growth.

Steady growth of consumer services is also driving the ground equipment market, which holds the second largest share of market revenues after the satellite services sector.[15] End-user products for individual consumers such as HD TV, satellite radio, and navigation are key drivers.

More satellite launches and a growing satellite services sector have a direct impact on the commercial manufacturing industry. Although satellite manufacturers continue to suffer from pressure to lower prices, strong demand for broadcasting, broadband, and mobile satellite services combined with a strong replacement market to drive an increase in orders that is projected to continue.[16] Nonetheless, revenues decreased slightly in 2007, in part due to the launching of a higher proportion of microsatellites.[17] Although revenue has been unevenly divided between government and commercial payloads, the balance is changing, with commercial payloads accounting for almost 50 percent of revenues in 2008, compared with 25 percent in 2006.[18]

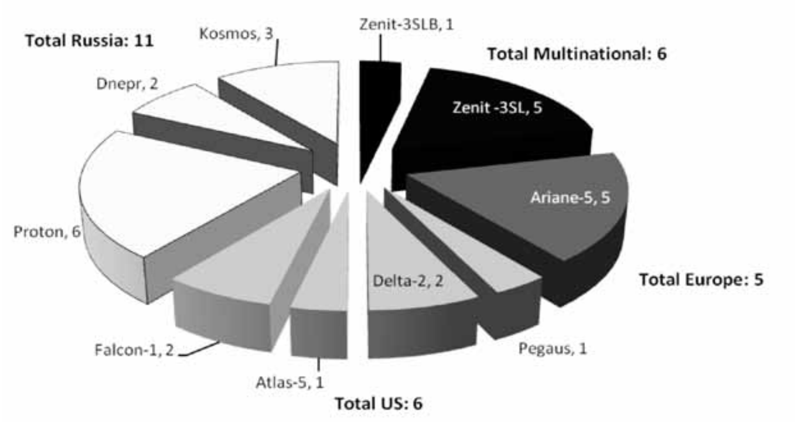
The shape of the commercial space industry is beginning to shift as it becomes more global. Once dominated by the US, Europe, and Russia, other countries, in particular India and China, are getting involved. India is reportedly positioning itself to compete for a portion of the commercial launch service market by offering lower-cost launches.[19] India also intends to compete in the satellite manufacturing industry.[20] It has a strong presence in the commercial remote sensing industry, claiming to have captured 20 percent of data sales in 2007.[21] For the first time in 2007, China both manufactured and launched a satellite for another country, Nigeria's Nigcomsat-1.[22] Developing countries are the prime focus of these efforts.[23] Moreover, because it uses no US components, China is marketing its manufactured satellites as ITAR-free, reportedly at prices below industry standard.[24]

2008 Developments

Continued industry growth driven by consumer services and a strong satellite replacement market

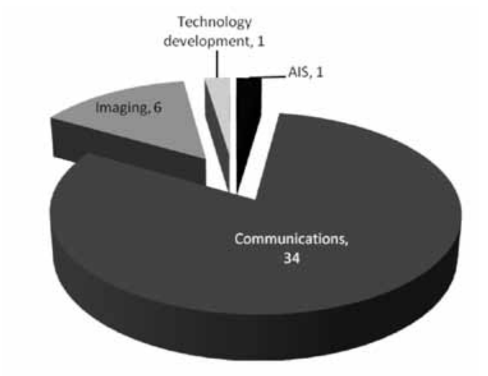
There was a significant increase in commercial launches in 2008, with a rebound to numbers not seen since before the downturn in the industry in 2001. Of 69 launches in 2008, 28 were commercially competed. Although Russia continued to lead the industry in number of commercial launches, its market share decreased to 39 percent and Europe, with 19 percent of the market, earned an estimated $700-million in revenue compared to Russia's $581-million.[25] Revenues have increased steadily since 2004, doubling from approximately $1-billion in 2004 to $2-billion per year in 2008.[26]

Figure 4.2: Commercial launches in 2008 by vehicle[27]



The 28 commercial launches carried a total of 46 payloads, of which 35 provide commercial services.[28] Telecommunications continued to dominate the commercial satellite industry, with 34 payloads launched in 2008. However, while numbers alone might indicate expansion of the commercial space sector, many of the satellites launched were replacements for ageing spacecraft, particularly in non-geostationary orbit, for which launches have risen significantly.[29]

Figure 4.3: Commercial satellites launched in 2008*[30]

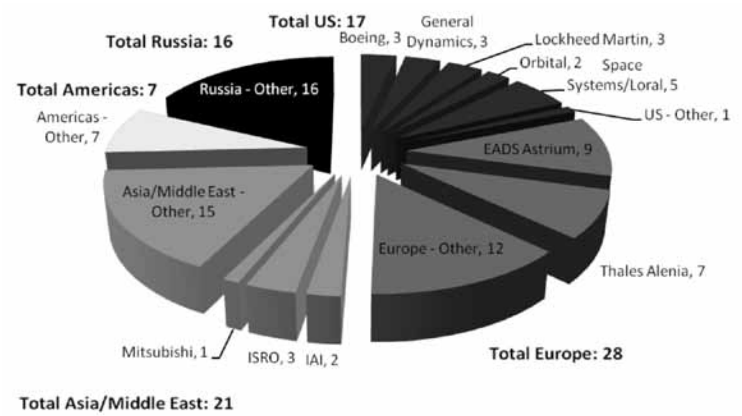


* Commercial satellites defined as those operated by commercial actors or providing commercial services as primary function

Nonetheless, the high number of commercial launches in 2008 is indicative of the overall health of the industry, which is being driven by strong demand for consumer-oriented products and services.[31] Revenues for satellite services and ground equipment increased by 16 percent and 34 percent respectively, both of which were dominated by consumer products, in particular satellite television and GPS equipment.[32]

The breakdown of manufacturers of spacecraft launched in 2008 reflects growing competition in the industry, which is no longer dominated by the US — its share of satellites launched in 2008 dropped to 29 percent from 41 percent in 2007.[33] However, private US firms continue to earn up to 75 percent of corporate space revenue, in significant part due to the size of the US military space sector.[34]

Figure 4.4: Manufacturers of commercial spacecraft launched in 2008[35]



2008 Developments

Growing international competition from China, India, and Japan

In January 2008 India launched Israel's military Earth observation satellite Tecsar using its Polar Satellite Launch Vehicle (PSLV).[36] Although not commercially competed, this was India's second launch for a foreign client. India is reportedly positioning itself to compete for a portion of the commercial launch service market by offering launches, which it claims cost "60 to 70 percent of what is charged by other international space agencies."[37] India also intends to compete in the satellite manufacturing industry.[38] Marking another milestone for the country's commercial interests, the Indian Space Research Organisation (ISRO) built Eutelsat's W2M communications satellite as part of a joint venture with prime contractor EADS Astrium. It was launched by Arianespace on 20 December 2008[39] but failed in orbit. ISRO has another contract through EADS to build a satellite for Avanti Screen Media.[40] In a 2008 study of space competitiveness by the Futron Corporation, India ranked fifth out of 10, just behind China.[41]

China continues to expand its business of launching satellites for foreign countries, including Venezuela's Venesat-1 communications satellite, which China manufactured and launched in October 2008.[42] A similar satellite built and launched for Nigeria in 2007 (NigComSat-1) failed in orbit in October 2008 after a power failure.[43] China also aims to compete as a low-cost launcher in the global space industry, but has not yet been able to break into the commercial market.[44] However, in April 2008 reports emerged that the European commercial satellite operator Eutelsat had purchased insurance to enable it to use Chinese launchers in the future. A Chinese launch of a communications satellite reportedly costs roughly $50-million, or about half the cost of US or European launches.[45] Some of China's non-competed commercial launches are for so-called "ITAR-free" satellites, which do not use US components to avoid US export controls. One such launch includes the Thales Alenia Space-built Chinasat-9, launched on 9 June 2008.[46] China's highest ranking economic body has approved plans for a multi-billion-dollar commercial satellite research city. This move is interpreted by Western analysts as a long-term commitment to commercial satellite business.[47]

Finally, Mitsubishi Heavy Industries, which makes and markets Japan's H-2A heavy launcher, is taking steps to compete in the commercial satellite launch market. Historically Japan's launchers have cost too much for the commercial market, but it reportedly slashed costs in

2008 in line with international rivals and is negotiating deals with US and South Korean telecommunications firms for 2009 launches.[48] South Korea's KOMPSat-3 remote sensing satellite will be launched in 2009 along with the JAXA'a GCom satellite, reducing the cost.[49]

It should be noted, however, that the relative strengths of different currencies and Purchasing Power Parities factor into the competitiveness of different national space sectors, including satellite manufacturing and launch.

2008 Developments

Growth opportunities for small, low-cost satellites may expand access to space

While the satellite industry has traditionally been underpinned by large, high-capability spacecraft, a second path being developed is the manufacture and launch of small satellites.[50] Small satellites are being used more in space because they reduce both manufacturing and launch costs and are capable of providing a growing number of functions. Several countries are investing in this second market as a source of future growth. India intends to have a significant presence in the small satellite market and to that end has established a special team within ISRO.[51] In 2008 India signed an agreement with France to conduct joint research and development activities on small satellites.[52] ISRO will launch two such satellites, YouthSat (with one payload by students of Moscow University) and SARAL (with a French payload), in 2009 and 2010.[53] Similarly, the Russian Federal Space Agency is partnering with the Russian technology company Rosnanotech to promote nanotechnology in its space industry in order to enter other international markets and to remain competitive with both India and China in this field.[54] NASA also announced plans in 2008 to "develop a new economy in space"[55] by developing nanosatellites capable of powering telecommunications and networks in space.

A 2008 report by the Futron Corporation identified the sectors in which the low-cost satellites would be most useful for commercial operators, including a range of communications and remote sensing functions. But it cautioned that ongoing obstacles include a lack of awareness of small satellites, risk, and the current limited availability of low-cost launchers. [56]

2008 Space Security Impact

Although the strong commercial launch industry in 2008 was in part due to the ongoing replacement of satellites, continued growth is also seen in satellite services and ground equipment revenues, driven by consumer-oriented products. Ongoing growth of the industry suggests that there is overall confidence in the security of space and the ability of both companies and consumers to continue to rely on space resources. Further, individual consumers continue to become more significant stakeholders in space. Growing competition in the commercial launch market may contribute to space security by providing greater access to outer space, although tensions may arise if future demand for space resources such as orbital slots and radio frequencies exceeds supply. Currently, however, the positive gains in the sector's value and ubiquity outweigh the greater friction with respect to supply and demand.

Trend 4.2: Commercial sector supporting increased access to space

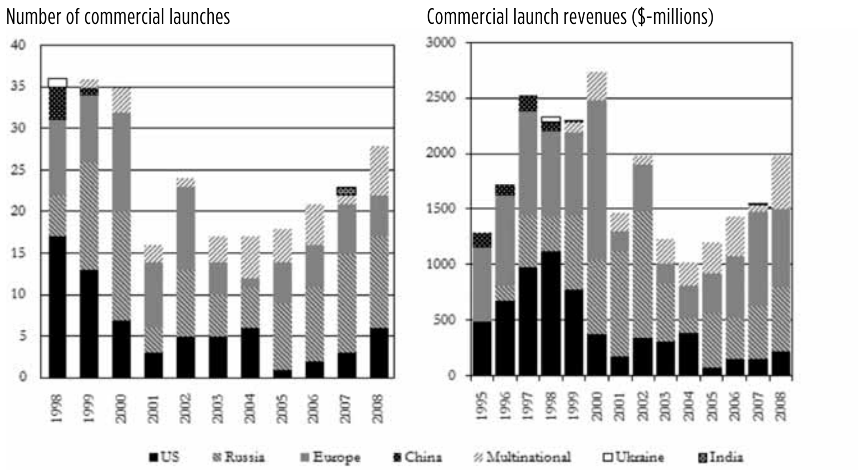
Space launches

A commercial launch is defined as one in which at least one satellite payload's launch was contracted internationally, so that, in principle, a launch opportunity was available to any capable launch services provider.[57] Russian, European, and American companies remain world leaders in the commercial launch sector, with Russia launching the most satellites annually, both commercial and in total, but Europe garnering higher revenues.[58] Generally, launch revenues are attributed to the country in which the primary vehicle manufacturer is based, except in the case of Sea Launch, which is designated as "multinational."[59]

Commercial space access grew significantly in the 1980s. At that time, NASA viewed its provision of commercial launches more as a means to offset operating expenses than as a viable commercial venture. European and Russian companies chose to pursue commercial launches via standard rocket technology, which allowed them to undercut US competitors during the period when the US was only offering launches through its Space Shuttle

Increasing demand for launch services and the ban of commercial payloads on the Space Shuttle following the 1986 Challenger Shuttle disaster encouraged further commercial launch competition. The Ariane launcher, developed by the French in the 1980s, captured over 50 percent of the commercial launch market during the period 1988-1997.[60] The Chinese Long March and the Russian Proton rocket entered the market in the early and mid-1990s. The Long March was later pressured out of the commercial market due to "reliability and export control issues."[61] However, China has opened the possibility of reentering the commercial spaceflight market.[62] Today Ariane, Proton, and Zenit rockets dominate the commercial launch market.

Figure 4.5: Worldwide commercial orbital launch trends[63]



Japanese commercial efforts have suffered from technical difficulties and its H-2 launch vehicle was shelved in 1999 after flight failures.[64] Although the H-2 was revived in 2005, Japan lags behind Russia, Europe, the US, and China in global launches.[65] In May 1999 India's Augmented Polar Satellite Launch Vehicle performed the country's first Low Earth Orbit (LEO) commercial launch, placing German and South Korean satellites in orbit.[66]

Today's top commercial launch providers include Boeing Launch Services and Lockheed Martin Commercial Launch Services (vehicles procured through United Launch Alliance) and Orbital Sciences Corporation in the US; Arianespace in Europe; ISC Kosmotras, Polyot (with partners), and ZAO Puskovie Uslugi in Russia; Antrix in India; China Great Wall Industry Corporation in China; and international consortia Sea Launch, International Launch Service (ILS), Eurockot Launch Services GmbH, and Starsem. Sea Launch, comprised of Boeing (US), Aker Kvaerner (Norway), RSC-Energiya (Russia), and SDO Yuzhnoye/PO Yuzhmash (Ukraine), launches from a mobile sea-based platform located on the equator in the Pacific Ocean. ILS was established as a partnership between Khrunichev State Research and Production Space Center (Russia), Lockheed Martin Commercial Launch Services (US), and RSC-Energiya (Russia). In 2006 Lockheed sold its share to US Space Transport Inc. Eurockot is a joint venture between EADS Space Transportation and Khrunichev, while Starsem is a joint venture between the Russian Federal Space Agency, TsSKB-Progress, EADS Space Transportation, and Arianespace. New commercial launch vehicle builders such as Space Exploration Technologies (SpaceX) are seeking to compete by providing cheaper, reusable launch vehicle designs.

In addition to a proliferation of rocket designs, the launch sector has also seen innovations in launch techniques. For example, since the early 1990s companies such as the UK's Surrey Satellite Technology Ltd. have used piggyback launches — a small satellite is attached to a larger one to avoid costs for a dedicated launch. It is now also common to use dedicated launches to deploy clusters of smaller satellites on small launchers such as the Cosmos rocket and India's PSLV.

Increased competition supported a decrease in space access costs in the 1990s. Specific launch cost data indicates that the cost to launch commercial payloads into GEO declined by approximately 35 percent in the 1990s, from an average of about $40,000 per kilogram to $26,000 per kilogram in 2000. There was no clear pricing trend for commercial payloads going to LEO during this decade, but launches between 1995 and 2000 clustered around $5,000 per kilogram, with significant variances.[67] It should be noted that it is difficult to compare launch costs across payloads and launch vehicles due to the number of important differences between them and the fact that launches are negotiated project-by-project. Moreover, the price of a launch is often not made public, especially since the increase in competition after 2000.[68] Nonetheless, based on current public data it would appear that prices have consolidated and may be rising.[69]

See Annex 3 for a list of global launch vehicles.

Commercial Earth imagery

Until a few years ago only a government could gain access to remote sensing imagery; today any individual or organization with access to the Internet can use these services through Google Maps, Google Earth, and Yahoo Maps programs.[70] Currently several companies in Canada, France, Germany, Israel, Russia, and the US are providing commercial remote sensing imagery. The resolution of the imagery has become progressively more refined and affordable. In addition to optical photo images, synthetic aperture radar images up to one meter in resolution are coming on the market. A growing consumer base is driving up revenues. One report put global expenditures on remote sensing products as high as $7-billion in 2006.[71] Security concerns have been raised, however, due to the potentially sensitive nature of the data (see Trend 4.3).

Commercial satellite navigation

Initially intended for military use, satellite navigation has emerged as a key civilian and commercial service. The US government first promised international civilian use of its planned Global Positioning System (GPS) in 1983, following the downing of Korean Airlines Flight 007 that strayed over Soviet territory, and in 1991 pledged that it would be freely available to the international community beginning in 1993.[72] US GPS civilian signals have dominated the commercial market, but new competition may emerge from the EU's Galileo system, which is specifically designed for civilian and commercial use, and Russia's GLONASS.[73] China's regional Beidou system is also be available for commercial use.[74]

The commercial satellite positioning industry initially focused on niche markets such as surveying and civil aviation, but has since grown to include automotive navigation, agricultural guidance, and construction.[75] The core of revenues to the commercial satellite positioning industry is sales of ground-based equipment. Sales to commercial users first outpaced those to military buyers in the mid-1990s.[76] The commercial GPS market continues to grow with the introduction of new receivers that integrate the GPS function into other devices such as cell phones.[77] Global revenue from the sale of GPS equipment is estimated at $56.19-billion for 2007.[78]

Commercial space transportation

An embryonic private spaceflight industry continues to emerge, seeking to capitalize on new concepts for advanced, reliable, reusable, and relatively affordable technologies for launch to near-space and low Earth orbit. In early December 2004 the US Congress passed into law the "Commercial Space Launch Amendments Act of 2004." Intended to "promote the development of the emerging commercial human space flight industry," the Act establishes the authority of the Federal Aviation Administration (FAA) over suborbital space tourism in the US, allowing it to issue permits to private spacecraft operators to send customers into space.[79] In 2006 the ESA announced the "Survey of European Privately-funded Vehicles for Commercial Human Spaceflight" to support the emergence of a European commercial space transportation industry.[80]

The market for commercial space transportation remains small but has attracted a great deal of interest. By the end of 2008 six private citizens had purchased and flown on orbital spaceflights through Space Adventures, which sells seats on the Russian Soyuz.[81] Prices for this opportunity are increasing, with Charles Simonyi paying $25-million for his trip in 2007 and $35-million for a second trip scheduled for 2009.[82] In June 2004 SpaceShipOne, developed by US Scaled Composites, became the first private manned spacecraft, but only conducts suborbital flights.[83] This market is also generating commercial investment in space infrastructure. For example, Bigelow Aerospace is building a privately owned, inflatable in-space platform that could be capable of supporting a three-person crew by 2010. Bigelow projects that user crews would primarily consist of industry workers, although some tourist use could occur.[84] While the industry continues to face challenges — including a lack of international legal safety standards, high launch costs, and export regulations[85] — important liability standards are beginning to emerge. In 2006 the FAA released final rules governing private human spaceflight requirements for crew and participants.[86] Final rules were also issued for FAA launch vehicle safety approvals.[87]

Insurance

Insurance affects both the cost and risk of access to space. Insurance rates also influence the ease with which start-up companies and new technologies can enter the market:[88] Although governments play an important role in the insurance sector insofar as they generally maintain a certain level of indemnification for commercial launchers, the commercial sector assumes most of the insurance burden. There are two types of coverage: launch insurance, which typically includes the first year in orbit, and on-orbit insurance for subsequent years. Most risk is associated with launch and the first year in orbit. When covering launches, insurance underwriters and brokers discriminate among launch vehicles and satellite design so that the most reliable designs subsidize the insurance costs of the less reliable hardware.[89] Following a decade of tumultuous rates due to tight supply of insurance and a series of industry losses, many companies abandoned insurance altogether, but recently there has been a softening of the launch insurance market.[90] The approximate premium for each of the vehicles in early 2008 was: Ariane-5, 6.5 percent (of the launch cost); Atlas-5, 6.6 percent; Sea Launch, 7.5 percent; Chinese Long March, 7.9 percent; and Proton, 10.3 percent.[91] Terms have become more restricted though. Insurers do not generally quote premiums more than 12 months prior to a scheduled launch and in-orbit rates are usually limited to one-year terms and often do not cover events such as terrorism or “Acts of God.”[92] It is possible that insurance costs may go higher in the future, owing to the risk caused by the significant increase in space debris in recent years.[93]

The market for in-orbit insurance has also been tumultuous, but operators have had more flexibility in dealing with it. Like launch insurance, rates skyrocketed in the early 2000s and terms tightened, leading many companies to discontinue insurance and instead self-insure through the production of satellite backups.[94]

With the advent of space tourism, the space insurance industry may expand to cover human spaceflight. In the US, the FAA requires commercial human spacecraft operators to purchase third-party liability insurance, although additional coverage is optional. Each of the first two space tourists purchased policies for training, transportation, and time spent in space.[95]

2008 Developments

New launchers entering the market increase capacity, but no indication of significant cost reductions

In addition to the growing competition in the launch market offered by India, China, and Japan (see Trend 4.2), the development of new launch vehicles is increasing options for accessing space. The long-anticipated Falcon-1 small launcher by SpaceX had its first successful launch on 28 September 2008, following three failures. The Falcon-1 is the first privately developed liquid fuel rocket to place an object in Earth orbit.[96] The next mission will carry Malaysia’s RazakSat remote sensing satellite in 2009. Three other launches in 2009 and as many as five launches in 2010 are planned for Falcon-1. Starting in 2010, a new version, 1e, will be available, with a heavier lift capability of 1010 kilograms.[97] SpaceX’s heavy launcher, the Falcon-9, underwent preparations in 2008, following a delay of its first test launch to 2009.[98] The company claims that Falcon-1 provides the lowest cost/flight of any launcher, and Falcon-9 will provide the lowest cost/weight access to space,[99] but reliability is likely to remain a concern of prospective clients. Reflecting growing competition in the market, United Launch Alliance announced in 2008 that it would restructure the Delta-2 program to increase cost competitiveness.[100]

Commercial operator Sea Launch returned to flight in 2008 following the 30 January 2007 explosion of its Zenit-3SL rocket.[101] On 15 January 2008 Sea Launch placed the commercial communications Thuraya-3 satellite into orbit,[102] and on 28 April 2008 its affiliated company Land Launch conducted its first successful launch of the Israeli Amos-3 telecommunications satellite.[103] Like Sea Launch, Land Launch uses the Ukrainian rocket

Zenit-3SL, but operates from Russia's Baikonur Cosmodrome in Kazakhstan and can only launch satellites that weigh no more than 3,600 kilograms. Europe's Vega small launch vehicle may also begin preparations as early as 2010.[104]

Other new launchers are being developed, but entry into the market remains in the distant future. Brazil signed an agreement with Russia in 2008 to develop a family of launch vehicles based on Russia's new Angara rocket, which will be part of Brazil's Cruzeiro do sul (Southern Cross) program. Brazil has allocated $1-billion for the program over the next six years and $650-million for the construction of five launch pads.[105] But untested technologies face significant challenges, including high insurance costs and a wary clientele.[106]

2008 Developments

Private human access to space slowly progressing

The role of the private sector in providing access to space for humans and cargo is governed in the US by NASA's Commercial Orbital Transportation Services (COTS) program. COTS is designed to spur private development of commercial spacecraft that can service the International Space Station when the Space Shuttle is retired in 2010. After earlier setbacks caused when Rocketplane Kistler was dropped from the program in 2007 for failing to meet financial milestones,[107] in a second round NASA awarded contracts to Orbital Science Corporation for its Cygnus spacecraft design and SpaceX for its Dragon vehicle launched from Falcon-9. Announced in 23 December 2008, the contracts include "eight flights valued at about $1.9 billion from Orbital and 12 flights valued at about $1.6 billion from SpaceX," for the period 1 January 2009–31 December 2016.[108] However, these contracts are being protested by PlanetSpace, a losing bidder; NASA might have to restart the procurement process.[109]

Efforts to construct a private space station also moved forward in 2008. Bigelow Aerospace's second inflatable module, Genesis-2, continued to orbit in 2008 while the company arranged a deal with Lockheed Martin to use a modified Atlas-5 launcher to provide both human and cargo transportation to the follow-on habitable module.[110] The deal may signal the intent of Lockheed Martin to enter the still nascent orbital space tourism market.

2008 Developments

Commercial operators continue to expand availability of Earth imagery

Two commercial operators provided additional remote sensing resources for the global market in 2008. GeoEye-1 is the world's highest-resolution commercial remote sensing satellite (41 centimeters) and is licensed to sell its imagery commercially at a resolution as high as 50 centimeters;[111] they are also available via the Google online mapping site.[112] Germany's RapidEye launched a constellation of five satellites on 29 August 2008 and can provide daily images of any point on Earth at 6.5-meters in resolution (see Trend 4.3 below for additional details).[113] Global revenues for commercial Earth imaging data was estimated at $735-million in 2007, having grown 15 percent over the last five years.[114] Both civil and military branches of governments are the primary market for commercial remote sensing data, representing over 80 percent of the total market. However, use by individual consumers is increasing, with GoogleEarth reporting over 300 million registered users. In 2008, organizations such as Human Rights Watch and Amnesty International were able to monitor activities in regions such as Darfur and Georgia, and images revealed potential weapons buildups in parts of Sri Lanka controlled by the Liberation Tigers of

Tamil Eelam, and in Iran and China.[115] On the other hand, sites such as Google Earth have been accused of aiding terrorism, most recently the November 2008 attacks on Mumbai, India.[116] Consequently, government efforts to restrict access to data are ongoing (see Trend 4.3).

Figure 4.6: Commercially operated remote sensing satellites*

Operator	System	Current Satellites	Type	Highest Resolution (meters)
ImageSat International	EROS	EROS A EROS B	Optical	1.5 0.7
GeoEye	IKONOS OrbView GeoEye	IKONOS-2 OrbView-2 GeoEye-1	Optical Optical Optical	0.8 1,000 0.41
DigitalGlobe	Quickbird WorldView	QuickBird-2 WorldView-1	Optical Optical	0.6 0.5
MDA	Radarsat	Radarsat-1 Radarsat-2	Radar Radar	8 3
Spot Image	Spot	SPOT 2 SPOT 4 SPOT 5	Optical Optical Optical	10 10 2.5
DMC International Imaing	Disaster Monitoring Constellation	AISAT-1 (Algeria) NigeriaSAT-1 (Nigeria) UK-DMC (United Kingdom) Beijing-1 (China)	Optical Optical Optical Optical	32 32 32 4
Infoterra GmbH	TerraSar	TerraSar-X	Radar	1
RapidEye	RapidEye	RapidEye-1 RapidEye-2 RapidEye-3 RapidEye-4 RapidEye-5	Optical Optical Optical Optical Optical	6 6 6 6 6

*Note that some government-operated spacecraft also provide imagery data for the global market

2008 Space Security Impact

Sustained competition in commercial space launch may slightly reduce the cost of access to space in the near future, but in the absence of revolutionized technologies, there is not likely to be a significant impact on space access. Moreover, while efforts are being made to support private human access to space, such access may cause challenges to space security, both in terms of the sustainability of the space environment as well as the applicability of international laws, such as the Astronaut Rescue Agreement (see Laws, Policies, and Doctrines Trend 2.1). Finally, while the space industry is facilitating greater use of space applications, in particular remote sensing data, there are legitimate fears about the security implications on Earth of widely available imaging data.

Trend 4.3: Government's dependency on the commercial space sector means that subsidies and national security concerns continue to play an important role

Government support

Governments have played an integral role in the development of the commercial space sector. Many spacefaring states consider their space systems an extension of national critical infrastructure, and a growing number view their space systems as critical to national security. Full state ownership of space systems has now given way to a mixed system in which many commercial space actors receive significant government and military contracts and a variety of subsidies. Certain sectors, such as remote sensing or commercial launch industries, rely more heavily on government clients, while the satellite communications industry is commercially sustainable without government contracts. On the other hand, due to the security concerns associated with commercial space technologies, governments also play an active role in the sector through regulation, including export controls and controls on certain applications, such as Earth imaging.

A report commissioned by the FAA indicates that the success of the US commercial launch industry is viewed as "beneficial to national interests."[117] Indeed, the US Space Launch Cost Reduction Act of 1998 established a low-interest loan program to support the development of reusable vehicles.[118] In 2002 the US Air Force requested $1-billion in subsidies for development of Lockheed Martin's Atlas-5 and Boeing's Delta-4 vehicles as part of the Evolved Expendable Launch Vehicle (EELV) program.[119] To maintain the financial feasibility of the program, the 2005 Space Transportation Policy requires the Department of Defense (DOD) to pay the fixed costs to support both companies (since merged into the United Launch Alliance) until the end of the decade rather than forcing price-driven competition.[120] Similarly, the 2003 US Commercial Remote Sensing Space Policy directs the US government to "rely to the maximum practical extent on U.S. commercial remote sensing space capabilities for filling imagery and geospatial needs for military, intelligence, foreign policy, homeland security, and civil users" to "advance and protect U.S. national security and foreign policy interests by maintaining the nation's leadership in remote sensing space activities, and by sustaining and enhancing the US remote sensing industry."[121]

The European Guaranteed Access to Space Program adopted in 2003 requires that ESA underwrite the development costs of the Ariane-5, ensuring its competitiveness in the international launch market.[122] The program explicitly recognizes a competitive European launch industry as a strategic asset and is designed to ensure sustained government funding for launcher design and development, infrastructure maintenance, and upkeep.[123] The 2007 European Space Policy "emphasises the vital importance for Europe to maintain an independent, reliable and cost-effective access to space at affordable conditions…bearing in mind that a critical mass of launcher activities is a precondition for the viability of this sector."[124]

Russia's commercial space sector maintains a close relationship with its government, receiving contracts and subsidies for the development of the Angara launcher and launch site maintenance.[125] China's space industry is indistinguishable from its government, with public and private institutions closely intertwined.[126] The industries responsible for supporting China's space program fall under the auspices of the China Aerospace Science and Technology Corporation (CASC), which is directly linked to the government.

In many instances, governments are partnering with the private sector to subsidize the commercial development of systems also intended to meet national needs. For example, the US National Geospatial-Intelligence Agency's (NGA) NextView program subsidizes commercial remote sensing to meet military needs for high-resolution images, which are then for sale commercially at a lower resolution.[127] Similarly, the commercial Radarsat-2 satellite was largely paid for by the Canadian Space Agency, which pre-purchased $445-million in data, which is also sold commercially[128] in an arrangement similar to that for Germany's TerrSar-X remote sensing satellite.[129] Remote sensing is not the only instance of such partnering. The UK's Skynet-5 secure military communications satellite is operated by a private company, which sells its excess capacity.[130] However, partnering with the commercial sector involves risks to the government. In 2007, after a five-year delay due largely to bureaucratic obstacles and the failure of a public-private consortium to develop the Galileo satellite navigation system, the European Commission abandoned its partnership with the public sector on the project.[131] And in 2008, the Canadian government intervened to block the sale of MacDonald, Detwiler and Associates, maker of the Radarsat-2 satellite, to a US firm to protect national interests.[132]

Export controls

National security concerns continue to play an important role in the commercial space industry, particularly through export controls. Trade restrictions aim to strike a balance between commercial development and the proliferation of sensitive technologies that could pose security threats, but achieving that balance is not easy, particularly in an industry characterized by dual-use technology. Space launchers and intercontinental ballistic missiles use almost identical technology, and many civil and commercial satellites contain advanced capabilities with potential military applications. Dual-use concerns have led states to develop national and international export control regimes aimed at preventing proliferation. The regime most pertinent to commercial space security considerations is the Missile Technology Control Regime (MTCR).

The MTCR, formed in 1987, is composed of 34 member states seeking to prevent the further proliferation of capabilities to deliver weapons of mass destruction by collaborating on a voluntary basis to coordinate the development and implementation of common export policy guidelines.[133] However, export practices differ among members. Although the US "Iran Nonproliferation Act" of 2000 limited the transfer of ballistic missile technology to Iran, for example, Russia is still willing to provide such technology under its Federal Law on Export Control.[134] Most states control the export of space-related goods through military and weapons of mass destruction export control laws, such as the Export Control List in Canada, the Council Regulations (EC) 2432/2001 in the EU, Regulations of the People's Republic of China on Export Control of Missiles and Missile-related Items and Technologies, and the WMD Act in India.[135]

From the late 1980s to late 1990s, the US had agreements with China, Russia, and Ukraine to enable the launch from foreign sites of US satellites and satellites carrying American components. However, in 1998 a US investigation into several successive Chinese launch failures led to allegations about the transfer of sensitive US technology to China by aerospace companies Hughes and Loral. Concerns sparked the transfer of jurisdiction over satellite export licensing from the Commerce Department's Commerce Control List to the State Department's US Munitions List (USML) in 1999.[136] In effect the new legislation treated satellite sales the same as weapons sales, making international collaborations more heavily regulated, expensive, and time consuming.

Exports of USML items are licensed under the International Traffic in Arms Regulations (ITAR) regime, which adds several additional reporting and licensing requirements for US satellite manufacturers. A recent US Government report noted that, in total, it now takes "nine to 20 months on average to gain approval for a satellite export and notify Congress."[137] A subsequent study of the market conditions for US satellite manufacturers argued that "nearly every potential international buyer of satellites in 2002… indicated that the US export control system is a competitive disadvantage for US manufacturers."[138] Industries are maneuvering around ITAR restrictions by purchasing ITAR-free satellites and launch services. China was able to launch the Chinasat 6B telecommunications satellite, built by Thales Alenia Space, in its Long March launcher because the satellite was built without US components. Thales Alenia Space is the only western company that has developed a product line deliberately designed to avoid US trade restrictions on its satellite components.[139]

Finally, because certain commercial satellite imagery can serve military purposes, a number of states have implemented regulations on the sector. The 2003 US Commercial Remote Sensing Policy sets up a two-tiered licensing regime that limits the sale of sensitive imagery.[140] In 2001 the French Ministry of Defense prohibited open sales of commercial Spot Image satellite imagery of Afghanistan.[141] Indian laws require the 'scrubbing' of commercial satellite images of sensitive Indian sites.[142] Canada has recently passed a regulatory regime that will give the Canadian government "shutter control" over the collection and dissemination of commercial satellite imagery due to national security or foreign policy concerns, and priority access in response to possible future major security crises.[143] Analysts note, however, that competition among increasing numbers of commercial satellite imagery providers may eventually make shutter control prohibitively expensive.[144]

Commercial space systems as critical infrastructure

Space systems, including commercial systems, are viewed by some states as critical national infrastructure and strategic assets. During the overcapacity of the 1990s, the US military began employing commercial satellite systems for non-sensitive communications and imagery applications. During Operation Enduring Freedom in Afghanistan in 2001 the US military used 700 megabytes per second of bandwidth, 75 percent of which was from commercial systems.[145]

The US DOD is the single largest customer for the satellite industry, although it accounts for less than 10 percent of most large satellite operators revenues.[146] By November 2003 it was estimated that the US military was spending more than $400-million each year on commercial satellite services.[147] This figure jumped to more than $1-billion a year for commercial broadband satellite services alone by 2006.[148] "DoD estimates that commercial satellite systems are providing over 80 percent of the satellite bandwidth supporting Operation Iraqi Freedom."[149] In recognition of this new reality, DOD is studying different acquisition methods to facilitate satellite service procurement.[150] The aim is to provide a more strategic, long-term partnership between DOD and its commercial providers.

This growing dependence upon commercial services prompted a December 2003 US General Accounting Office report to recommend that the US military be more strategic in planning for and acquiring bandwidth by, among other things, consolidating bandwidth needs among military actors to capitalize on bulk purchases.[151] A 2004 study of the US National Security Telecommunications Advisory Committee Satellite Task Force noted the great dependence of the national security and homeland security communities on commercial space services.[152]

European states also view the space sector as a strategic asset "contributing to the independence, security, and prosperity of Europe."[153] And China's 2006 White Paper on

Space Activities identifies the development of an independent space industry as a key component to its goals for outer space.[154]

Governance

While governments and industry have long worked together to develop and control the commercial space sector, there is evidence that they may also start working together to provide better governance in outer space. Few rules govern security and safety in outer space, but following the Chinese intercept of one of its own satellites in 2007, Dave McGlade, CEO of Intelsat, added his voice to those of several governments in calling for a code of conduct or rules of the road to provide norms and guidelines on space activities.[155] The importance of the private sector in space safety and governance issues has also been highlighted by the US government. Under a program called the Commercial and Foreign Entitites (CFE) program, the US DOD is attempting to align government and industry resources to address growing space security challenges and to increase space situational awareness.[156] The program is intended to enhance safety, reduce risk, and contribute to the sustainable use of key orbits.[157]

2008 Developments

Military dependence on commercial satellite services continues to expand, deepen

Military users, particularly in the US, continue to depend on commercial space services, and in many respects subsidize the industry. Joseph Rouge, Director of the National Security Space Office, specified in June 2008 that 80 percent of US defense satellite communications with fixed ground stations are provided by commercial operators;[158] this is 2.3 percent of global commercial capacity.[159] Rouge stated, "We now expect to use commercial satellite capacity indefinitely. This is very different from the past…. Last year, we invited the industry in and asked them to outline the services they could provide. Now that we realize everything they can do, we have incorporated their capabilities into our strategy."[160] Moreover, strong demand is likely to continue as key capability replacements face delays (see Space Support for Terrestrial Military Operations).[161]

Demand from other countries is also growing, particularly those in Europe. Currently only five percent of European military communications are provided commercially, but it is anticipated that this figure could grow to 20 percent in the near future. The European Defence Agency has created a special group to bring together satellite communications requirements of the various European defense forces to coordinate purchases of commercial capacity.[162]

Militaries are also one of the most significant purchasers of commercial satellite remote sensing imagery. In 2008 the US Department of Defense bought $5-million worth of commercial synthetic aperture radar imagery from the Canadian Radarsat system; similar purchases from Italy, Israel, and Germany are being considered.[163] The US DOD also committed to purchase $197-million worth of imagery over the first 18 months of operation of GeoEye-1 (see Trend 4.3 above).[164]

2008 Developments

Relationship between governments and commercial sector continues to evolve toward more substantial partnerships

In some respects the relationship between governments and the commercial sector is shifting away from one that is client-based toward partnership. One indication of this shift in 2008 is the growing interest in commercially hosted payloads for military sensors. In June 2008 Americom received a three-year contract to host an experimental sensor for the US Air Force Space and Missile Systems Center on a satellite to be launched in 2010, eliminating the need to launch a dedicated military satellite to launch the sensor.[165] This followed a 2007 contract with Intelsat General to oversee the Internet Routing In Space project and host a payload to demonstrate the viability of the concept. Such hosting reduces costs for the government and also provides an anchor tenant to the commercial provider.[166] In this sense, it is similar to another growing trend whereby governments directly subsidize, or pre-purchase, the services of commercial spacecraft. Two examples in 2008 are the GeoEye-1 satellite launched on 6 September 2008 and the RapidEye constellation of five satellites launched on 29 August 2008 (see Trend 4.2 aboe). The US National Geospatial-Intelligence Agency provided half of the developmental costs of the GeoEye spacecraft ($502-million) as part of its NextView program and has agreed to purchase $197-million worth of imagery over the first 18 months and the Geman Aerospace Center (DLR) has provided RapidEye with €15-million to support the program.[167]

2008 Developments

Ongoing debate over how to apply trade restrictions for security purposes

The US ITAR export control process was the focus of ongoing policy debate in the US in 2008. A report put out by the Center for Strategic and International Studies said that the gap between the United States and its competitors on technology in the global communication satellite market has significantly closed in the last decade due to ITAR. The export control regime is designed to enhance US national security, but reportedly "did not do what it intended… [and] In some cases, it had the opposite effect." The study did indicate that the overall financial health of the top manufacturers in the US space industry was good despite foreign market losses.[168] In part, however, this is due to heavy dependence on the US military.[169] The report recommends that commercial satellites, weather satellites, and satellite subsystems be removed from the US Munitions List. Similarly, April 2008 testimony by the US Government Accountability Office stated that export controls have not been properly coordinated or updated to ensure adequate protection of US interests, creating vulnerabilities.[170] There are indications that newly elected President Barack Obama will take steps to modify the implementation of the regime.[171] An effort to initiate changes in ITAR has been undertaken by Bigelow Aerospace, which has petitioned the US government for a change in the export licensing jurisdiction for the inflatable module technology that is the basis of its commercial space habitat.[172]

Implementation of trade restrictions remained an issue in 2008. A former Boeing engineer was charged with providing trade secrets to China, including technologies for a phased array communication antenna for the Space Shuttle and a cryogenic fueling system used on the Delta-4 launcher.[173] China denied the allegations.[174] Although the concern is that China will use the information for military technologies, some argue that none of the data is critical or sensitive.[175] China is a major spacefaring nation, however, and many companies are eager to do business there. Thales Alenia Space has built satellites without US components so that they can be exported to and launched by China, and has also used this arrangement to compete for international satellite deals, winning one from Indonesia. In response, Space Sytems/Loral petitioned the US government in 2008 to block Thales Alenia Space from offering China's Long March rocket as a launcher in commercial competitions. At a price "two-thirds" that of competing launch vehicles, it is argued that this arrangement gives Thales Alenia a competitive advantage.[176] Other companies that are making efforts to do business with China include Eutelsat, which may launch a satellite via China; this satellite was built without any US components at an additional cost of $32-million.[177]

2008 Developments

Commercial operators engage in space governance

Space is becoming more crowded and the number of independent operators is increasing, making safe operations more difficult without access to shared orbital data. Several efforts involving the commercial space sector in 2008 seek to address this challenge. One effort, led by the US DOD, which currently operates the Commercial and Foreign Entities (CFE) program to share specific orbital data with others, is a “Neighborhood Watch” network that would create a new plan to share data among the US government, companies, and allies. In another instance, some of the major satellite companies have joined together to examine a new concept for data sharing known as the “data center,” which would create a shared repository of orbital data from both operators and the CFE. A group headed by Gerard Brachet, formerly the Chairman of the UN Committee on the Peaceful Uses of Outer Space, is considering a global database that would include data from countries in addition to the US and industry, as part of an effort to define future cooperative measures for the long-term sustainability of space (see Laws, Policies, and Doctrines Trend 2.2).[178]

2008 Space Security Impact

The strong relationship between military and commercial uses of space and the security dimensions of many commercial services have complex impacts on space security. On the one hand, multiple-use spacecraft could become military targets in the future, resulting in an overall decrease in security. Alternatively, the proliferation of dual-use assets in space could make a military attack less useful and, therefore, less likely. This could increase overall space security. The focus of the year has been a constant discussion on changes that ought to be brought about in ITAR to increase the commercial competitiveness of the US satellite and launch industries, specifically in the light of the ITAR-free satellites manufactured by Europe for the Chinese market.

CHAPTER FIVE

Space Support for Terrestrial Military Operations

This chapter assesses trends and developments in the research, development, testing, and deployment of space systems that are used to support terrestrial military operations. This includes early warning; communications; intelligence, surveillance, and reconnaissance; meteorology; as well as navigation and weapons guidance applications. Estimated at $29-billion, almost half of all global spending on space is for defense-related programs. Although the US spends 95 percent of this amount, spending on military space programs is increasing around the world.[1]

Extensive military space systems were developed by the US and the USSR during the Cold War. Satellites offered an ideal vantage point from which to monitor the Earth to provide strategic warning of signs of nuclear attack, such as the launch plume of a ballistic missile or the light signature of a nuclear detonation. Satellites also offered the first credible means for arms control verification, leading US President John F. Kennedy to realize that fears of a missile gap between the US and the Soviet Union were greatly overstated. The space age opened new chapters in the development of reconnaissance, surveillance, and intelligence collection capabilities through the use of satellite imagery and space-based electronic intelligence collection. In addition, satellite communications provided extraordinary new capabilities for real-time command and control of military forces deployed throughout the world.

By the end of the Cold War the US and USSR had begun to develop satellite navigation systems that provided increasingly accurate geographical positioning information. Building upon the capabilities of its Global Positioning System (GPS), the US began to expand the role of military space systems, integrating them into virtually all aspects of military operations, from providing indirect strategic support to military forces to enabling the application of military force in near-real-time tactical operations through precision weapons guidance. The development of radar satellites offered the potential to detect opposition forces on the ground in all weather at all times.

At present the US leads in the deployment of dedicated space systems to support military operations, accounting for over half of all military satellites. Russia maintains the second largest number of dedicated military satellites. Together, these two actors dwarf the military space capabilities of all other states, although this situation is changing. The US and USSR/Russia have launched more than 3,000 military satellites, while the rest of the world has launched under 100. At the end of 2008 there were over 150 operational dedicated military satellites worldwide, with the US operating approximately 76, and Russia approximately 36.[2]

This chapter identifies the development of the military space capabilities of the US and Russia as a distinct space security trend. It also examines the efforts of a growing number of other states that have begun to develop national space systems to support military operations and their rapidly expanding capabilities, primarily in the areas of imagery intelligence and communications. Many of these systems are dual-use, meaning that they also support civilian applications. This section does not examine military programs pertaining to space systems protection or negation, or space-based strike capabilities, which are described in their respective chapters.

Space Security Impact

Over half of all space systems to date have been developed to support terrestrial military operations, making the military space sector an important driver behind the advancement of capabilities to access and use space. In addition to encouraging an increasing number of actors to access space, the military sector has played a key role in bringing down the cost of space access, and many of today's common space applications such as remote sensing and navigation were first developed for military use. The increased use of space has also led to greater competition for scarce space resources such as orbital slots and, in particular, radio frequency spectrum allocations. While disputes over these scarce resources also affect the civil and commercial space sectors, they become more acute in the military sector, where they are associated with national security.

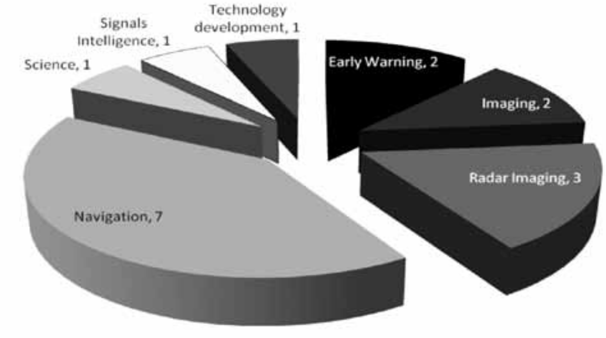
Space assets play an important strategic and, increasingly, tactical role in the terrestrial military operations of certain states. In most cases, space systems have augmented the military capabilities of advanced states by enhancing battlefield awareness, including, as mentioned above, precise navigation and targeting support, early warning of missile launch, and real-time communications. Furthermore, remote sensing satellites have served as a national technical means of verification of international nonproliferation, arms control, and disarmament regimes. These uses have driven an increasing dependence on space, particularly by the major spacefaring states.

An increasing number of state actors are integrating space capabilities and space-derived information into their day-to-day military planning. This can have a positive effect on space security by increasing the collective vested interest in space security through mutual vulnerability. The use of space to support terrestrial military operations can also have a negative impact on space security if potential adversaries, viewing space as a new source of military threat or as critical military infrastructure, develop space system negation capabilities to neutralize the advantages of those systems.

Because the space systems that support military operations are seen as vulnerable, actors acquire greater incentives to protect them by developing space system protection and negation capabilities, which may lead to an arms escalation dynamic. Moreover, many of the space systems used for military purposes today are integrated with civilian and commercial uses, thus raising the potential of extensive collateral damage if they are targeted during warfare.

Concern has been expressed that extensive use of space in support of terrestrial military operations blurs the notion of "peaceful purposes" as enshrined in the Outer Space Treaty, but state practice over the past 40 years has generally accepted these applications as peaceful insofar as they are not aggressive in space (see Space Laws, Policies, and Doctrines Trend 2.1). Space has been militarized since the first satellite, Sputnik, was placed into orbit. Of concern here is not whether militaries should use space, but rather how the use of space by militaries improves or degrades the security of space.

Figure 5.1: Dedicated military spacecraft launched in 2008 by application[3]



Trend 5.1: US and Russia continue to lead in deploying military space systems

During the Cold War, the US and USSR developed military space capabilities at a relatively equal pace. The collapse of the USSR, however, saw a massive drop in Russian military space spending while the US expanded its military space capabilities. There has been a general decrease in the number of military launches by both states in recent years. However, American and Russian dependence on military space systems appears to be increasing. While new systems are being orbited at a slower rate, they have greater capabilities and longevity and are more integrated with the military. Commercial systems are also playing a rapidly growing military support role. Figures 5.3 and 5.4 provide an overview of US and Russian military satellites launches since 1957.

United States

The US has dominated the military space arena since the end of the Cold War, and continues to give priority to its military and intelligence programs, which account for more than twice the amount of spending as that allotted to civil programs.[4] The US currently outspends all other states combined on military space applications. Although tracking is difficult, it is estimated that in FY2007[5] the US Department of Defense allocated $25-billion to space expenditures, which does not include money for the National Reconnaissance Office, National Geo-Spatial Agency, or Missile Defense Agency. US military and intelligence space-based capabilities continue to dwarf those of the rest of the world, and by all indications the US is the actor most dependent on its space systems. While the US is currently faced with challenges in upgrading almost all of its major military space systems, they remain robust.[6]

Satellite Communications

Satellite communications have been described by one expert as "the single most important military space capability."[7] The Military Satellite Communication System (Milstar) is currently one of the most important of these systems, providing protected communications for the US Army, Navy, and Air Force through five satellites in Geostationary Orbit (GEO). Replacement of Milstar satellites with Advanced Extremely High Frequency (AEHF) satellites is underway in cooperation with Canada, the UK, and the Netherlands. The US hopes to deploy the next-generation Transformational Satellite Communications System (TSAT) to provide protected, high-speed, internet-like information availability to the military, including laser communications in a second stage.[8] Development of TSAT has been disrupted by repeated delays and the first launch has been postponed seven times, from 2009 to 2019.[9] The entire program's procurement has been estimated to cost between $14-billion and $25-billion by 2016.[10]

The Defense Satellite Communications System (DSCS) — the workhorse of the US military's super-high frequency communications — is a hardened and jam-resistant constellation that transmits high-priority command–and–control messages to battlefield commanders using nine satellites in GEO. A planned follow-on to this system, the Advanced Wideband System, is expected to significantly increase available bandwidth.[11] The Global Broadcast System and Ultra High Frequency (UHF) follow-on satellites provide wideband and secure, anti-jam communications, respectively. The Wideband Global SATCOM (WGS) is intended to bridge the transition between retirement of the DSCS and full deployment of the Advanced Wideband System constellation — the first of four satellites was launched in 2007. It is the US military's highest capacity communications satellite, providing more bandwidth than the entire DSCS system, but with fewer protection capabilities.[12] The US military also maintains a polar military satellite communications system to ensure communications in those regions.

In addition to these dedicated systems, space-based military communications use commercial operators such as Globalstar, Iridium, Intelsat, Inmarsat, and Telstar.[13] Increased use of unmanned aerial vehicles (UAV) is straining both military and commercial capacity in places such as the Middle East and secure, high-speed, high-volume data transmission is critical to meet current and future demand.[14] The cost of commercial broadband satellite service is estimated at $1-billion a year. The US DOD will likely remain dependent on these services in the future, even with the deployment of new systems.

Early Warning

Space-based early warning systems provide the US with critical missile warning and tracking capabilities. The first such system, the US Missile Defense Alarm System, was first deployed in a polar orbit in 1960. The current US Defense Support Program (DSP) early warning satellites were first launched in the early 1970s and the final one in 2007, providing enhanced coverage of Russia while reducing the number of necessary satellites to four.[15] The US plans to replace the DSP system with the Space Based Infrared System (SBIRS) to provide advanced surveillance capabilities for missile warning and missile defense.[16] While SBIRS is behind schedule and significantly over budget, with an estimated cost of up to $10-billion, it appears to be on track again. The Alternative Infrared Space System, intended to act as insurance in case of further difficulties with the SBIRS program, was redesigned in 2007 as a follow-on program, the Third Generation Infrared Surveillance (3GIRS).[17] The anticipated US Space Tracking and Surveillance System (STSS) is intended to work with SBIRS to support missile defense responses (see Space Systems Protection Trend 6.1 and Space Systems Negation Trend 7.2).

Intelligence

The first US optical Corona satellites for imagery intelligence were launched as early as 1959, with the Soviets following suit by 1962. These early remote sensing satellites had lifetimes of only days and were equipped with film-based cameras. At the end of their operational lifetimes, capsules with the exposed film were ejected from the satellite and collected, usually from the ocean. Gradually, resolution of these cameras was improved from about 10 meters to less than one meter. As early as 1976 the US began to fit its remote sensing satellites with charge-coupled devices that took digital images, which could be transmitted back to Earth via radio signal, providing near-real-time satellite imagery.[18] Open source information suggests that the US currently operates between eight and 10 imagery intelligence satellites through two optical systems known as Crystal and Misty, and one synthetic aperture radar system known as Lacrosse. While the exact resolution of today's remote sensing satellites remains classified, the Improved Crystal satellites are believed to have a resolution of up to 6 inches.[19] The US operates between 18 and 27 signals intelligence satellites in four separate systems — the Naval Ocean Surveillance System, Trumpet, Mentor, and Vortex. [20]

The US is currently struggling with its next-generation capabilities for imagery intelligence. The Future Imagery Architecture, intended to provide next-generation reconnaisance capabilities through electro-optical and radar remote sensing, was cancelled in 2005 at a loss of at least $4-billion in what has been called "the most spectacular and expensive failure in the 50-year history of American spy satellite projects."[21] The Misty Stealth Reconnaissance Imaging program was also cancelled due to costs, schedule delays, and poor performance.[22] The National Reconnaissance Office is now reportedly working on a new multibillion-dollar spy satellite program called BASIC, which is also under review.[23] An additional setback was caused by the failure of USA-193 in orbit in 2006. These events leave US military reconnaissance capabilities largely based on outdated systems. While there is not a gap in coverage, "the constellation is fragile."[24]

The US military also uses commercial imagery services from DigitalGlobe and GeoEye (see Commercial Space). For example, Landsat is a dual-use remote sensing imaging satellite used by the US military for tactical planning. The Defense Meteorological Satellite Program provides environmental data in support of military operations. There are several dual-use civilian-military meteorology spacecraft, including the Geostationary Operational Environmental Satellite and the Polar-orbiting Operational Environmental Satellite.[25]

Figure 5.2: Characteristics of key US dedicated military space systems[26]

Current programs	Function	Orbit	Constellation	Notes on potential follow-on systems
Defense Satellite Communications System III	Communications	GEO	9	Wideband Global SATCOM (2007); Advanced Wideband System (2009)
Military Satellite Communication System (Milstar)	Communications	GEO	5	Advanced Extremely High Frequency (2008); Transformational Satellite Communications System (TSAT) (2016)
Interim Polar Satellite Program	Communications	GEO	2	Enhanced Polar System (2014)
UHF Follow-on Satellite	Communications	GEO	9	Mobile User Objective System (MUOS) (2010)
Satellite Data System	Communications	GEO	4	
Defense Meteorological Satellite Program	Weather	LEO	5	
Global Positioning System	Navigation	MEO	31	
Defense Support Program	Early Warning	GEO	7	Space Based Infrared System (2009); Space Tracking and Surveillance System (2007)
N/A	Tactical Warning			Space Radar (2016)
Crystal	Remote sensing	LEO	4	
Lacrosse	Remote sensing	LEO	4	
Misty	Remote sensing	LEO	1	Program cancelled (2007)
Naval Ocean Surveillance System (NOSS)	SIGINT	LEO	17	
Mentor (Advanced Orion)	SIGINT	GEO	4	
Vortex (Mercury)		SIGINT	GEO	2
Trumpet (SB-WASS)	SIGINT	HEO	3	

Navigation

In 1964 the first navigation system was deployed for military applications by the US Navy, and its position resolution was accurate to 100 meters. This system and others that followed were ultimately replaced by the GPS, which was declared operational in 1993 and uses a minimum constellation of 24 satellites orbiting at an altitude of about 20,000 kilometers. On the battlefield GPS is used at all levels, from navigation of terrestrial equipment and individual soldiers to target identification and precision weapons guidance. The most recent phase of system modernization is near completion.[27] GPS is also an important civil and commercial service (see Civil Space Programs and Global Utilities Trend 3.4). The US systems is accurate within 3-15 meters for commercial grade receivers, and better for military users.

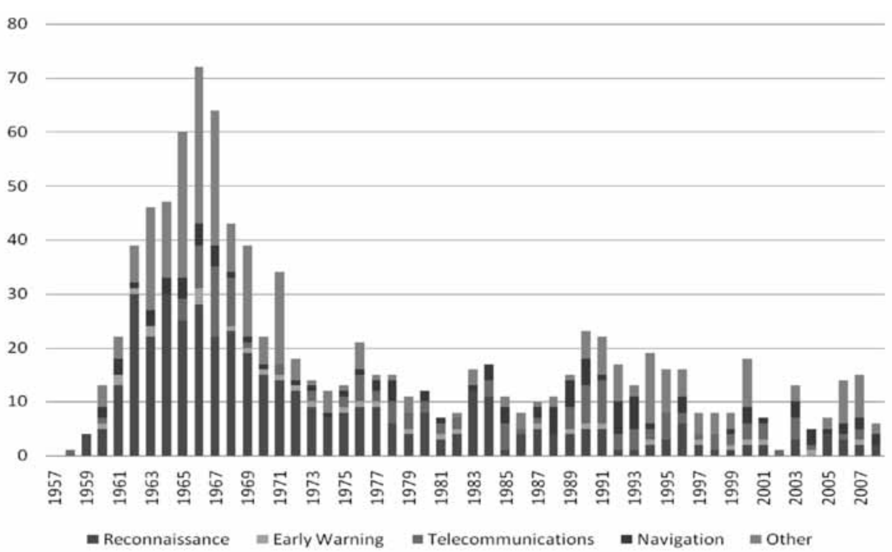
Launch

In 2007 the US DOD Operationally Responsive Space (ORS) Office was opened at the Kirtland Air Force Base in New Mexico to coordinate the development of hardware and doctrine in support of ORS across the various agencies.[28] New launch capabilities such as SpaceX's Falcon form the cornerstone of this program (see Space Systems Protection Trend 6.4). ORS would also allow deployments of space systems designed to meet the needs of specific military operations. For example, the US TacSat microsatellite series is intended for ORS demonstration, combining existing military and commercial technologies such as remote sensing and communications with new commercial launch systems to provide "more rapid and less expensive access to space."[29] The satellites are controlled directly by deployed US commanders.[30]

The Evolved Expendable Launch Vehicle (EELV) program is a $31.8-billion USAF effort that began in 1994, with the objective of reducing launch costs by at least 25 percent by partnering with industry to develop capabilities that could be used for both commercial and government purposes.[31] To meet future government requirements, both Lockheed Martin and the Boeing Company are pursuing a Heavy Lift launch capability in a joint venture, the United Launch Alliance, which markets both the Delta-4 and the Atal-5 launch vehicles (see Commercial Space Trend 4.2).

The growing dependence of the US upon space systems to support military operations has raised concerns about the vulnerability of these assets. As early as 2001 the Report of the Commission to Assess United States National Security Space Management and Organization warned that US dependence on space systems made it uniquely vulnerable to a "space Pearl Harbor" and recommended that the US develop enhanced space control capabilities (see Space Systems Protection and Space Systems Negation).[32]

Figure 5.3: US military spacecraft launched by application: 1957-2008[33]



Russia

Russia maintains the second largest fleet of military satellites, but its capabilities remain focused primarily on providing strategic rather than tactical support. Its current early warning, imaging intelligence, communications, navigation, and signals intelligence systems were developed during the Cold War, and between 70 and 80 percent of spacecraft have exceeded their designed lifespan, making the current operational status of these programs uncertain.[34] Forced to prioritize upgrades, Russia focused first on its early warning systems, and more recently has moved to complete the GLONASS navigation system.[35] In 2004 Russia stated that it would focus on "maintaining and protecting" its fleet of satellites and developing satellites with post-Soviet era technology.[36] In 2006, the first year of a 10-year federal space program, Russia increased its military space budget by as much as one-third, following a decade of severe budget cutbacks.[37] Despite the recent growth in Russia's spending, capabilities will only gradually increase because there are significant investments required to upgrade virtually all parts of its military space systems.

Satellite Communications

Russia maintains several communications systems, most of which are dual-use. The Raduga constellation of three satellites, promoted as a general purpose system, is reported to have secure military communications channels. The Geizer system is designed to deploy four GEO satellites as a communications relay system for Russian remote sensing and communications satellites in Low Earth Orbit (LEO), but currently has only one operational satellite in orbit. The Strela-3 military communications system was deployed in the late 1980s and more recently has been paired with commercial Gonets satellites in the same LEO orbits, potentially augmenting the military satellite system.[38] There are indications that maintenance of the Strela and Raduga systems will remain a priority for Russia.[39] Molniya-1 and -3 satellites are in Highly Elliptical Orbits (HEO) and serve as relay satellites for both military and civilian use. They will be replaced by the Meridian satellite system over the next few years.[40]

Early Warning

The USSR launched its first early warning Oko satellite in 1972 and by 1982 had deployed a full system of four satellites in HEO to warn of the launch of US land-based ballistic missiles. Over 80 Oko satellite launches allowed the USSR/Russia to maintain this capability until the mid-1990s. By the end of 1999 the Oko system was operating at the minimum possible level of four HEO satellites needed to maintain a continuous capability to detect the launch of US land-based ballistic missiles. As of January 2009 there are only three satellites in the Oko system, which provides coverage of US intercontinental ballistic missile fields about 18 hours a day, but with reduced reliability — capable of detecting massive attacks but not individual missile launches.[41] The Oko system is complemented by an additional early-warning satellite in Geosynchronous Orbit (GEO), which is believed to be a next-generation US-KMO or Prognoz satellite capable of detecting missiles against the background of the Earth.[42] Russia began launching Prognoz satellites in 1991. There have been up to six launches, but the program has been plagued by satellite malfunctions. A new Integrated Space System is being planned for 2009-10.[43] Plans have also been announced to restore the space-based component of its missile attack warning system, for which funding has been increased.[44]

The importance of adequate early warning capabilities was highlighted in 1995 when Russian early warning radars mistakenly warned of a potential incoming Trident nuclear missile. Russian President Boris Yeltsin made a decision not to retaliate with its own nuclear launch, averting disaster.[45]

Intelligence

The USSR began using film-based optical imagery satellites in 1962 and by the 1980s it was able to electronically transmit images while still maintaining a film-based system.[46] Russia's optical imaging capabilities have declined since the Cold War. The three Russian film-based and opto-electronic reconnaissance systems used today are the Kobalt, Arkon, and Orlets/Don systems, which in 2008, 2002, and 2006 respectively received new satellites, but with lifespans of only 60-120 days. In 2005 Russia announced plans for a constellation of high-resolution space radars in the next few years, using Arkon-2 and Kondor-E satellites. The Arkon-2 satellite will provide photos with a resolution of up to one meter while the Kondor-E satellite will have multirole radar that provides high-resolution images along two 500-kilometer sectors to the left and right of its orbit.[47] The current status of the program is unclear. Russia maintains two signals intelligence satellite systems, neither of which is fully operational. US-PU/EORSAT is dedicated to detecting electronic signals from surface ships, while Tselina is used for more general signals intelligence purposes.

Navigation

The first Soviet navigational system is thought to have been the Tsyklon system deployed in 1968. Tsyklon was followed by the Parus military navigation system, deployed in 1974 and still operating, with an accuracy of about 100 meters.[48] Currently, however, this constellation provides more services to the civilian than the military sector. In 1982 the USSR began development of its second major navigation system, GLONASS, which became operational in 1996. Unlike Tsyklon and Parus, GLONASS can provide altitude as well as longitude and latitude information by using a minimum constellation of 24 satellites at a 19,100-kilometer orbit.[49] However, the constellation remains incomplete. To complete the project, the budget for GLONASS has been increased significantly.[50] Nonetheless, ongoing problems with the ground segment may hamper its success.[51] The inadequacies of the GLONASS system are also becoming more apparent. Not only is it inaccurate, providing at best positional accuracy of 10-17 meters, but it is also unstable, sometimes providing no reading at all.[52] GLONASS also has important civilian applications (see Civil Space and Global Utilities Trend 3.4).

Launch

As noted in 5.4, Russia has tended to maintain an average annual satellite launch rate slightly higher than that of the US, demonstrating robust launching capabilities. To maintain its high rate of military launches in the future, Russia plans to build a launch facility for military and civilian satellites in the eastern Amur region, near the border with China. The station is expected to begin operations is 2015.[53]

2008 Developments

US faces increased demands in military satellite capabilities as it continues to upgrade its systems

The US continued to give priority to the development of its military space program in 2008 — $11.9-billion was requested for Air Force space projects alone, an annual increase of 5.3 percent.[54] Although some major replacement projects progressed, others continued to struggle, while demand for services continued to increase.[55] In response, the US Department of Defense (DOD) launched a major overhaul of its acquisition policies in December 2008.[56]

Intelligence

The US National Reconnaissance Office (NRO) lost its authority over the procurement of imaging satellites in 2008 following previous cancellations of the Future Imagery Architecture program and the Misty Stealth Reconnaissance Imaging program.[57] In October 2008 the intended replacement program, the Broad Area Satellite Imagery Collection (BASIC) program, was also cancelled.[58] At $1.7-billion, BASIC was intended to "collect black-and-white and color imagery through a camera aperture 1.1 m across"[59] and have a capability to provide 16-inch resolution images exclusively for use by the intelligence community.[60] Some critics pointed out that commercial operators DigitalGlobe and GeoEye are already providing similar capabilities.[61] Some of BASICS's budget has been directed to a study to determine whether the US needs more satellite imagery, and more of it will be used to fund new projects if needed.[62] The long-anticipated Space Radar program, designed to detect ground movement and provide mapping information and high-resolution radar imagery to the US Air Force and NRO was also cancelled in 2008, following pressure from Congress about cost overruns, schedule delays, and technical difficulties.[63] Nonetheless, neither the Air Force nor the NRO has given up on the concept. A decision has been made by the DOD to spend $40-million investigating alternatives to the discontinued program, which would use small and less costly satellites that could be delivered much sooner while still maintaining Space Radar capabilities.[64] In the meantime, the US continues to recruit allies as well as commercial vendors to fill the gaps in its imagery intelligence programs. In addition to DigitalGlobe and GeoEye, the DOD has purchased data from Canada's Radarsat-2, Germany's SAR-Lupe, and Israel's TecSar satellites.[65] The US still maintains the most advanced intelligence imagery capability, outlined in Figure 5.2.

Satellite Communications

Upgrades to the aging military communications infrastructure was a significant focus in 2008. An additional $400–$500-million was added to the Advanced Extremely High Frequency (AEHF) program intended to replace the Milstar system and purchase of a fourth satellite was approved, bringing the total program cost to $9.9-billion.[66] According to the latest indications, the launch of AEHF-1 has been moved back to November 2009.[67] The system is supposed to fill in the gap before the next-generation TSAT system becomes operational, which faced a complete overhaul in 2008.[68] Following an authorized budget of $786-million for 2009 and persistent claims that the technology is mature,[69] the Air Force announced on 23 December 2008 that the TSAT program had been terminated due to delays and unsustainable cost overruns. Requests for proposals will be released for a new restructured program that will be "a slimmed-down" version of the original project, to be called TSAT digital core (Block 10).[70] It will be comprised of five satellites to begin launching in 2019 and "will lose the planned satellite-to-satellite laser links and Ka-band intelligence, surveillance and reconnaissance support."[71]

Early Warning

The last Defense Support Program (DSP) early-warning satellite, launched in November 2007, failed in orbit in mid-September 2008 when the spacecraft stopped responding to commands. Efforts to resume contact have failed. The current system will remain fragile until it is replaced by the next-generation Space Based Infrared System (SBIRS).[72] On 13 March 2008 the second SBIRS sensor was put into HEO onboard a classified reconnaissance satellite; it provides early-warning coverage of the northern hemisphere for about 12 hours a day.[73] Nonetheless, launch of the first dedicated satellite in GEO has slipped from 2004 to 2010, with other launches scheduled for 2011, 2014, and 2016 if the program stays on course.[74] The DOD approved purchase of a fourth satellite in 2008, which is needed for global coverage.[75] But with the capabilities of DPS potentially degrading before SBIRS is fully operational, the US Air Force is considering procurement of a single Infrared Augmentation Satellite to be launched as a gap filler in 2014. Congressional support continued to falter for the Third Generation Infrared Surveillance (3GIRS) program, which was deemed to be "premature" and received only $75-million of the $149.1-million requested.[76]

Launch
The US military and intelligence communities confirmed their commitment to faster[77] asset deployment, use of commercial space infrastructure,[78] and design of smaller spacecraft in 2008 in an effort to get more responsive space capabilities.[79] The US Army indicated that it will launch its own constellation of eight small satellites, called 'cubesats'. The $5-million project will provide the Army with communications below brigade level in the parts of the world where the army does not posses SATCOMS, such as Africa.[80] The TacSat satellite program also continued, but the $80-million TacSat-3 scheduled to be launched in October 2008 was delayed until 2009.[81] TacSat-5 is scheduled for a 2011 launch. So far only one TacSat mission, TacSat-2, has been put into orbit.[82] Most of this procurement is done through the newly created Operationally Responsive Space Office (ORS), which is designed to quickly accommodate the space needs of the US military.

2008 Developments

Russia increases investment in GLONASS again, pursues other high priority upgrades

Russia continues to struggle to replace its aging Soviet-era military assets, particularly satellite navigation and imaging. The operational status of its current systems remains uncertain.[83] Ministry of Defence officials maintain that additional defense expenditure on satellite assets will enable the Russian forces to better monitor borders and areas of interest. [84]

Navigation
In 2008 the Russian president reportedly signed a directive allocating up to $2.6-billion for the completion of the GLONASS satellite navigation system.[85] Despite multiple satellite launches over the past few years, the short lifespan of GLONASS satellites has contributed to continued weakness of the system, which has not been able to meet the demands of the armed forces. However, the new GLONASS -M satellites have a lifespan of more than seven years, and the next-generation GLONASS -K promises to have a lifespan of more than ten years.[86] GLONASS requires 18 satellites to cover the entire Russian landmass and 24 to provide global coverage.[87] Russia launched six GLONASS -M satellites in 2008,[88] bringing the number of the satellites in the constellation up to 20 "of which 16 are operational, two are undergoing maintenance, and one is due to be withdrawn."[89] However, reports maintain that the "GLONASS system's quality and capabilities…leave a lot to be desired."[90] According to the head of the Russian Space Agency positioning accuracy of the GLONASS will approach that of GPS only after 2010.[91]

Communications and Intelligence
Russia is also taking steps to improve its intelligence and communications capabilities. For the first time in seven years, Russia has digital access to satellite imagery. Cosmos-2441, the first Persona optical imaging satellite, was launched on 26 July 2008.[92] In recent years Russia has been relying on film-based imaging systems, namely the Kobalt, Arkon, and Orlets/Don systems. A Kobalt M4 film-reentry satellite (Cosmos-2445) was launched on 14 November 2008. Images distributed by Google Earth in 2008 indicated that Russia has built a satellite station near Pskov, which is suspected of collecting signals intelligence (SIGINT). The station is located "within the footprint of one of the most important Inmarsat satellites, Inmarsat 4-F2," carrying private, government, and secret voice data in the Atlantic Ocean Region-West.[93] To improve communications capabilities, three Gonets-class military communications satellites (Cosmos-2437, 2438, and 2439) were launched on 23 May 2008.[94] They are most likely Rodnik series satellites, the military counterpart of the civilian Gonets-DM communication system, which is replacing the previous Strela-3 system.[95]

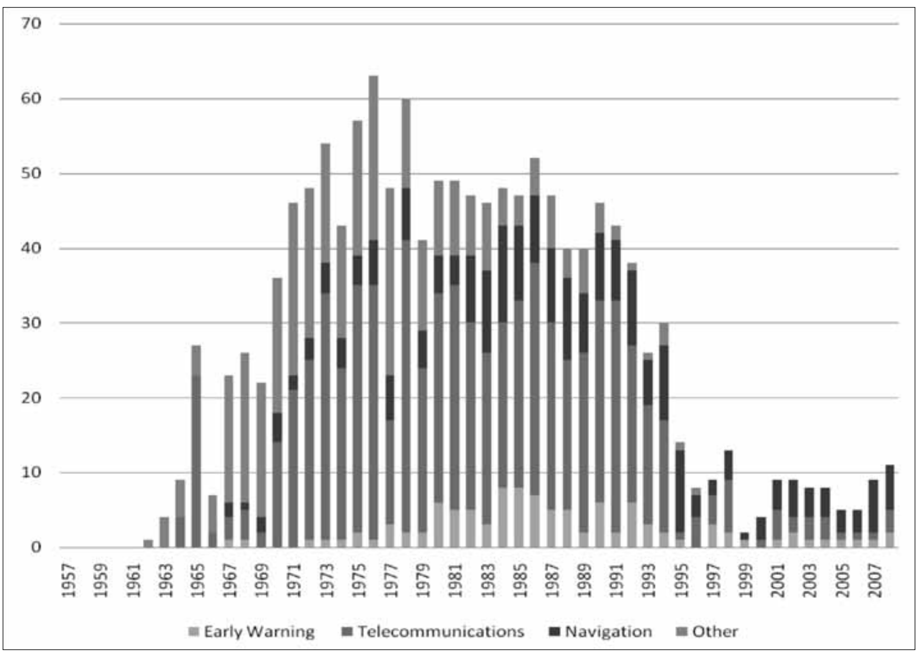
Early Warning

Russia has been struggling to maintain its early warning capabilities since the end of the Cold War. In June 2008, Russia launched in circular geosynchronous orbit Cosmos-2440, a US-KMO early-warning satellite that may replace the aging US-KMO satellite Cosoms-2379, that has been working since 2001 and is approaching the end of its lifespan.[96] On 2 December 2008 Russia launched Cosmos-2446, a first-generation US-KS early-warning satellite (also known as Oko) in HEO.[97] Russia's space-based early-warning satellite system now has five satellites: three US-KS located in HEO and two US-KMO in GEO. Russia also continued to upgrade the ground portion of its early warning system in 2008 with the construction of a new radar station. Russia terminated an early warning agreement with Ukraine in January 2008, and the Ukrainian radars will be replaced with the Russian Voronezh-type radar Armavir station, which is not yet in service but is expected to provide coverage of the entire Russian landmass.[98]

Launch

Russia has historically launched more satellites than any other country, and to maintain its competitive advantage it has started construction of a new launch facility at the military Plesetsk Cosmodrome to launch the new Angara rocket intended for heavy payloads. The facility is scheduled to be finished in 2011. The equipment to furnish the new station will begin to arrive in 2009.[99] It will reduce Russia's reliance on Kazakhstan's Baikanur Cosmodrome.

Figure 5.4: Russian military spacecraft launched by application: 1957 – 2008



2008 Space Security Impact

Despite ongoing acquisition challenges in providing next-generation space capabilities for its military and intelligence communities, the US maintains the most capable and robust systems, which are one indication of secure and sustainable access to and use of space. While ongoing dependence on space systems for security makes the US particularly vulnerable in space, efforts are being made to mitigate this risk through the use of commercial capabilities and smaller satellites that can be launched quickly. Russian space efforts and funding are focused on finishing the GLONASS program and upgrading early warning capabilities, both of which could be positive for security in space by providing redundancy for US GPS and greater stability through more reliable early-warning data.

Trend 5.2: More states developing military and dual-use space capabilities

During the Cold War, states allied with either the US or the USSR benefited from their capabilities. Today, declining costs for space access and the proliferation of space technology enable more states to develop and deploy military satellites. The UK, NATO, and China were the only other actors to launch dedicated military satellites until 1988, when Israel launched its first. In 1995 France and Chile both launched dedicated military satellites (see Figure 5.6).[100] Traditionally, military satellites outside the US and Russia have been almost exclusively intended for communications and imagery intelligence. Recently, however, states such as China, France, Germany, Japan, Italy, and Spain have been developing satellites with a wider range of functions. According to a recent report, security has become a key driver of established government space programs, pushing spending higher, and encouraging dual-use applications.[101] Indeed, in the absence of dedicated military satellites, many actors use their civilian satellites for military purposes or purchase data and services from satellite operators.[102] This is contributing to the blurring of the divide between military and civilian and commercial space assets and applications.

Figure 5.5: Minimum resolutions for remote sensing target identification[103]

Target on the Ground	Detection	General Identification	Precise Identification	Technical Analysis
Vehicles	1.5	0.6	0.3	0.045
Aircraft	4.5	1.5	1.0	0.045
Nuclear weapons components	2.5	1.5	0.3	0.015
Rockets and artillery	1.0	0.6	0.15	0.045
Command and control headquarters	3.0	1.5	1.0	0.09
Ports and harbors	30.0	15.0	6.0	0.3

Europe

European states have developed a range of space systems to support military operations, with France having the most advanced and diversified independent military space capabilities. European military space spending has recently been estimated at $1.35-billion annually.[104] While European states have pursued independent space capabilities for military support, many of these capabilities are also shared among several European states, in particular communications and imagery intelligence. Greater harmonization of the EU through the Lisbon Treaty, development of the European Security and Defence Policy, and budget restrictions in members states are driving states to cooperate.

The classified Besoin Operationnel Commun (BOC) provides the framework for space systems cooperation among the ministries of defense of France, Germany, Italy, Spain, Belgium, and Greece.[105] France's Helios-1 and -2 military observation satellites in LEO are included under this agreement.[106] They are joined by Germany's first dedicated military satellite system, Sar-Lupe, which uses synthetic aperture radar for high-resolution remote sensing, and Italy's COSMO-SkyMed radar satellites, which are to be integrated with France's Pleiades dual-use optical remote sensing satellites in 2010.[107] Several states also cooperate on the dual-use ORFEO satellite network involving Austria, Belgium, France, Italy, Spain, and Sweden. France is also working on the optical and radar MUSIS (Multinational Space-based Imaging System) project with seven other European countries: Belgium, Germany, Greece, Italy, Netherlands, Spain, and Poland.[108] The new optical component of the MUSIS is designed to replace the French Helios-2 optical satellite by 2015.[109] In 2005 the UK launched an optical imagery microsatellite TopSat, built by Surrey Satellite Technology Ltd.

There are also several dedicated and dual-use satellite communications systems in Europe. In 2006 France completed the Syracuse-3 next-generation communication system, described as "the cornerstone in a European military Satcom system."[110] France also maintains the dual-use Telecomm-2 communications satellite and the military Syracuse-2 system.[111] The UK operates a constellation of three dual-use Skynet-4 UHF and Super High Frequency (SHF) communications satellites and a next-generation Skynet-5 system.[112] In 2006 Spain launched the dedicated military communications satellite Spainsat to provide X-band and Ka-band services to the Ministry of Defense. Spain also owns the dual-use communications satellite XTAR-EUR and the dual-use Hispasat system, which provides X-band communications to the Spanish military. In 2006 Germany signed a procurement contract with MilSat Services GmbH to provide the German Armed Forces with a secure information network to assist its units on deployed missions.[113] Italy's Sicral military satellite provides secure UHF, SHF, and EHF communications.[114] Syracuse, Skynet, and Sicral all provide SHF capacity for NATO.

Other military space capabilities in Europe include France's constellation of four signals intelligence satellites know as Essaim, launched in 2004. France plans to launch two Spirale early warning microsatellites for a probative research and technology demonstration and has commissioned four Elisa microsatellites from EADS Astrium at $142.3-million each, which.are expected to be launched together in 2009. The satellite system will gather signals intelligence data and identify civil and military radars for the French intelligence community.[115] Other European states have thus far refused to participate or invest in a pan-European missile-warning system.[116]

The EU has called for a more coherent approach to the development of space systems capable of supporting military operations and has begun to actively develop dual-use systems. The 2007 European Space Policy makes specific reference to defense and security applications, indicating a shifting focus to support increasing synergies between military and civil space programs.[117] The joint EU/European Space Agency (ESA) Global Monitoring for the Environment and Security (GMES) project will collate and disseminate data from satellite systems and is anticipated to be operational by 2012 at a cost exceeding $2.7-billion.[118] It will support activities given priority in the European Security and Defense Policy, such as natural disaster early warning, rapid damage assessment, and surveillance and support to combat forces.[119] Similarly, the Galileo satellite navigation program initiated in 1999 and jointly funded by the EU and the ESA will provide location, navigation, and timing capabilities for both civilian and military users.[120] ESA, which has traditionally been restricted to working on projects designed exclusively for peaceful purposes, has begun to invest in dual-use, security-related research. Future projects, including a European space-surveillance system, will have "multiple" end-users, but the ESA itself will not be designing or operating military spacecraft.[121]

China

China's governmental space program does not maintain a strong separation between civil and military applications. Officially its space program is dedicated to science and exploration,[122] but as with the programs of many other actors, it is believed to provide data to the military. China's space program is led by the Space Leading Group, whose members include three senior officials of government bodies that oversee the defense industry in China.[123] Most of China's satellites are civilian or commercial, but many have capabilities that could also be used for military purposes. Although China has never published a military space doctrine, its national defense strategy is based on "active defense" that "aims at winning local wars in conditions of informationization" that include maintaining "space and electromagnetic space security."[124]

China has advanced remote sensing capabilities that could support imagery intelligence. It began working on space imagery in the mid-1960s, launching its first satellite in 1975.[125] It successfully launched 15 recoverable film-based satellites, the last of which was reportedly decommissioned in 1996.[126] Today China maintains two ZY-2 series transmitting-type optical imagery satellites in LEO that could support tactical reconnaissance and surveillance.[127] In 2005 China launched the Beijing-1 (Tsingshua-1) microsatellite, which is a civil Earth observation spacecraft that combines a multispectral camera with a high-resolution panchromatic imager and could also support the military.[128] More recently, China has launched a series of six Yaogan satellites for "scientific experiment, survey of land resources, appraisal of crops and disaster prevention and alleviation."[129] Two of these satellites are believed to use synthetic aperture radar, which would provide the Chinese government with all-weather/night-day imagery advantageous for military use.[130]

Western experts believe that Chinese military satellite communications are provided by a DFH-series satellite, ChinaSat-22. Officially a civilian communications satellite, ChinaSat-22 is thought to enable "theater commanders to communicate with and share data with all forces under joint command" through C-band and UHF systems.[131] A replacement satellite was launched in 2006.[132]

China also operates the Beidou regional navigation system that is comprised of four satellites in GEO designed to augment the data received from the US GPS system and to enable China to maintain navigational capability if the US were to deny GPS services in times of conflict.[133] Beidou may also improve the accuracy of China's intercontinental ballistic missiles (ICBMs) and cruise missiles.[134] In 2006 China committed to building a global satellite navigation system, the Beidou-2 or "Compass" system, expanding on the regional system to include five satellites in GEO and 30 in MEO. Responsibility for Compass falls to China's defense ministry, but it is intended to provide both an Open Service with position accuracy of 20 meters and an Authorized Service that will be "highly reliable even in complex situations."[135] China launched the first Compass-M1 test satellite into MEO in 2007.[136] Concerns have been expressed that Compass will use the same radio frequencies as Galileo and possibly GPS (see Space Environment Trend 1.4); however, China maintains that this is still under negotiation. Some analysts have suggested that using the same radio frequencies would make it more difficult for the Compass system to be jammed.[137]

China experimented with electronic intelligence satellites, called "technical experimental satellites," in the mid-1970s, but these programs were discontinued. It relies on modern air, sea, and land platforms, not satellites, to perform signals intelligence missions. However, in 2006 China launched two Shi Jian experimental satellites (SJ-6/2A and SJ-6/2B) that some

Western experts believe are providing signals intelligence, although their official purpose is to measure the space environment.[138]

South Asia

India does not operate any dedicated military satellites, but it is undergoing a process of greater military use of outer space and, like China's, its space program is certainly governmental. It has one of the oldest and largest space programs in the world, which has developed a range of indigenous dual-use capabilities. Space launch has been the driving force behind the Indian Space Research Organisation (ISRO). It successfully launched its Satellite Launch Vehicleto LEO in 1980, followed by the Augmented Satellite Launch Vehicle in 1994, the Polar Satellite Launch Vehicle in 1994, and the Geostationary Satellite Launch Vehicle in 2004.

During this time ISRO developed a series of civilian Indian Remote Sensing satellites and currently maintains a constellation of six satellites that provide imagery for the Indian military. Two in particular are suitable for intelligence with resolutions up to one meter: Cartosat-2 and the Technology Experiment Satellite, which provides tactical and strategic intelligence to the armed forces.[139] Referring to Cartosat-2, Secretary of the Department of Space and Chairman of ISRO, G Madhavan Nair has explained that "we don't put a restriction on anybody using it,"[140] confirming beliefs that India's civil space program is available for military use.

India's Military Surveillance and Reconnaissance System was to be launched in 2007.[141] It is intended to provide India with dedicated military satellite intelligence, including military shutter control over key satellites, through the use of the Defence Imagery Processing and Analysis Centre in New Delhi and a satellite control facility in Bhopal. It would incorporate Cartosat-1 and -2, TES, as well as GLONASS. ISRO is also developing the Radar Imaging Satellite using synthetic aperture radar that will be able to take three-meter resolution images in all-terrain, all-weather, day/night conditions, which is a significant dual-use capability. The launch is scheduled for 2009.[142] India's military also uses images from Russian and Israeli satellite feeds.[143]

The Indian National Satellite System[144] is one of the most extensive domestic satellite communications networks in Asia. India uses its Metsat-1 satellite for meteorology. To use enhance its use of US GPS it is developing GAGAN, the Indian Satellite-Based Augmentation System, which will be followed by the Indian Regional Navigation Satellite System (IRNSS) to provide an independent satellite navigation capability (see Civil Space and Global Utilities Trend 3.4).[145] In 2007 India signed an agreement with Russia to jointly use its GLONASS navigation system.[146] Although these are civilian-developed and -controlled technologies, they are used by the Indian military for dual-purpose applications.[147] Moreover, in 2007 a space cell was established under the Air Vice Marshal,[148] with dialogue on the shape of the eventual aerospace command expected to take place between the three branches of the Indian armed forces. In 2008 the US-India civilian nuclear cooperation agreement was approved, ending longstanding sanctions that could allow for greater cooperation between ISRO and the military (see Commercial Space Trend 4.3).[149]

Pakistan's space-based capabilities are significantly less advanced than India's. China launched Pakistan's Badar-1 multipurpose satellite in 1990; in 2001 Russia launched the Badar-2 Earth observation satellite.[150] Pakistan plans to construct the Remote Sensing Satellite System to provide high-resolution satellite images to its military, but its status is unclear.[151] While India and Pakistan seem intent on developing space systems to support military operations, significant progress remains a longer-term objective.

East Asia

The commercial Superbird satellite system provides military communications for Japan, which also has four "information gathering" remote sensing satellites — two optical and two radar — that were launched in 2003 and 2007 following growing concerns over North Korean missile launches.[152] Officially called the Information Gathering Satellite series and under the control of the Prime Minister's Cabinet Office, IGS 3A and 3B provide images of up to one-meter resolution to the Japanese military.[153] Japan is primarily interested in monitoring the Korean Peninsula, but the IGS system provides a scan of the entire planet at least once a day.[154]

In December 2003 South Korea announced its intentions to increasingly use space for military purposes.[155] South Korea operates the civilian Kompsat-1 satellite with 6.6-meters resolution, which is "sufficient for [military] mapping although not for military intelligence collection."[156] It also bought 10 Hawker 800 series satellites from the US, and has operated them for signals intelligence since 1999.[157] On 22 August 2006 Sea Launch launched South Korea's dual military/commercial Koreasat-5 (Mugunghwa 5) communications satellite to replace Koreasat-2 by providing Ku band, C band, and military SHF band communications. Jointly owned by the French Agency for Defense Development (DGA) and South Korea's KT Corp, it will provide secure communications for South Korea's defense forces.[158] South Korea also launched the Kompsat-2 high-resolution Remote Sensing Satellite for Earth mapping in 2006.[159] Although a civilian spacecraft, its one-meter resolution could allow it to serve as a reconnaissance asset.[160]

In July 2004 Thailand signed a deal with the European Aeronautic Defence and Space Company (EADS) Astrium to provide its first remote sensing satellite, which is expected to be used for intelligence and defense.[161]

Taiwan, which has its own space program, operates the civilian Formosa-2 optical imaging satellite with a resolution of 1.8 meters, which is also used by its military forces.[162]

Middle East

Israel operates the dedicated military Ofeq optical imaging system, which provides both panchromatic and color imagery for intelligence purposes.[163] The newest satellite in the system, the Ofeq-7, was launched in 2007 and can identify objects as small as approximately 0.5-meter.[164] Ofeq's capabilities are augmented by the dual-use Eros-A and -B imagery satellites, the latter able to capture black-and-white images at 70-centimeter resolution.[165] Israel plans to launch a dedicated military satellite for secure communications by 2010. In the meantime it uses commercial services provided by Israel's Amos-1 and -2, Tadiran Communications Wi-Max wireless broadband, and Motorola-Israel.[166] In 2005 Israel successfully tested the latest Shavit Space Launch Vehicle, intended to give Israel independent launch capabilities.[167] However, due to its geographic location, Israel must launch satellites westward, using more fuel and necessitating a smaller payload. A recent agreement to have India launch one of Israel's military satellites is thought to demonstrate a new era of military space cooperation between the two states.[168]

Iran launched its first satellite, the Sina-1, in 2005 with the support of a Russian launcher. It has a resolution precision of approximately 50 meters.[169] Although the satellite is intended to collect data on ground and water resources and meteorological conditions, the head of Iran's space program said that it is capable of spying on Israel.[170] However, its poor resolution means that it is not very useful for military purposes. Iran also has a space launch vehicle program, which some speculate is linked to its development of intercontinental-range ballistic missiles and the Shahab-4 and Shahab-5 missiles.[171]

Egypt's civilian Egyptsat-1 remote sensing microsatellite was launched in 2007. Weighing just 100 kilograms, it has an infrared imaging sensor and a high-resolution multispectral imager to transmit black-and-white, color, and infrared images intended to support construction and cultivation and fight desertification.[172] Egypt has not released public details about the resolution or clarity of the images it provides, but an Israeli source has made an unconfirmed claim that it can detect objects as small as four meters.[173]

Turkey has awarded a $250-million contract for its first military optical imaging satellite, the GOKTURK. It is intended to have an 80-centimeter resolution, and the launch is planned for 2011.[174]

Australia

Until recently the Australian defense forces used X-band facilities on satellites owned by the US and other allies.[175] In 2003, however, Australia launched the Defence C1 communications satellite. The satellite will be part of a new Australian Defence Satellite Communications Capability system, which will provide the country's defense forces with communications across Australia and throughout the Asia Pacific region in the X, Ka, and UHF radio frequency bands.[176] Australia is also participating in the US Wideband Global SATCOM program.[177]

Canada

Canada currently relies on commercial satellite communications and imaging services to meet its military needs.[178] In June 2005, however, Canada's Department of National Defence announced the creation of Project Polar Epsilon, a $52.1-million joint space-based wide area surveillance and support capability, which will provide all-weather, day/night observation of Canada's Arctic region and ocean approaches.[179] The project will build two dedicated military ground stations to receive data from the Radarsat satellites, as well as other sources to produce high quality imagery for military and other applications.[180] Radarsat-2, a commercial satellite developed with the Canadian Space Agency, uses synthetic aperture radar to produce images with a resolution of up to three meters.[181] It also has an experimental Ground Moving Target Indicator capability to detect and track the movement of vehicles and ships.[182] A low-cost ($27-million) Joint Space Support Project is intended to provide surveillance information for commanders in the field via direct in-theatre download of imagery provided by commercial satellites such as Radarsat-2, and also provide space situational awareness data gathered by the US Space Surveillance Network.[183] Canada will have its first access to dedicated military satellite communications capability when the US AEHF satellite system becomes operational.[184]

Canada is also investigating the use of microsatellites to respond to needs of the Canadian forces deployed on missions.[185] Two examples are the dual-use Near Earth Object Surveillance Satellite (NEOSSat) and the Maritime Monitoring and Messaging Microsatellite (M3MSat).

Figure 5.6: States' first dedicated military satellites and their function[186]

■ Military satellite-owning state ■ Satellite-owning state

Year	State/Actor	Satellite	Description
1958	US	Project SCORE	Communications and experimental satellite
1962	USSR	Cosmos-4	Remote sensing (optical)
1969	UK	Skynet-1A	Communications
1970	NATO	NATO-1	Communications
1975	China	FSW-0 No. 1	Remote sensing (optical)
1988	Israel	Ofeq-1	Remote sensing (optical)
1995	France[187]	Helios-1A	Remote sensing (optical)
1995	Chile	Fasat-Alfa	Communications and remote sensing (optical)
1998	Thailand	TMSAT	Communications
2001	Italy	Sicral	Communications
2003	Australia	Optus and Defence-1	Communications
2003	Japan	IGS-1A and IGS-1B	Remote sensing (optical)
2006	Spain	Spainsat	Communications
2006	Germany	SARLupe-1	Remote sensing (radar)

* Note that other states have civil or commercial satellites that may be used for military purposes, as described in this chapter.

2008 Developments

European states continue to cooperate on military space projects

In 2008 European states continued to develop new national military space systems and cooperate on projects including communications, early-warning, and remote sensing for intelligence.

Intelligence

The development of shared space intelligence assets is unique to Europe. These assets were a major focus in 2008. Germany launched its fourth dedicated military SAR-Lupe satellite on 27 March 2008 and a fifth on 22 July 2008, completing the constellation.[188] On 25 October 2008 Italy launched its third COSMO-SkyMed dual-use, synthetic aperture radar imaging satellite, which is part of the military Besoin Operationnel Commun arrangement and the dual-use ORFEO satellite network.[189] The Italian government wants to remain a leader in radar imaging satellites and plans at least two more Cosmos spacecraft at a cost of $750-million.[190] French President Nicolas Sarkozy announced a massive investment in "space-based intelligence" in 2008, calling for a doubling of the current annual French military space budget of $585-million.[191]

Spain took a step toward having its own dedicated military space program with an agreement to purchase an optical imaging satellite from EADS-CASA in 2008. The Spanish satellite is to be called Ingenio; it is priced at $177-million and will provide up to 2.5-meter resolution.[192] Spain also intends to build a small military radar imaging satellite (Seosar, also known as Paz) by 2015.[193] Britain is considering a new optical imaging satellite project called SkySight for 2010. The first two microsatellites will provide full-color images at 1.2-meters resolution, and the second two are intended for submetric resolution (less than 0.5 meters). The cost of the SkySight proposal currently stands at approximately $184-million, which includes three years of operational support.[194]

Norway approved funding for AISsat-1, an experimental satellite that will monitor ship traffic, assist with ship navigation, and monitor Arctic waters from space by receiving Automatic Identification System signals transmitted by ships. The satellite will have dual civil and military uses, with most of the funding coming from the Norwegian Space Centre, while the Norwegian Defence Research Establishment is responsible for planning.[195]

Communications

The UK launched the third and final Skynet-5 secure communication satellite on 12 June 2008. The €3.6-billion project is the largest UK space program.[196] As a public–private partnership it is owned and operated by Paradigm, a subsidiary of Astrium, and is the first example of a privately owned secure communications system.[197]

The French and Italian governments evaluated bids in 2008 to jointly procure a communications satellite for both civil and military use, called Athena/Fidus, for launch by 2012. The satellite is to be financed by the space agencies and defense ministries of both governments. Belgium has been granted access to the satellite's services, while France will have command and control of its operations. Similarly, France and Italy are jointly procuring Sicral-2 (Sistema Italiano per Comunicazioni Riservate ed Allarmi), a dedicated military communication satellite that will carry a French and an Italian payload, with Italy in charge of operations. A contract for Sicral-2 is expected to be awarded to Thales Alenia Space in 2009, with launch of the spacecraft planned for 2012.[198]

2008 Developments

The Council of the European Space Agency endorses military use of its dual-use space projects

The European Space Agency (ESA) assumed a growing role in European space-based security and defense in 2008 when it approved its planned Galileo satellite navigation system for use by European military and defense organizations.[199] Following restructuring of the program in 2007 from a failed private–public partnership to a fully public system, a new procurement process was launched in 2008 involving $4.6-billion for 26 satellites, launches, and ground control stations.[200] The second Galileo In-Orbit Validation Element satellite built by Surrey Satellite Technology Limited underwent successful testing in 2008.[201] The system is scheduled for full deployment in 2013.[202] Half of the Galileo users are expected to be military and law enforcement agencies using the encrypted Public Regulated Service (PRS). The PRS remains a sensitive issue within the EU and ESA, however, with some concerns that military use will undermine the civil-only reputation of the project. EU governments have promised that PRS will be accessible to EU-based clients only.[203] There is also a concern that the shift in ESA policy to dual-use and military applications has not been matched by a shift in funding, which continues to come largely from civilian budgets.[204] Other military-related projects approved by the ESA in 2008 include $302-million for the European Data Relay Satellite System, and $62.8-million for the European Space Situational Awareness program (see Space Systems Protection Trend 6.1). The ESA Global Monitoring for Environment and Security (GMES), initially a civilian project, was also approved for dual civilian and military use in 2008 and is also financed by the EU. The program is intended to provide users with remote sensing data using both terrestrial and space-based sensors (see Civil Space and Global Utilities Trend 3.4).[205] For military users, GMES will provide data on military-theatre management, training tools for military forces, and crisis monitoring.[206]

Despite acknowledging the applicability of many ESA projects for military users, ESA members stressed that military use of projects including GMES and Galileo "must be consistent with the principle that these are civilian systems under civilian control."[207]

In December 2008, following years of negotiations, France, Germany, and Italy agreed to provide the European Union Satellite Centre with both free and paid access to their military imaging satellites. The move is intended to contribute to EU security and defense policy.[208]

2008 Developments

China continues to launch potential dual-use spacecraft

In 2008 China launched a range of satellites that may be used to support capabilities for terrestrial military operations, but this use is ambiguous. In particular, two additional satellites were added to China's constellation of Yaogan remote sensing satellites, including a second one with synthetic aperture radar capabilities. Yaogan-4 and -5 launched on 1 and 15 December 2008 respectively. This series of satellites is described as supporting disaster prevention and relief, but high-resolution imagery, especially radar, is also conducive to military uses due to its ability for all-day/all-weather imaging. Moreover, theses satellites have often been launched secretly, and the lack of information about them prompts some analysts to suspect that they support the collection of intelligence for military uses.[209] In addition, two satellites described as supporting physics experiments in space are believed by some analysts to be also providing signals intelligence data, but this use is not confirmed.[210] Finally, the China Meteorological Administration added two additional Fengyun satellites (2E and 3A) to its constellation, which provides "high-quality data for weather forecasting, climate change prediction and natural disaster supervision." Statistics show that "more than 2,500 users, both at home and abroad, have accessed data processed by the Fengyun-2 satellite series."[211] Although there is no evidence that the Fengyun satellites are actively used by China's military, meteorology is a service generally used by civilian, commercial, and military actors alike.

2008 Developments

India and Israel cooperating on space

Evidence of military cooperation between Israel and India is beginning to emerge as the two countries face similar regional security concerns.[212] On 21 January 2008 India launched the Israeli military TecSar (Polaris) satellite into polar orbit. The satellite is equipped with synthetic aperture radar all-day/all-weather imaging capabilities. It is one of the most powerful radar imaging satellites in the world, with 10-centimeter resolution.[213] According to some sources, Israel has promised to share some of the satellite's data with India. Israel also plans to lease to India some of the capacity of its optical Ofeq-5 imaging satellite, which has been upgraded with new software that enables it to collect more imagery.[214] Israel is planning to launch two more imagery intelligence satellites, Ofeq-8 and TecSar-2, in the next two years.[215]

India's use of space for military purposes took another step forward with the formation of the long anticipated Integrated Space Cell. Under the Integrated Defence Services Headquarters of the Ministry of Defence, it is intended to permit "more effective utilization of the nation's space-based assets for military purposes and to counter offensive counter-space systems,"[216] acting "as a single window for integration among the armed forces, department of space, and the Indian Space Research Organization."[217] One such area of integration involves satellite imaging capabilities. On 20 April 2008 the civilian Indian Space Research Organisation (ISRO) launched its Cartosat-2A remote sensing satellite into sun-synchronous orbit. It has a panchromatic camera capable of producing black-and-white pictures with a one-meter resolution. ISRO has reported that data from the satellite will be made available to interested space agencies and other civilian users, which some speculate will include the military.[218]

2008 Developments

Japan plans new military uses of space

On 21 May 2008 Japan passed a new Basic Space Law, removing a longstanding ban on military use of space in response to what Japan calls "changing global security situations."[219] The law also created a new cabinet-level Strategic Headquarters for Space Policy (SHSP) "in order to comprehensively and systematically promote measures with regard to space development and use."[220] The SHSP will draw up a five-year Basic Space Plan for civil and military space projects in 2009, but the Ministry of Defence will make the final decision on defense-related space programs, with both early warning satellites and dedicated military communications satellites possibilities.[221]

In 2009 the Japanese Ministry of Defence requested $674-million for space-related projects that will include the establishment of a Space Maritime Security Policy Office and a Space Technology Planning Section. However, most of the funds will be spent on the development of a Missile Defense System, with only $1-million allocated to studies for military space use and administrative costs. Plans are in place to enhance the existing Information Gathering Satellite (IGS) remote sensing system that is under the civilian Office of Cabinet Secretariat, including the launch of an optical imaging satellite with a resolution of up to 61 centimeters. This resolution, currently the highest commercially available, is a key restriction of the IGS system and its follow-on, which was approved prior to adoption of the Basic Space Law.[222] Despite the new law, internal tensions about the use of space remain. For example, although Japan is participating in US ballistic missile defense and may be expected to intercept a missile that it detects from space, Japan's constitution still prevents the country "from exercising the right to collective self-defense."[223]

2008 Developments

Canada continues to develop dual-use space capabilities

Canada continued to expand its plans for dual-use space capabilities in 2008.[224] Canada initiated work with MacDonald Detwiler and Associates on three small satellites to form the Radarsat Constellation. At a cost of $580-million, these new satellites are intended to complement and expand Radarsat's existing capabilities. Satellite launches are planned for 2014, 2015, and 2016.[225] The Department of National Defence, in Project Polar Epsilon, is building two dedicated military ground stations to make use of data from Radarsat-2.[226] The Canadian Space Agency (CSA) is also considering a Polar Communications and Weather satellite program, which could support dual military functions.[227]

The CSA and Defence Research Development Canada continued to invest in dual-use microsatellite projects that can respond to the operational needs of users, including the Canadian Forces. ComDev was awarded $8.6-million in 2008 to develop the Maritime Monitoring and Messaging Micro-satellite (M3MSat), intended to "support Canadian sovereignty, security, safety and communications needs within the territorial and maritime regions of Canada and beyond."[228] The project is expected to be completed by 2010.

2008 Space Security Impact

The drive for more states to develop and deploy both dedicated military and dual-use space systems demonstrates the continued accessibility of the space environment and greater access to space technologies. In general, these systems are being developed independently of one another and, while in theory some, such as satellite navigation, could be interoperable to enhance security, such cooperation is not the rule. However, Europe is emerging as the one region where space-based capabilities are being developed cooperatively, thus providing access to more states and redundancy of capabilities. As more states become dependent on space systems for military operations and national security, greater vulnerability may provide incentives to enhance the security of outer space or to develop capabilities to quickly negate space systems. At the same time, increasing reliance on dual-use spacecraft will make intentions difficult to determine.

Space Systems Protection

This chapter is focused on one aspect of technology related to space security, namely the research, development, testing, and deployment of physical and technical capabilities to better protect space systems from potential negation efforts, which involve human actions intended to interfere with a satellite system (see Space Systems Negation). Physical protection capabilities are designed to mitigate the vulnerabilities of the ground-based components of space systems, launch systems, communications links to and from satellites, and satellites themselves, to ensure sustainable access to and use of outer space. Capabilities to protect against environmental hazards such as space debris are examined in The Space Environment chapter.

While physical and technical capabilities can provide a certain degree of protection from potential negation efforts, they cannot make satellite systems invulnerable. Consequently, initiatives to provide non-physical protection by managing the proliferation and use of negation capabilities are covered in the chapter on Laws, Policies, and Doctrines.

Both active and passive means can be used to provide three main types of space systems protection: capabilities to detect space negation attacks; physical and electronic means to withstand attacks on ground stations, communications links, and satellites; and reconstitution and repair mechanisms to recover from space negation attacks.[1] While countermeasures to the space negation capabilities of others are considered protection measures by some, they are indistinguishable from other negation systems and are thus addressed in the Space Systems Negation chapter.

The ability to detect, identify, and locate the source of space negation attacks through early warning and surveillance capabilities is critical to space protection efforts. It is important to know whether the failure of a space system is being caused by technical or environmental factors or by the deliberate actions of another actor. Detection is often a precondition for effective protection measures such as electronic countermeasures or maneuvering a satellite out of possible harm. The ability to detect a potential negation effort is also a prerequisite for deterrence.

Because it is currently difficult to distinguish between satellite failures caused by environmental factors and deliberate attacks, greater space situational awareness (SSA) can improve security in space.[2] However, SSA can be used for many purposes, including monitoring the natural environment in space and tracking and targeting foreign satellites, as examined in chapters on The Space Environment and Space Systems Negation.

Protecting satellites, satellite ground stations, and communications links depends on the nature of the space negation threat that such systems face, but in general terms threats can include cybernetic attacks against space system computers, electronic attacks on satellite communications links, conventional or nuclear attacks on the ground- or space-based elements of a space system, and directed energy attacks such as dazzling or blinding satellite sensors with lasers.

A more advanced space systems protection capability is the ability to recover from a space negation attack in a timely manner by reconstituting damaged or destroyed components of the space system. While capabilities to repair or replace ground stations and reestablish satellite communications links are generally available, capabilities to quickly rebuild space-based systems are much more difficult to develop.

Space Security Impact
Most space systems remain unprotected from a range of threats, assessed by experts to include (in order of decreasing likelihood): (1) electronic warfare such as jamming communications links, (2) physical attacks on satellite ground stations, (3) dazzling or blinding of satellite sensors, (4) hit-to-kill anti-satellite weapons, (5) pellet cloud attacks on low-orbit satellites, (6) attacks in space by microsatellites, and (7) high-altitude nuclear detonations (HAND).[3] Other potential threats include radio frequency weapons, high-powered microwaves, and "heat-to-kill" ground-based lasers. Growing awareness of the vulnerabilities of space systems has led actors to develop space systems protection capabilities to better detect, withstand, and/or recover from an attack. Nonetheless, there are no effective physical protections against the most direct and destructive types of negation such as the use of kinetic or high-powered energy force against satellites.

These protection capabilities can have a positive impact on space security by increasing the ability of a space system to survive negation efforts, thus helping to assure secure access to and use of space, and potentially to deter negation attempts. Actors may refrain from interfering with well protected space systems if such attacks would seem both futile and costly. Moreover, the use of protective measures to address system vulnerabilities could offer a viable alternative to offensive means to defend space assets. Given the concerns surrounding space debris, passive defensive measures may also offer more sustainable approaches to physical security in space.

However, the security dynamics of protection and negation are closely related, and under some conditions, protection systems can have a negative impact on space security. Like many defensive systems, they can stimulate an arms escalation dynamic by motivating adversaries to develop weapons to overcome protection systems. Conceivably, robust protection capabilities could also reduce an actor's fear of retaliation, thus lowering the threshold for using space negation capabilities. Finally, protection, which often increases the mass of the space system, can have cost implications that affect space access and use, and can thereby reduce the number of actors with secure use of space.

Trend 6.1: US and Russia lead in ability to detect rocket launches, while US leads in development of technologies to detect direct attacks on satellites

The ability to distinguish space negation attacks from technical failures or environmental disruptions is critical to maintaining international stability in space. Early warning also enables the mounting of physical protection efforts, although the type of protection available may be limited. Detecting attacks on satellite ground stations is not addressed in any detail in this trend assessment since this capability is available to almost all actors with a conventional military capability.

Detecting rocket launches
During the Cold War the US and USSR developed significant space-based early warning systems to detect ballistic missile and space rocket launches. These systems also provided some ability to detect the ground-based launch of an anti-satellite missile by monitoring the trajectory of the launch to see if it could place its payload into the same area as that of an existing satellite. Only the US and Russia currently have a space-based early-warning capability, although France is developing two early warning demonstrator satellites called Spirale.[4]

The USSR launched its first space-based early warning Oko satellite in 1972 and had fully deployed the system by 1982. As of January 2009 there were only three satellites in the Oko system, which provides coverage of US intercontinental ballistic missile fields about 18 hours a day, but with reduced reliability; it can detect massive attacks but not individual missile launches.[5] The Oko system is complemented by two additional early-warning satellite in Geostationary Orbit (GEO), which is believed to be a next-generation US-KMO or Prognoz satellite capable of detecting missiles against the background of the Earth.[6] The complete US-KMO system would consist of up to seven GEO satellites to provide global coverage. A new Integrated Space System is being planned for 2009-10.[7] Plans have also been announced to restore the space-based component of its missile attack warning system, for which funding has been increased.[8] See Space Support for Terrestrial Military Operations for additional details.

Russia's space-based early warning capabilities are complimented by nine land-based radar stations, including a new Voronezh meter-band early warning radar near Lekhtusi in the Leningrad Region, which was put online in 2006, closing a seven-year coverage gap in its northwestern region.[9] However, Russia intends to stop using five of these stations, which are located outside of Russian territory in Azerbaijan, Belarus, Kazakhstan, and Ukraine.[10]

The US military has always emphasized space protection as one of the key pillars of its space doctrine.[11] First launched in 1970 US Defense Support Program (DSP) early warning satellites have provided the US with the capability to detect missile/rocket launches worldwide. By 2002 the DSP system had increased from four to seven GEO satellites, enhancing reliability by allowing certain areas to have additional satellite coverage.[12] The intended replacement for DSP is the US Air Force's (USAF) next-generation Space Based Infrared System (SBIRS), which will require four satellites in GEO to provide global coverage.[13] The SBIRS program is estimated to cost $11-billion and is seven years behind schedule.[14] Due to its numerous delays and cost overruns the USAF initiated the Alternative Infrared Satellite System, now renamed Third Generation Infrared Surveillance Program (3GIRS)[15] in 2006 as a less complex alternative using existing technologies, but it is now considered a follow-on program.[16]

The second layer of US next-generation space-based ballistic missile detection and tracking is the Space Tracking and Surveillance System (STSS) under development by the US Missile Defense Agency (MDA). STSS is intended to track missiles through space, differentiate missile warheads from decoys and debris, and provide targeting data for a missile defense interceptor using a system of 20 to 30 sensor satellites in Low Earth Orbit (LEO). The program has been restructured and renamed several times since 2001 and has experienced significant cost growth.[17] STSS could also be used to support space systems negation efforts and space-based strike capabilities.

Sea-based and terrestrial assets perform ballistic missile launch detection and tracking for China, France, and the UK. China's four Yuan Wang tracking ships are used for satellite tracking as well as missile detection and tracking. China is also believed to have one Large Phased-Array Radar for missile launch detection near Xuanhua in the west.[18] France employs the Monge tracking ship with ARMOR radars to track ballistic missiles, primarily for its missile testing program. On the Monge ship there are two C-band ARMOR radars with 10-meter receiver dishes capable of viewing objects up to 4,000 kilometers away.[19] Royal Air Force Fylingdales in North Yorkshire, UK is a major space surveillance site with a Large Phased-Array Radar operating in the UHF frequency range. Fylingdales is one of three radars in the Ballistic Missile Early Warning System, which performs missile launch detection for Europe and the US. The radar also acts as a collaborative sensor for the US Space Surveillance Network (SSN) and is currently being updated to play a role in the US ballistic missile defense program.[20] Another early warning system has been proposed for the Czech Republic.

Detecting Anti-Satellite Weapon (ASAT) attacks

Most actors have a basic capability to detect a ground-based electronic attack on their space systems, such as jamming, by sensing the interference signal of the attacker or detecting the loss of communications with the system under attack. Many actors also have the capability to use multiple sensors to geo-locate the source of jamming signals, which helps to determine if the interference is intentional. It is also reasonable to assume that all actors operating a satellite have some capability to detect spoofing (feeding a false signal), since basic electronic error code checking routines are relatively simple to implement. However, early warning for such attacks remains a challenge.

Directed energy attacks such as laser dazzling or blinding and microwave attacks move at the speed of light, so advance warning is very difficult to obtain. These attacks can be detected either by the loss of a data stream from optical or microwave instrumentation or by thermal sensors. Onboard satellite-specific laser sensors can detect either the key laser frequencies or radiant power. Such capabilities could trigger a variety of reactive passive protection measures, such as automated mechanical shutters or the release of smoke to block the laser, which might prevent damage, depending on the sophistication of the attacker.[21] Only US satellites are known to have such capabilities, but Russia, France, Germany, China, Japan, and others have critical remote sensing satellites that might employ such capabilities (see Space Support for Terrestrial Military Operations).

Conventional weapons based in space could be detected through the tracking of satellite maneuvers to monitor whether a satellite is in an orbit that could allow it to intercept or attack another satellite. Both the US and Russia have a limited ability to do this through their space surveillance capabilities. The US has the most capabilities in this regard through the SSN. It has been slowly augmenting this capability with the development of the Space Surveillance Telescope, the Deep View radar, and the Space Based Space Surveillance (SBSS) system; however, these programs are not fully developed. A greater capability to monitor satellites in GEO is expected from Canada's space-based space surveillance satellite Sapphire, which will contribute data to the US Space Surveillance Network. [22] The US refers to this capability as Space Situational Awareness, which the US government viewed as having greater importance after the 2007 Chinese satellite intercept.[23] European Union (EU) member states have also discussed the feasibility of developing an independent space surveillance system, based on the existing national capabilities of a few members. See The Space Environment Trend 1.3.

No space actor currently has the ability to constantly monitor all satellites to detect hostile maneuvers. But space surveillance capabilities can also contribute more passively to protection in space by improving transparency in space activities, which is necessary to confidently operate safely in outer space. However, there is currently no process in place to create a global system for space surveillance and transparency, in part because such data can also be used to support negation efforts. This is why the US moderates access to information from its SSN.[24] Technical and policy challenges also put constraints on data sharing, although some efforts among select actors are under way to overcome these challenges.

Space surveillance capabilities are discussed at length in The Space Environment Trend 1.3 and Space Systems Negation Trend 7.2.

Another approach to detection would be to place sensors on every satellite to allow the detection of local satellites and potential negation efforts. While no actor has fully developed these capabilities, the US is pursuing tactical, on-orbit space-based situational awareness via a $30-million project called Self-Awareness Space Situational Awareness (SASSA) (see development below). The US is also developing capabilities to detect electromagnetic interference on satellites through its Rapid Attack Identification Detection and Reporting System (RAIDRS) program. This largely classified program is defined by the US as a defensive counterspace system designed to identify, locate, and report attacks on US space systems, thus enabling timely deployment of defensive responses.[25] The system has been operating since 2005 with six fixed ground stations and three deployable ground segments.[26]

Finally, the USAF is developing the Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) to shadow a space asset and provide local, on-orbit space situational awareness and anomaly characterization.[27] The first ANGELS launch is currently expected in 2009. ANGELS is intended to develop tools for "high value satellite defense."[28] While there are concerns about its potential use for space systems negation, information in open literature does not indicate that it will have the capacity to significantly change orbit to target foreign satellites.

A high altitude nuclear detonation (HAND) can be detected by using gamma ray/X-ray/neutron flux detectors in orbit. Only the US and Russia are known to have such capabilities, and no other actors are known to be developing them. The US developed and launched 12 Vela series satellites, which would detect nuclear tests, to monitor compliance with the 1963 Limited Test Ban Treaty. Subsequently such instruments were integrated with DSP early warning satellites and Global Positioning System (GPS) satellites.[29] Russia integrates nuclear detonation warning sensors onto its GLONASS satellites. Actors in direct line of sight could also detect a HAND.

2008 Developments

US and Russia continue to upgrade early warning systems, and Japan considers developing a national early warning capability

In mid-September 2008 the 23rd US DSP missile-warning satellite launched in November 2007 failed in orbit.[30] The loss of US DSP-23, the newest satellite in an ageing system, may reduce the lifespan of the system or its capabilities, so that there will be a gap in capability until the next-generation Space-Based Infrared System (SBIRS) can fully take over; that projected date is 2016, if the program stays on course (see Space Support for Terrestrial Military Operations Trend 5.1).[31] In 2008 the US Department of Defense (DOD) opted to increase the planned constellation to four, which is necessary for global coverage.[32] A second SBIRS sensor was launched onboard a classified satellite in HEO on 13 March 2008 and both were to be operational by January 2009.[33] To ensure that there are no capability gaps, however, the US Air Force is proposing an interim capability satellite, the Infrared Augmentation Satellite, which would be launched in 2014 if approved by the US Congress. Congressional support continued to falter for the Third Generation Infrared Surveillance (3GIRS) program, which was deemed "premature" and received only $75-million of the $149.1-million requested.[34]

The failure of DSP-23 also meant the loss of a sensor onboard designed to detect even small nuclear tests from space to monitor global compliance with nuclear weapons treaties.[35]

In June 2008, Russia launched the early warning satellite Cosmos-2440 to enhance its fragile early warning system.[36] The new Cosmos-2440 may replace the aging US-KMO satellite, Cosmos-2379, which was commissioned in 2001 and is approaching the end of its lifespan.[37] On 2 December 2008 Russia launched Cosmos-2446, a US-KS early warning satellite placed in HEO, bringing the total constellation to five satellites — two in GEO and three in HEO. The satellites in HEO are able to detect launches from US territory only, while the system in GEO is intended for global coverage, but is not yet fully operational.[38]

The upgrades to Russia's early warning system also include the construction of a new radar station. Russia terminated an early warning agreement with Ukraine in January 2008 and the Ukrainian radars will be replaced with the new Russian Voronezh-type radar station in Armavir.[39] The station was supposed to be operational by the end of 2008, but was not.[40]

Experiencing tensions with China and North Korea, Japan is developing a plan to promote the defensive use of rockets and early warning satellites. Following a change in legislation in May 2008 to allow Japan to deploy military satellites for self-defense (see Laws, Policies, and Doctrines Trend 2.4), Japan's Ministry of Defense is now considering plans for its own ballistic missile early warning satellite.[41]

2008 Developments

US pursues on-orbit warning and attack detection capabilities to enable defensive responses

The US Air Force is pursuing tactical, on-orbit space-based situational awareness via a $30-million project called Self-Awareness Space Situational Awareness (SASSA) that is intended to provide data on possible anti-satellite attacks, including lasers and radio frequency jamming, and to evaluate potential threats in the local operating environment via a sensor on a host satellite.[42] The sensory payload will be designed to: 1) provide indications of an attack; 2) identify the source of such an attack; 3) assess any damage to the host satellite; and 4) identify environmental and potential anti-satellite anomalies in space. There are no plans to include countermeasures or other active defenses in the program,[43] but negation enabling capabilities are conceivable (see Trend 7.2). The biggest challenge for responsive measures will be pinpointing the origin of possible interference. While the program is only in the development stage, capabilities are expected to be integrated into such future satellites as the Operationally Responsive Space Office's TacSat-5, anticipated in 2011.[44]

Similarly, in 2008 the US Air Force received $6.3-million in the FY2009 Defense Authorization budget for an "active and/or passive threat warning sensor for detection of a direct ascent or co-orbital vehicle," which some analysts suspect is part of ANGELS.[45] The 2009 request includes selection of "two technology options that provide defensive capability" for "incorporation" in GEO and LEO satellites.[46] The ANGELS program is to provide some degree of awareness to their host satellite, enabling the satellite to deploy countermeasures or maneuver in the event of a threat.[47]

The US demonstrated a provisional capability to inspect and characterize satellites and potential abnormalities on-orbit in 2008 by using the Microsatellite Technology Experiments (MiTEx) satellites following the failure of the US DSP-23 early-warning satellite in GEO in September 2008. However, there are concerns about potential use of on-orbit defensive systems to also engage in activities that target other spacecraft (see Space Systems Negation Trend 7.4).

Early warning data is only useful for space protection if it can be used to respond defensively to a potential threat. The US Air Force intends to improve this ability through an upgraded version of the RAIDRS Block 20. Although currently conceptual, it is intended specifically to detect possible attacks on satellites. The new systems would be able to monitor all US military satellites for signs of potential interference and would collect data from open and classified sources on "space weather; missile-warning alerts…; satellite position and telemetry from space; and intelligence from various sources."[48] The intent is to predict when a threat is coming and use the data to make decisions about how to maneuver around a threat. As the system progresses, data from new threats, including those in orbit, will be added. Initial deployment is planned for 2011.

2008 Developments

Improvements in access to independent space surveillance data, and ongoing discussions about options to share such data

The ability to use space surveillance capabilities for protection measures in space remains predominantly limited to passive abilities to detect, monitor, and track satellites in orbit that may be potentially hostile. Even these functions cannot be constantly carried out for every satellite. Space surveillance can also improve transparency in space activities, particularly if such data is widely shared. Developments in national capabilities and the potential for sharing data are covered under The Space Environment Trend 1.3.

2008 Space Security Impact

Efforts to improve missile early warning capabilities in the US and Russia contribute to space security by maintaining the foundation of capabilities to monitor compliance with international controls on missile and nuclear technology developments that could be used to threaten objects in space (see Space Systems Negation), and to warn of impending threats. Thus the loss of the US sensor to detect nuclear blasts weakens an important protection measure, while the potential for early warning capabilities to be developed by additional actors is a positive measure that could increase the robustness of these efforts. US interest in developing local, on-orbit capabilities to warn of possible attacks or detect interference with a satellite can enhance protection of specific space systems by enabling defensive responses and possibly deterring attempts to interfere with those satellites. More broadly these capabilities could contribute to increased stability if they were able to identify the source of interference and if it were intentional, accidental, or environmental. It is noted, however, that on-orbit surveillance and warning can potentially facilitate aggressive counteractions in space, which could be destabilizing and spiral into conflict.

Trend 6.2: Efforts to protect satellite communications links but ground stations remain vulnerable

Protection of satellite ground stations

Satellite ground stations and communications links are the likeliest targets for space negation efforts since they are vulnerable to a range of widely available conventional and electronic weapons. While military satellite ground stations and communications links are generally well protected, civil and commercial assets tend to have fewer protection features. A study published by the US President's National Security Telecommunications Advisory Committee emphasized that the key threats to the commercial satellite fleet are those faced by ground facilities from computer hacking or possibly, but less likely, jamming.[49] Satellite communications can usually be restored, however, and ground stations rebuilt for a fraction of what it costs to replace a satellite.

The vulnerability of civil and commercial space systems raises concerns, since a number of military space actors are becoming increasingly dependent on commercial space assets for a variety of applications. Many commercial space systems have a single operations center and ground station,[50] leaving them potentially vulnerable to some of the most basic attacks. Responding to such concerns, in 2002 the US General Accounting Office recommended that "commercial satellites be identified as critical infrastructure" (see Commercial Space Trend 4.3).[51] In the event of an attack the use of standardized protocols and communications equipment could allow alternative commercial ground stations to be brought online.

Most, if not all, space actors are capable of providing effective physical protection for their satellite ground stations within the general boundaries of their relative military capabilities, although they may not elect to do so. Thus this trend focuses on the increasingly critical area of the protection of satellite communications links.

Electronic protection

Satellite communications links require specific electronic protection measures to safeguard their utility. Although unclassified information on these capabilities is difficult to obtain, one can assume that most space actors, by virtue of their technological capabilities to develop and operate space systems, are also able to take advantage of simple but reasonably robust electronic protection measures. These basic protection capabilities include: 1) data encryption; 2) error protection coding to increase the amount of interference that can be tolerated before communications are disrupted; 3) directional antennas that reduce interception or jamming vulnerabilities, or antennas that utilize natural or manmade barriers as protection from line-of-sight electronic attacks; 4) shielding and radio emission control measures that reduce the radio energy that can be intercepted for surveillance or jamming purposes; and 5) robust encryption onboard satellites.[52]

Sophisticated electronic protection measures were traditionally unique to the military communications systems of technologically advanced states, but they are slowly being expanded to commercial satellites. These advanced protection capabilities include: 1) narrow band excision techniques that mitigate jamming by using smaller bandwidth; 2) burst transmissions and frequency-hopping (spread-spectrum modulation) methods that communicate data in a short series of signals or across a range of radio frequencies to keep adversaries from "locking-on" to signals to jam or intercept them; 3) antenna side-lobe reduction designs that mitigate jamming or interception vulnerabilities by providing more focused main communication beams and reducing interference from jamming in the side-lobe regions; and 4) nulling antenna systems (adaptive interference cancellation), which monitor interference and combine antenna elements designed to nullify or cancel the interference.[53] This last technique is considered the most comprehensive anti-jamming technique in existence.[54]

During the Cold War the US and the USSR led in the development of protection systems to protect satellite communications links. The US currently appears to be leading in the development of more advanced capabilities. For example, US/NATO Milstar communications satellites use multiple anti-jamming technologies, employing both spread-spectrum modulation and antenna side-lobe reduction. Adaptive interference cancellation is being developed for next-generation satellites.[55] Through its Global Positioning Experiments project, the US has also demonstrated the ability of GPS airborne pseudo-satellites to relay and amplify GPS signals to counter signal jamming.[56]

The US and several other countries, including Germany and France, are currently developing laser-based communications systems, which could provide a degree of immunity from conventional jamming techniques in addition to more rapid communications; however, they continue to face technological challenges.[57] The US has also initiated a Cyberspace Command responsible for the military's Internet and other computer networks, as well as the electromagnetic spectrum, which could cover satellite protection from directed energy weapons and communications jamming.[58] Commercial technologies to protect against electronic jamming are increasingly available.

In response to several jamming incidents in past years allegedly attributed to the Falun Gong, in 2005 China launched its first anti-jamming satellite, the Apstar-4 communications satellite.[59] China is also reportedly upgrading its Xi'an Satellite Monitoring Center to monitor and diagnose satellite malfunctions, eliminate harmful interference, and prevent purposeful damage to satellite communications links.[60]

2008 Developments

Plans for US Cyber Command evolve; NATO opens Co-operative Cyber Defense Center

Announced in 2006 and set to become operational on 1 October 2008, the USAF Cyber Command would have been a USAF 'major command' and was to 'dominate' cyberspace. Plans were put on hold in August 2008, however, when the Air Force announced that it would not activate a major command. [61] Plans to create a numbered air force subordinate to Air Force Space Command were announced in mid-October; its responsibilities include both defense of DOD networks and capabilities to launch attacks (see Space Systems Negation Trend 7.1).[62] On the defensive side, the Air Force is struggling to stay ahead of online attackers by 're-writing the rules' of cyberspace with the newly announced Integrated Cyber Defense program of the Air Force Research Laboratory. Its aims include "making hostile traffic inoperable on Air Force networks, locating and identifying once-anonymous hackers, [and] enabling Air Force servers to evade or dodge electronic attacks."[63] In the meantime, significant activities in cyberspace are the responsibility of the Navy's Network Warfare Command and the Space and Naval Warfare Systems Center.[64]

On 14 May 2008 seven NATO members (Estonia, Latvia, Lithuania, Germany, Italy, Spain, and Slovakia) formally established a Co-operative Cyber Defense Center of Excellence based in Tallinn, Estonia.[65] The Center is intended to improve the defense of key information systems against cyber attacks and to share best practices. Its establishment followed the adoption of a common NATO policy on cyber defense at the NATO summit meeting held in April 2008 to develop a coordinated approach to cyber attacks.[66]

2008 Developments

US focuses on improved security of existing communications links while efforts to develop laser links continue, but face both technical and budgetary challenges

The US continued to improve the security of its existing radio-based satellite communications systems in 2008. A second Eagle Sentry system, first deployed in 2007 to track interference with commercial communications systems used by the US government, was deployed in Europe in 2008 to monitor communications in Afghanistan and Iraq. The system localizes and characterizes interference as a weather event or an enemy attack.[67] The US military has a similar capability with RAIDRS Block 10, which is currently operating in the Middle East with a prototype system and will begin full operations in 2011.[68] The DOD also approved a $9.2-million contract with General Dynamics for the development of improved satellite encryption methods, which should be completed and ready for production by late 2009.[69]

Laser satellite communications links remain an ongoing interest for both increasing data transfer rates and improving security. A private German company, Tesat-Spacecom, tested laser communications technology between two satellites over several months beginning in February 2008 using the German TerraSAR-X radar satellite and US Near Field Infrared Experiment (NFIRE) satellite. The two exchanged data at speeds of 5.5 gigabits per second, nearly one hundred times faster than conventional radio communication links.[70] The link was maintained for twenty-minute increments, at straight-line distances between 2,000 and 8,000 kilometers.[71] Future tests are planned between satellites and ground stations in Germany and Spain. These tests will produce a different set of challenges, since laser communications suffer losses due to physical obstacles such as atmospheric particles and clouds.[72] Development of the technology has taken more than ten years. Similar efforts by the US military continued to face ongoing technical and budgetary challenges in 2008 (see "TSAT" under Space Support for Terrestrial Military Operations Trend 5.1).

2008 Space Security Impact

Efforts to secure the network safety of critical infrastructure, which includes satellite command and control stations, reflects the interdependence of security in space with other terrestrial security issues and the complexity of defending against potential threats. These efforts are positive insofar as they reduce the number and severity of network attacks; encourage international cooperation, currently limited to NATO members; and enable governments to keep pace with innovations in cyber attacks. Laser communication technologies continue to offer the promise of better protection for ground-to-satellite communications, which is one of the most prevalent sources of attacks on space system. But progress remains slow and is currently focused on satellite-to-satellite transmissions. Efforts to improve the security of both computer networks and communications links demonstrate the spiral effect of protection-negation dynamics in space, where capabilities to improve one lead actors to improve the other.

Trend 6.3: Protection of satellites against some direct threats is improving but remains limited

Although a less likely occurrence than interference with satellite ground stations or communications links, direct interference of satellites by conventional, nuclear, or directed energy weapons is much more difficult to defend against. In this case, the primary source of protection for satellites stems from the difficulties associated with launching an attack of conventional weapons into and through the space environment to specific locations.

There are inherent protection elements associated with the space environment. For example, energy weapons must overcome atmospheric challenges and be effectively targeted at satellites, which orbit at great distances and move at very high speeds. Also, the distances and speeds involved in satellite engagements can be exploited to enhance protection. Satellites in lower altitude orbits are more difficult to detect with space-based infrared sensors because of their proximity to the Earth's atmosphere. Lower orbits are also less predictable because of greater atmospheric effects, such as fluctuations in density in the upper atmosphere, which alter satellite drag. For example, at an altitude of about 800 kilometers the predictability of orbits is limited to an error of approximately one kilometer one day in advance of the calculation, using readily available models. Higher operational orbits also raise the power demands for terrestrial radars, leaving only optical systems capable of tracking satellites in altitudes beyond 5,000 kilometers. The fact that LEO can be reached in a matter of minutes, while GEO takes about a half-day to reach by completing a Hohmann transfer orbit, illustrates the unique protection dynamics associated with different orbits.[73] Some military systems are being placed into higher orbits such as Medium Earth Orbit (MEO) or GEO, but orbits are largely dictated by function. Surface finishes and designs optimized for heat dissipation and radar absorption can also reduce the signatures of a satellite and the ability to observe it, further complicating negation targeting efforts, such as the US stealth satellite program Misty (cancelled in 2007).[74] But if an actor has the ability to overcome these natural defenses, there are few ways to physically protect a satellite against a direct attack.

Protection against conventional weapons

Efforts to protect satellites from conventional weapons, such as kinetic hit-to-kill, explosive, or pellet cloud methods of attack, assume that it is almost impossible to provide physical hardening against such attacks because of the high relative velocities of objects in orbit. As previously discussed, however, the difficulty of attacking into and maneuvering through space facilitates the protection of satellites from conventional weapons threats. For example, tests of the Soviet co-orbital ASAT system in the 1960s and 1970s were limited to two opportunities a day, when the longitude of the interceptor launch site matched that of the target satellite. This introduced an average delay of six hours between a decision to attack a satellite in LEO and the launch of an interceptor.

Once an interceptor has been launched toward a satellite, it has committed a significant amount of its limited fuel to a specific attack strategy. Evasive maneuvers by the targeted satellite can force an interceptor to expend valuable fuel and time in reorienting its line of attack. While such defensive maneuvers require valuable fuel mass and few satellites carry extra fuel specifically for this purpose, all operational satellites have some fuel allocated to maintain their orbital positions, known as "station keeping," in case of natural orbital disturbances. These evasive maneuvers must only be large enough to avoid the weapons effects or target acquisition range of the interceptor,[75] but the extra fuel required might represent more than 10-20 percent of the satellite cost.[76]

An interceptor is also vulnerable to deception by decoys deployed from a target. For example, an interceptor's radars could be deceived by the release of a cloud of metal foil known as chaff, its thermal sensors could be spoofed by devices imitating the thermal signature of the satellite, or its sensors could be jammed.[77]

Dispersing capabilities is a well established practice in terrestrial conflict that can be applied to satellite operations.[78] Dispersion both increases the number of targets that must be negated to affect a satellite system, and increases system survivability through the use of a constellation. The US Defense Advanced Research Projects Agency (DARPA) is developing a project called System F6, which seeks to research, develop, and test a satellite architecture where the functionality of a single satellite is replaced by a cluster of free-fly subsatellites that wirelessly communicate with each other.[79] Each subsatellite of the system can perform a separate function or duplicate the function of another module, making the constellation less vulnerable to electronic or physical interference.

Redundancy in satellite design and operations offers a number of protection advantages. Since onsite repairs in space are not cost-effective, satellites tend to employ redundant electronic systems to avoid single point failures. Many GEO communications satellites are also bought in pairs and launched separately into orbit to provide system-level redundancy. In general, however, there is currently little redundancy of commercial, military, or civilian space systems, particularly of the space-based components, because of the large per-kilogram cost of launch, but operators are starting to address this weakness.

Greater dependence on space systems is motivating system redundancy. China, the European Space Agency (ESA) and the EU, Japan, and India are developing satellite navigation systems that will decrease dependency on US GPS. Constellations of satellites such as the US GPS are inherently protected by redundancy, since the loss of one satellite might reduce service reliability but not destroy the entire system. But additional systems can provide additional reliability, particularly if they are interoperable. Thus far, however, only the US GPS and ESA/EU Galileo systems are designed to be interoperable (see Civil Space Programs and Global Utilities Trend 3.4).[80]

Over the longer term, more active measures such as automated on-orbit repair and servicing capabilities may be able to further improve the survivability of space systems. Technology developments currently taking place include the DARPA/NASA Orbital Express program, which launched two spacecraft in 2007 to test automated approach and docking, fuel transfer, and component exchange.[81] If successful, future on-orbit servicing could enable greater maneuverability for defensive purposes and extend the life of satellites.

The US is also exploring other options for more active, direct protection of satellites, including the DARPA Tiny, Independent, Coordinating Spacecraft (TICS) program, in which 10-pound satellites could be quickly air launched by fighter jets to form protective formations, shielding larger satellites from direct attacks.[82] This program was cancelled in the FY2009 budget.[83] Both on-orbit servicing and formation shields such as TICS, however, would also have notable capabilities for negation if used against an uncooperative foreign satellite[84] (see Space Systems Negation). Further, as space-based protection capabilities become more active, they may become indistinguishable from negation capabilities, particularly because many space-based kinetic threats cannot be countered except with a preemptive attack.[85] Such measures could also create large amounts of space debris.

Protection against nuclear attack

Electronics are the foundation of satellite communications networks, and the threat of an Electromagnetic Pulse (EMP) attack, which would involve an "instantaneous, intense energy field that can overload or disrupt at a distance numerous electrical systems and high technology microcircuits," through a nuclear explosion or focused microwaves is a growing concern. Currently, the best protection from a High Altitude EMP (HEMP) event is hardening those electronics that provide essential services, in conjunction with surge protectors, which may provide an ability to withstand a HEMP blast.[86] When combined with redundancy of critical components, however, this type of protection is expensive and not practical for any but the most sensitive of military satellites.

Early space protection efforts undertaken by the US and the USSR during the Cold War were aimed at increasing the survivability of strategically important satellites in the face of nuclear attack. US systems such as the DSP early warning, Defense Satellite Communications System communications, and GPS navigation satellites were all hardened against the radiation and EMP effects of nuclear weapon detonations, as are all current generation military satellites of advanced space actors. Robust production lines, the use of satellite constellations, and responsive launch readiness contributed to the survivability of the USSR's space capabilities from nuclear attack. Both the US and Russia maintain hardening to protect against a HAND on their military assets, as do the UK and France. It is not clear from open sources whether other states employ such measures.

Radiation hardening enables satellites to withstand the effects of nuclear weapons through the use of radiation-tolerant components and automatic sensors designed to switch off non-essential circuits during a nuclear detonation. Photovoltaic or solar cells, employed as power sources in many satellites and particularly vulnerable to radiation effects, can be replaced by nuclear reactors, thermal-isotopic generators, or fused silica-covered radiation-resistant solar cell models built with gallium arsenide.

Alternatively, EMP shielding protects sensitive satellite components from the voltage surges generated by the reactions of nuclear detonations with the environment and the internal voltages and currents generated when X-rays from a nuclear detonation penetrate a satellite.[87] Technical measures to protect satellites from external EMP effects include: 1) metal shields and conductive coatings to prevent EMP radiation from entering satellite cavities, 2) linking and grounding of the exterior components of a satellite to create a Faraday cage that will prevent transmission of EMP radiation to interior components, 3) grounding straps and surge arresters to maintain surfaces at the same electrical potential, and 4) microwave filters that isolate internal satellite electronics from external electromagnetic radiation. The use of graphite composites instead of aluminum construction panels can further reduce the number of liberated electrons capable of disrupting components. Electro-optic isolators, specialized diodes, and filters can also be used to shield internal satellite circuits.

Scintillation and blackout measures can be used to avoid the disruption and denial of communications between satellites and their ground stations caused by nuclear detonations that generate an enhanced number of charged particles in the Earth's radiation belts. Protection against these communications failures can be provided by crosslink communications to bypass satellites in a contaminated area and enable communications via other satellites. Higher frequencies that are less susceptible to scintillation and blackout effects, such as EHF/SHF (40/20 gigahertz), can also be used.

As well as focusing on protective measures, the US is examining options to reduce the duration of atmospheric ionization in the case of a HAND. The High Frequency Active Auroral Research Program (HAARP) facility in Alaska has one of the few ionospheric heaters in the world. It can protect satellites by emitting radio waves to mitigate the effects of a HAND.[88]

Most commercial spacecraft must install radiation hardening to guarantee lifespan (typically 15 years) and include automated switch-off and recovery modes that protect systems from natural radiation events, such as solar flares. Generally, commercial satellites are not specifically protected from the EMP effects that would result from a HAND. However, some commercial spacecraft components may have some limited protection from radiation because they were made with materials developed to military specifications. Any physical protection normally creates an increased cost and it seems unlikely that the space industry will harden its satellites without significant prompting and subsidies from governments. Protection measures vary in cost; for example, hardening against the radiation effects of a nuclear detonation is estimated to be about two to five percent of satellite costs, while hardening against the EMP effects of a nuclear detonation can be up to 10 percent of satellite costs.[89]

The US is pursuing technologies other than hardening to reduce the damaging long-term radiation belts caused by a HAND. HAARP includes research on active measures to reduce the concentration of ionic particles in the upper atmosphere following a HAND.[90] Such measures would reduce the probability of satellite malfunction in the aftermath of a HAND.

Protection against a directed energy attack

The simplest form of directed energy weapon makes use of a ground-based laser directed at a satellite to temporarily dazzle or disrupt sensitive optics. Optical imaging systems on a remote sensing satellite or other sensors, such as the infrared Earth sensors that are part of the attitude control system of most satellites, would be most susceptible to laser interference. Because the attacker must be in the line of sight of the instrument, opportunities for attack are limited to the available territory below the satellite. A more advanced directed energy attack designed to degrade or damage sensitive optical or thermal imaging sensors requires higher laser powers (see Space Systems Negation). Protection measures that address these threats include: 1) laser sensors, mechanical shutters, or spectral or amplitude filters to protect from intense laser illumination; 2) the use of multiple imaging frequencies, including those attenuated by atmospheric absorption, to reduce the effectiveness of the laser weapon itself; and 3) the use of indirect imaging angles to avoid direct ground-based laser illumination. While such measures can help to prevent permanent damage, they may require a temporary disruption of the satellite's functions.

Highly advanced lasers capable of damaging other satellite subsystems through heating or shock continue to require higher power. Vulnerable subsystems include solar panels and some electronics. Protection can be provided by ablative coatings and isolated shields on the exterior of spacecraft; the use of spin stabilization to dissipate heat; and the selection of power generation technology other than photovoltaic cells, which can be damaged by lasers.[91] The US Air Force is developing a coating for critical system components that would offer some kind of protection from directed energy weapons such as lasers.[92] While the technology is being developed primarily for ground-based assets and missiles, the coating could offer an inexpensive way to protect satellites from energy attacks. The use of higher orbits also provides significant protection from this type of attack because of the distances involved; modest shields in GEO can prevent the destruction of a non-imaging satellite by laser heating.[93] Protection against microwave weapons, which use high-powered short pulse beams to degrade or destroy unprotected electronics, can be provided by over-voltage and over-current protection circuits within a satellite's receivers.

The US currently leads in developing technology to protect from directed energy attack. But commercial satellites typically lack protection from laser or microwave attack. Besides the US, only France and Russia are known to employ means such as higher orbits or spectral filtering on remote sensing satellites to provide protection from directed energy attacks.

2008 Developments

US, Canada, and Sweden experiment with formation flying, which could support dispersion techniques to reduce the vulnerability of satellite systems

DARPA's Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange (System F6) program, which seeks to replace the functionality of a single satellite with a cluster of satellites, awarded an initial $38.5-million in contracts to Boeing, Lockheed Martin, Northrop Grumman, and Orbital Sciences in 2008.[94] The initial stage involves testing the technologies needed for a fractionated spacecraft, including wireless communication, distributed computing, wireless power transfer, autonomous cluster navigation, and an econometric analysis to determine value.

The Canadian Advanced Nanospace Experiment 4 and 5 are a pair of nanosatellites designed to demonstrate formation flying. The two satellites are intended to adjust their relative position and orientation via a communication link to maintain several different configurations.[95] Similarly, the Swedish Prisma project is expected to be launched in 2009 into low, sun-synchronous orbit to test new technologies for formation flying and rendezvous.[96]

The use of smaller satellites to provide operational requirements in outer space, as well as the use of defensive clusters of satellites or the inclusion of space-based backup systems, could provide passive defensive measures to direct attacks in space by making systems less vulnerable and even deterring potential aggressors. These programs could also contribute to protection measures such as the rapid repair of space systems described in Trend 6.4.

2008 Developments

US pursues technology enablers for on-orbit repair

In 2008 Alliance Spacesystems, the prime contractor for the DARPA/National Research Laboratory's Front-End Robotics Enabling Near-Term Demonstration (FREND) program, completed development, testing, and delivery of the robotic arm to be used for spacecraft servicing.[97] The next phase in the development of the arm will see it used in integrated mission rehearsals, such as an autonomous grappling of objects representative of satellite hardware. The program offers the ability to salvage inoperable space assets via an autonomous rendezvous satellite and to reposition operating satellites that do not have the ability to maneuver on their own. However, on-orbit servicing technology such as the FREND program also raises potential anti-satellite concerns should approaching an enemy satellite and tampering with its hardware become possible. FREND was allocated $10.7-million in the FY2009 budget.[98]

A slightly different repair-enabling capability is being explored by the Fast Access Spacecraft Testbed (FAST) under DARPA's Tactical Technology Office. The goal of the program is to demonstrate a High Power Generation Subsystem that can be combined with electric propulsion systems for "light weight, high-power, highly mobile spacecraft."[99] According to DARPA such a system could enable satellites to be affordably launched to LEO and to self-transfer to GEO, with enough fuel remaining to perform a range of missions, including on-orbit servicing and space situational awareness. In 2008 Boeing won a contract to develop the first phase of the program, which was allocated $12-million in the defense budget.[100] However, an ability to easily maneuver through large distances in space, particularly by small satellites that are difficult to detect, can also provide the basis for negation activities against other satellites.

2008 Space Security Impact

Capabilities that would enable actors to disperse the function of a single large satellite into a cluster of smaller satellites are progressing and would contribute to security in space by reducing the vulnerability of space-based components, which would no longer rely on a single spacecraft. However, other security challenges, such as the ability to safely manage traffic in space, could increase. While enabling technologies to repair damaged spacecraft on-orbit through new propulsion, maneuvering, docking, and grappling capabilities is progressing, it remains a longer-term potential. As capabilities to protect satellites on-orbit become more active, however, there is a potential for them to be used against non-cooperative spacecraft. The long-term impact on space security will depend greatly on how technologies are used and how transparent usage is. Moreover, space-based protection capabilities could still be defeated by a determined actor, raising the potential for a spiral of protection and negation capabilities in space.

Trend 6.4: Efforts to develop capacity to rapidly rebuild space systems following direct attacks, but no operational capabilities

The capability to rapidly rebuild space systems in the wake of a space negation attack could reduce vulnerabilities in space. It is assumed that actors capable of operating a satellite are also able to recover from an electronic attack since such attacks do not, in most cases, cause permanent damage. It is also assumed that space actors have the capability to rebuild satellite ground stations. This assessment examines capabilities to rebuild space systems by launching new satellites into orbit in a timely manner to replace satellites damaged or destroyed by a potential attack. Although efforts are under way to enable rapid recovery, no actor currently has this capability.

During the Cold War the USSR and the US led in the development of economical launch vehicles capable of launching new satellites to repair space systems following an attack. The USSR/Russia has launched less expensive, less sophisticated, and shorter-lived satellites than those of the US, but has also launched them more often. Soviet-era pressure vessel spacecraft designs, still in use today, have an advantage over Western vented satellite designs that require a period of out-gassing before the satellite can enter service.[101] In principle Russia has the capacity to deploy redundancy in its space systems at a lower cost and to allow quicker space access to facilitate the reconstitution of its systems. Indeed in 2004 Russia conducted a large military exercise that included plans for the rapid launch of military satellites to replace space assets lost in action.[102] A significant number of Russia's current launches, however, are of other nations' satellites; Russia continues to struggle to maintain existing military systems in operational condition. Thus little redundancy is actually leveraged through this launch capability.[103]

The US leads in formal efforts to develop responsive space capabilities. In 2007 the DOD's Operationally Responsive Space (ORS) Office was opened at the Kirtland Air Force Base in New Mexico to coordinate the development of hardware and doctrine in support of ORS across the various agencies.[104] ORS has three main objectives: 1) Rapid Design, Build, Test with a launch-ready spacecraft within 15 months from authority to proceed; 2) Responsive Launch, Checkout, Operations to include launch within one week of a call-up from a stored state; and 3) Militarily Significant Capability to include obtaining images with tactically significant resolution provided directly to the theater. New launch capabilities form the cornerstone of this program. Indeed the USAF Space Command's *Strategic Master Plan FY06 and Beyond* notes, "An operationally responsive spacelift capability is critical to place timely missions on orbit assuring our access to space."[105] Several programs, including Falcon, address this concern.[106] Initial steps include a Small Launch Vehicle subprogram for a rocket capable of placing 100 to 1,000 kg into LEO on 24-hours notice for under $5-million; however, the program is ultimately linked to a long-term prompt global strike capability.[107] Under this program AirLaunch LLC was asked to develop the QuickReach air-launch rocket and SpaceX to develop the Falcon-1 to fulfill the SLV requirements.[108] The USAF TacSat microsatellite series is also intended for ORS demonstration, combining existing military and commercial technologies such as imaging and communications with new commercial launch systems to provide "more rapid and less expensive access to space."[109] A full ORS capability could allow the US to replace satellites on short notice,[110] enabling rapid recover from space negation attacks and reducing general space system vulnerabilities.

The concept for a US Space Maneuver Vehicle or military space plane first emerged in the 1990s as a small, powered, reusable space vehicle, operating as an upper stage of a reusable launch vehicle.[111] Two technology demonstrators have been built: the X-40 (USAF) and the X-37A (NASA/DARPA).[112] India is working on a similar design, the Reusable Launch Vehicle, which is not anticipated before 2015.[113] The commercial space industry is contributing to responsive launch technology development through advancements with small launch vehicles, such as the Falcon-1, developed by Space Exploration Technologies (see Commercial Space Trend 4.2).

Interest is increasing in the development of air-launched microsatellites, which could reduce costs and allow rapid launches as they do not require dedicated launch facilities. The Russian MiG-launched kinetic energy anti-satellite weapon program was suspended in the early 1990s, but commercial applications of similar launch methods continue to be explored. As early as 1997 the Mikoyan-Gurevich Design Bureau was carrying out research, using a MiG-31 to launch small commercial satellites into LEO.[114] The Mikron rocket of the Moscow Aviation Institute's Astra Centre, introduced in 2002, was designed for launch from a MiG-31 and is capable of placing payloads of up to 150 kg into LEO.[115] The US has been using the Pegasus launcher, first developed by Orbital Sciences Corporation in 1990, to launch military small payloads up to 450 kg from a B-52 aircraft.[116] Other efforts include the China Aerospace Science and Technology Corporation (CASC) plan to launch small payloads released from a modified H-6 bomber.[117]

2008 Developments

US, China, and France developing more capable microsatellites and rapid launch technologies

The US ORS Office lost its first satellite on 3 August 2008, when the Falcon-1 launch vehicle developed by the private company SpaceX failed for the third time. The launch, called "Jumpstart," was intended to "demonstrate that a spacecraft bus can be built, tested and integrated in a short period of time"[118] — in this case, seven months from the time that the ORS Office received funding and less than four months after the office chose a contractor for the satellite and the launch vehicle. Launch of Tactical Satellite 3 (TacSat-3), a satellite developed by the Air Force Research Laboratory to demonstrate the functionality of small satellites controlled directly by military officers in the field, was also delayed following technical difficulties.[119] Nonetheless, the Office is moving forward with additional plans to develop a rapid launch capability, which include experiments toward launches with as little as six days' notice, and experiments on TacSat-5, which will feature SASSA (see Trend 6.2).[120]

In other developments, Air Launch, which is under contract from DARPA and NASA, has claimed that its QuickReach rocket is capable of placing a 454-kg satellite into orbit from a C-17 airplane, in less than 24 hours' notice. The cost of such a launch would be approximately $5-million, compared to between $30-million and $100-million for a typical launch. However, the last portion of the DARPA/Air Force SLV program concluded in 2008 when AirLaunch conducted a series of test firings,[121] and the company is now grounded by a lack of funding. Research on new launch technologies is also under way. LaunchPoint is working with the US military to research a magnetic ring launcher that would be capable of launching smaller satellites into orbit for approximately $75,000 per launch and be able to launch satellites at a rate of one per day. The Electromagnetic Systems Division at the University of Texas at Austin is researching a combination of air launch and magnetic technologies called a railgun for nanosatellites.[122]

China is also working to develop more capable microsatellites for military and other space missions, and a classified "Shenlong air-launched booster designed for drop from a Chinese H-6 badger bomber for smallsat launch operations."[123] Similarly, in 2008 Dassault Systems, which manufactures France's Rafale fighter jet, revealed new details of its concept to use the fighter jet as a responsive space capability to launch small, 150-kilogram payloads up to 800 kilometers in orbit. Dassault has been working with the French civil space agency CNES on the concept for four years, and some interest has reportedly been shown by the French military.[124] As with US air-launch capabilities, including the Pegasus and the planned QuickReach, there is a possibility that these could be used to support the covert deployment of space-based anti-satellite capabilities.

2008 Space Security Impact

The ability to quickly launch new satellite systems, reconstitute damaged or failed components, or upgrade existing capabilities contributes to space security by reducing the vulnerability of space systems to environmental threats and natural degradation of capabilities and deterring potential attacks on space components. When combined with microsatellite constellations that can replace a single satellite (Trend 6.3), the longevity of the constellation is increased immeasurably. Relatively inexpensive systems are being developed to launch smaller satellites. As with most space technology, however, they could be used for other purposes, including the covert launch of space-based anti-satellite systems.

Space Systems Negation

This chapter assesses trends and developments related to the research, development, testing, and deployment of physical capabilities to negate the use of space systems, which includes Earth-to-space and space-to-space interference, as well as electromagnetic and cyber attacks. The focus here is on technical capabilities and *not* the intent of actors to use them. This chapter also assesses the development of space surveillance capabilities, which is a key enabling technology for space systems negation.

Space systems negation efforts can involve taking action from the ground or from space against the ground-based components of space systems, the communications links to and from satellites, space launchers, or satellites themselves. Negation can be achieved through the application of cybernetic or electronic interference, conventional weapons, directed energy (lasers), or nuclear capabilities used to carry out what are often referred to in the US as the five Ds: deception, disruption, denial, degradation, and destruction.

Many space negation capabilities apply to widely proliferated military equipment, technology, and practices. These include conventional attacks on ground stations, hacking into computer systems, jamming satellite communications links, using false radio transmissions (spoofing), or simple camouflage techniques to conceal the location of military space assets.

Space negation capabilities that involve attacks on satellites themselves are more sophisticated. With the exception of ground-based laser dazzling or blinding, a basic launch capability is required to directly attack a satellite. Space surveillance capabilities are also required to effectively target satellites in orbit. Some space-based negation techniques require highly specialized capabilities, such as precision maneuverability or autonomous tracking.

Degradation and destruction can be provided by conventional, directed energy, or nuclear anti-satellite (ASAT) weapons.[1] Conventional anti-satellite weapons include precision-guided kinetic-intercept vehicles, conventional explosives, and specialized systems designed to spread lethal clouds of metal pellets in the orbital path of a targeted satellite. A space launch vehicle with a nuclear weapon would be capable of producing a High Altitude Nuclear Detonation (HAND), causing widespread immediate electronic damage to satellites, combined with the long-term effects of false radiation belts, which would have an adverse impact on many satellites in low Earth orbit (LEO).[2]

Space Security Impact

Space systems negation capabilities are directly related to space security since they *enable an actor to restrict the secure access to and use of space by other actors*. The dynamics of space negation and space protection are closely related. For example, robust space negation efforts will likely succeed in the face of weak protection measures. Like other offense — defense relationships in military affairs, this space negation–protection dynamic raises concerns about an arms race and instability as actors compete for the strategic advantages that space negation capabilities appear to offer. Different negation activities are likely to stimulate different responses.[3] While interruption of communications links would probably not be viewed as very provocative, physical destruction of satellites would be more likely to trigger an arms race.

Soviet and US concerns that early warning satellites be protected from direct attack as a measure to enhance crisis management were enshrined in bilateral treaties such as the Strategic Arms Limitation Talks and the Anti-Ballistic Missile treaties (see Laws, Policies, and Doctrines). Recent space war games have also underscored the challenges generated by space negation efforts focused on "blinding" the strategic communications and attack warning capabilities of an adversary.[4]

These security concerns are compounded by the fact that many key space capabilities are inherently dual-use. For example, space launchers are required for many anti-satellite systems; microsatellites offer great advantages as space-based kinetic-intercept vehicles; and space surveillance capabilities can support both space debris collision avoidance strategies and targeting for weapons.

It is noteworthy that the application of some destructive space negation capabilities, such as kinetic-intercept vehicles, would generate space debris that could potentially inflict widespread damage on other space systems and undermine the sustainability of space security (see The Space Environment 1.1). Similarly, a HAND is indiscriminate in its effects and would generate long-term negative impacts on space security. These concerns have led some experts to argue that carefully targeted space negation efforts may have a positive impact on space security if such efforts prevent the targeted actor from using space systems to inflict widespread, long-term damage to the space environment or otherwise prevent access to space.

Trend 7.1: Capabilities to attack ground stations and communications links are widely spread

The most vulnerable components of space systems are the ground stations and communications links, which are susceptible to attack from widely accessible weapons and technologies. An attack on the ground segments of space systems with conventional military force is one of the most likely space negation scenarios. Only modest military means would be required for system sabotage; physical attack on the ground facility by armed invaders, vehicles, or missiles; and interference with power sources.

The US leads in developing advanced technologies to temporarily negate space systems by disrupting or denying access to satellite communications. The Department of Defense (DOD) "Counterspace Systems" budget line item has had steady funding for early-stage research and technology development of offensive programs "to disrupt, deny, degrade or destroy an adversary's space systems, or the information they provide, which may be used for purposes hostile to US national security interests."[5] In 2004 the mobile, ground-based CounterCom system, designed to provide temporary and reversible disruption of a targeted satellite communications signals, was declared operational.[6] An upgrade to this system was initiated in 2007 to fully equip two squadrons with seven jamming systems, up from the original two.[7] Next-generation jammers also under development will have "enhanced capabilities for SATCOM denial" using largely commercially available components.[8]

The US "Space Control Technology" program seeks to "continue development and demonstration of advanced counter-communications technologies and techniques…leading to future generation counter-communications systems and advanced target characteristics."[9] The mission description for this program notes that, "consistent with DoD policy, the negation efforts of this program focus only on negation technologies which have temporary, localized, and reversible effects."[10] The 2004 *Presidential Directive on Space-Based Positioning, Navigation and Timing Systems* calls for development of capabilities to selectively deny, as necessary, GPS and other navigation services.[11]

Although the US has the most advanced capabilities, abilities for electronic and information warfare, including hacking into computer networks and electronic jamming of satellite communications links, are widely available. Cited as "one of the most persistent jamming events ever recorded in the commercial satellite sector," jamming by Libyan nationals of Thuraya Satellite Telecommunications mobile satellite communications, in an effort to disrupt the activities of smugglers of contraband into Libya, lasted more than six months.[12] Reports emerged in November 2007 that China had deployed advanced GPS jamming systems on vans throughout the country.[13] Incidents of jamming the relatively weak signals of GPS are not new. Iraq's acquisition of GPS-jamming equipment during Operation Iraqi Freedom in 2003 suggests that jamming capabilities are proliferating through commercial means; the equipment was reportedly acquired from a Russian company, Aviaconversiya Ltd.[14] The US CounterCom system is largely based on commercially available components.[15]

Reported incidents of electronically jammed media broadcasts include interruptions to US broadcasts to Iran,[16] Kurdish news broadcasts,[17] and Chinese television.[18] Computer networks linked to communications systems have also been the targets of attack.[19] Commercial proliferation of these capabilities means that non-state actors are increasingly able to launch attacks on communications links. For example, in 2007 a group of hackers based in Indonesia collected data being transmitted by an older, unidentified commercial satellite.[20] It is often difficult to determine if satellite interference conducted by individual attackers is state-sponsored.

2008 Developments

US and China pursuing cyber attack capabilities

As with electronic jamming, cyber attacks that target information networks can interrupt or gain access to the data that space systems provide, or interfere with communications, command, and control systems. While the major cyberspace focus in the US is on promoting defensive capabilities (see Space Systems Protection Trend 6.2), efforts are also under way to improve the military's ability to launch cyber attacks. Under a draft doctrine "Cyberspace Operations -- Air Force Doctrine Document 2-11," the US policy of freedom of action in space is extended to cyberspace. Accordingly, "freedom of action... can be seen as freedom from attack and freedom to attack."[21] The classified Comprehensive National Cybersecurity Initiative, created by a presidential directive in January 2008 and approved by the US Congress under the Office of the Director of National Intelligence, with the Department of Homeland Defense and National Security Agency, aims to better protect federal computer networks and engage in online attacks.[22] The exact cost of this classified program is unknown, but estimates put it in the billions of dollars, with part of the funding coming from the Defense Advanced Research Projects Agency (DARPA) to create an electronic range where new forms of electronic attack can be tested.[23]

Although there are still plans to create a separate Cyber Command, they were temporarily put on hold in August 2008 and its duties were transferred to the US Air Force Space Command.[24] Although smaller, the unit will still include capabilities to launch online attacks.[25] A new training program has been unveiled to recruit operators and specialists capable of launching network-based attacks.[26] However, the extent of US offensive capabilities in cyberspace is still being debated.[27]

The People's Liberation Army (PLA) of China is also supporting knowledge of basic electronic warfare.[28] While there appear to be spiraling capabilities for both launching and defending against cyber attacks, this form of temporary and reversible negation against space systems is, for the time being, less damaging to security and stability in space than kinetic attacks against space hardware.

2008 Developments

States vulnerable to cyber attacks by individuals

Concerns about cyberspace security reflect a growing number of high-level security breaches, which are increasingly the result of individual hackers rather than state actors. Network attacks on the Pentagon raised concerns about Chinese cyber warfare capabilities because initially the attacks appeared to originate from China.[29] There is no evidence that connects the Chinese PLA to these intrusions, but they may be unofficially state-sponsored (sometimes called 'grey forces') or state-tolerated. For example, the Red Hacker Alliance is "a loosely affiliated group of as many as 400,000 hackers with primarily financial aims, which may be tolerated by the Chinese government for information purposes."[30] Alternatively, domestic hackers, masquerading as foreign agents through a method known as 'spoofing', may be responsible for the breaches. Detecting the source of such attacks is very difficult since the systems launching the attacks may not be aware of them.

Between 8 and 12 August 2008, at the beginning of the conflict between Russia and Georgia, Georgian government websites, including those of the Ministry of Foreign Affairs, the Defense Ministry, and the National Bank were targeted by distributed denial-of-service attacks. While initial speculation suggested that Russia was the culprit, it seems now that the attacks were likely the doing of independent nationalists, or grey forces.[31] This type of network attack, which requires technical knowledge but relatively little hardware or funds, illustrates a significant vulnerability of states to individual or 'rogue' actors, who are anonymous and difficult to trace, and thus difficult to respond to.

2008 Space Security Impact

Although cyber attacks in 2008 did not appear to target space systems, they nonetheless represent a growing threat to space security as capabilities to launch them are spreading and improving, in what is becoming a protection-negation spiral (see Space Systems Protection Trend 6.2). For now, cyber attacks are less damaging than kinetic or other physical attacks, since they are generally temporary and reversible. They can, however, seriously disrupt a nation's ability to respond to a more damaging attack, and so should not be taken lightly. Because there have been few known past events, data on the impact of cyber attacks is scarce and the full impact of such a breach is unknown. Moreover, because individuals, often anonymous, as well as states can interfere with this facet of space security, the consequences could be both more complex and destabilizing.

Trend 7.2: US leads in the development of space surveillance capabilities that can support negation

Driven by Cold War security concerns the US and USSR were pioneers in the development of space surveillance capabilities. Today a growing number of space actors are investing in space surveillance to facilitate debris monitoring, satellite tracking, and near Earth object (NEO) detection, but this is also a key enabling technology for space systems negation since tracking and identifying targeted objects in orbit are prerequisites to most negation techniques.

The US explicitly links space surveillance with its space control doctrine and desire to achieve "space situational awareness" (SSA). The 2001 *Quadrennial Defense Review Report* stated that the US would "pursue modernization of the aging space surveillance infrastructure, enhance the command and control structure, and evolve the system from a cataloging and tracking capability to a system providing space situational awareness."[32] Space control is defined by the US Air Force (USAF) as "combat, combat support, and combat service support operations to ensure freedom of action in space for the United States and its allies, and when directed, deny an adversary freedom of action in space."[33]

The US Space Surveillance Network (SSN) is the primary provider of space surveillance data. It has limited capabilities to provide real-time data collection, however. Restrictions were updated on the distribution of the data in the 2004 Defense Authorization Act,[34] in part because of concerns about satellite security.[35] The Space Situational Awareness Integration Office was created in 2002 within USAF Space Command, with responsibilities to oversee the integration of space surveillance to achieve space situational awareness.[36] Space-based surveillance, first demonstrated by the US through the Space Visible Sensor experiment, decommissioned in 2008,[37] is being pursued through the Space-Based Surveillance System (SBSS), described in the 2003 *Transformation Flight Plan* as "a constellation of optical sensing satellites to track and identify space forces in deep space to enable defensive and offensive counterspace operations."[38] The $823.9-million program is designed to collect real-time data and track other satellites in geostationary orbit (GEO) from its location in LEO, using "an optical telescope that is highly responsive to quick tasking orders, allowing it to shift from target to target quickly in space."[39] A pathfinder SBSS satellite is set for launch in 2009.[40] The Canadian military Sapphire satellite, scheduled to launch in 2011, is also intended to contribute space-based surveillance data to the US SSN.[41] Funding issues have hampered efforts to improve US space surveillance. In 2006 the US DOD cancelled the Orbital Deep Space Imager program, intended to develop satellites that would "provide a predictive, near real-time operating picture of space to enable space control operations" in GEO, citing budgetary constraints.[42]

Although the US maintains the most capable space surveillance system, Russia continues to have relatively extensive capabilities in this area; and China and India have significant satellite tracking, telemetry, and control assets essential to their civil space programs. China is reportedly upgrading its Xi'an Satellite Monitoring Center, the primary control center for China's network of 20 ground monitoring stations and six satellite tracking ships.[43] Upgrades include increased orbit determination and capabilities to track domestic and foreign satellites, which could be used to target negation activities against space-based assets.[44] The satellite intercepted by China on 11 January 2007 was tracked and targeted from this center.[45] Canada, France, Germany, Japan, and the UK are all actively expanding their ground- and space-based space surveillance capabilities (see The Space Environment Trend 1.3).

The French space surveillance radar GRAVES has detected between 20 and 30 satellites in LEO that are not listed in the official US Defense Department satellite catalog, but are assumed to be US military satellites. French officials have claimed that they have enough information to determine the size, location, orbit, and transmitting frequency of the unlisted satellites.[46] Capable of detecting spacecraft as small as one meter in diameter,[47]GRAVES has detected and categorized more than 2,200 objects since it became operational at the end of 2005. The GRAVES system, together with similar systems in Germany and the UK, may contribute to a future European Space Surveillance system.[48]

2008 Developments

US space surveillance and tracking data enable destruction of a failed satellite, as global efforts to improve access to such data continue

The US considers SSA to be a central component of its space control (both defensive and offensive) efforts,[49] and space surveillance data can support both protective and potential negation capabilities, depending on how the data is used. The US demonstrated an ability to integrate the data with command and control systems when tracking data from the US SSN was used to engage the failed US-193 satellite with an anti-missile system on 20 February 2008 (see Trend 7.3 below). As more detailed, tactical-level data becomes available, the capability to use it for potential negation activities will continue to increase. For example, the new $30-million Self-Awareness Space Situational Awareness (SASSA) program, intended to provide data on possible anti-satellite attacks by identifying environmental and potential anti-satellite anomalies in space (see Space Systems Protection),[50] does not call for equipping satellites with their own countermeasures, but the possibility of integrating them in the future exists. Other ongoing improvements to space surveillance data in the US include upgrades to the SSN, particularly the Space Fence network of ground-based sensors. Upgrades to the Space Fence have been delayed and underfunded for several years; however, the US Air Force plans a massive upgrade in 2008 at a cost of over $1-billion to track objects as small as five centimeters in diameter in medium Earth orbit (MEO).[51]

Other efforts to develop space surveillance capabilities include one by the European Space Agency (ESA), which approved a $62.8-million SSA program over three years that includes development of a data security and data-release policy, a study of space weather and near-Earth objects, work on a ground-based tracking radar, and design of space surveillance data centers (see Space Systems Protection Trend 6.1).[52] China also upgraded its space tracking and telemetry capabilities in 2008 by adding a new, sixth Yuanwang space tracking ship in advance of its human spaceflight and spacewalk mission in September 2008. Previous human spaceflight missions have relied on the use of four of these ships for tracking and support, but the new ship was also deployed in 2008 to monitor space walks.[53]

2008 Space Security Impact

Space surveillance capabilities can be used to both enhance and degrade security in outer space, but activities in 2008 seemed to favor positive impacts (see Space Environment Trend 1.3 and Space Systems Protection Trend 6.1). The US engagement of a de-orbiting satellite in 2008 demonstrates the applicability of surveillance data to negation, but also the fact that such capabilities are used far more extensively to support civil space efforts such as human spaceflight, mitigate the risk of collision with debris, and manage space traffic. Nonetheless, the potential for independent space surveillance capabilities to support deliberate attacks against satellites and other space objects, demonstrated through the centrality of space surveillance in identifying foreign satellites, space control efforts, and close proximity operations, is one of the obstacles preventing access to the more precise data that is needed for some of the more protection-oriented functions listed above.

Trend 7.3: Ongoing proliferation of ground-based capabilities to attack satellites

As noted in Figure 7.1 a variety of American and Soviet/Russian programs during the Cold War and into the 1990s sought to develop ground-based weapons that employed conventional, nuclear, or directed energy capabilities against satellites.

Figure 7.1: History of ground-based anti-satellite demonstrations[54]

System	Actor	Dates	No. of Intercepts	Description of program
Bold Orion air-launched ballistic missile	US	1959, single test	0	Air-launched ballistic missile passed within 32 kilometers of the US Explorer VI satellite
SAtellite INTerceptor (SAINT)	US (USAF)	1960-1962		
Idea abandoned in the late 1960s	0	Designed as a co-orbital surveillance system, the satellite could be armed with a warhead or 'blind' the enemy satellite with paint		
Program 505	US (US Army)	1962-1964	1?	Nike-Zeus nuclear-tipped anti-ballistic missile system employed as an ASAT against orbital vehicles
Program 437	US (USAF)	1963-1975	1?	Nuclear-armed Thor ballistic missile launched directly into the path of the target
Co-orbital (IS) ASAT	USSR	1963-1972,		
1976-1982	12?	Conventional explosives launched into orbit near target, detonated when within range of one kilometer		
Polaris submarine launched ASAT	US (US Navy)	1964-late 1960s	?	Submarine-launched ballistic missile fitted with tracking sensors and launched into orbit as satellite passed overhead to detonate a warhead filled with steel pellets in satellite's path
Laser ASAT	USSR	1975-1989	0	Sary Shagan and Dushanbe laser sites reported to have ASAT programs
Air-Launched Miniature Vehicle	US (USAF)	1982-1987	1	Missile launched from high-orbit F-15 aircraft to destroy satellite with a high-speed collision
MiG-31 Air-launched ASAT	USSR	1980-1985	?	Exploration of kinetic-kill ASAT to be launched from MiG-31 aircraft, never tested
MIRACL Laser	US (USAF)	1989-1990 Tested in 1997 though not acknowledged as an ASAT test	1	Megawatt-class chemical laser fired at satellite to disable electronic sensors
Ground-Based Kinetic Energy ASAT	US (US Army)	1990-2004	0	Kinetic-kill vehicle launched from the ground to intercept and destroy a satellite
* Medium-range ballistic missile-based kinetic energy ASAT	China (PLA)	2007-	1	Destroyed the Feng Yun 1C weather satellite on 11 January 2007
†Modified Standard Missile-3 launched from the Aegis Ballistic Missile Defense System (not a dedicated anti-satellite program)	US (US Navy)	N/A	1	Single engagement of the failed, de-orbiting US-193 satellite that resulted in the kinetic intercept and consequent destruction of the satellite on 20 February 2008

* The Chinese government states that the intercept of the Feng Yun 1C satellite was a scientific experiment and not an anti-satellite test or demonstration

† The US government states that the engagement of the US-193 satellite was done to protect populations on Earth, and that the modification of the system was a one-time occurrence that has been reversed.

Conventional (kinetic intercept) weapons

Launching a payload to coincide with the passage of a satellite in orbit is the fundamental requirement for a conventional anti-satellite capability. Twenty-eight actors have demonstrated suborbital launch capabilities; 10 of this number have demonstrated an orbital launch ability (see Civil Space and Global Utilities Trend 3.1). Tracking capabilities would allow a payload of metal pellets or gravel to be launched into the path of a satellite by suborbital rockets or missiles (such as a SCUD missile).[55] Kinetic hit-to-kill technology requires more advanced sensors to home in on the target. Targeting satellites from the ground using any of these methods would likely be more cost-effective and reliable than space-based options.[56]

USAF *Counterspace Operations* Doctrine Document 2-2.1 outlines a set of "counterspace operations" designed to "preclude an adversary from exploiting space to their advantage… using a variety of permanent and/or reversible means."[57] Among the tools for offensive counterspace operations, the document lists direct ascent and co-orbital ASATs, directed energy weapons, and electronic warfare weapons. The US Army invested in ground-based kinetic energy ASAT technology in the late 1980s and early 1990s. The small, longstanding Kinetic Energy ASAT program was terminated in 1993 but was later granted funding by Congress in FY 1996 through FY2005.[58] Congress appropriated $14-million for the KE ASAT for FY2005 through the Missile Defense Agency's (MDA) Ballistic Missile Defense Products budget.[59] It is part of the Army Counterspace Technology testbed at Redstone Arsenal.[60] The US has also deployed a limited number of ground-based exoatmospheric kill vehicle (EKV) interceptors, including the Aegis (Sea-Based Midcourse) and Ground-Based Midcourse Defense Systems, for ballistic missile defense purposes.[61] EKVs use infrared sensors to detect ballistic missiles in midcourse and maneuver into the trajectory of the missile to ensure a hit to kill.[62] With limited modification, the EKV could be used against satellites in LEO.[63] Japan is the largest international partner with the US on ballistic missile defense, and has its own Aegis system. In 2007 a Japanese destroyer successfully performed a sea-based midcourse intercept against an exoatmospheric ballistic missile target.[64]

Russia's only dedicated anti-satellite system is the Co-Orbital ASAT system, designed to launch conventional explosives into orbit near a target satellite via a missile, which maneuvers toward the satellite, then dives at it and explodes.[65] Russia has continued to observe a voluntary moratorium on anti-satellite tests since its last test in 1982. The precise status of its system is not known, but it is most likely no longer operational.[66] Russia has also developed a long-range (350-kilometer) exoatmospheric missile, the Gorgon, for its A-135 anti-ballistic missile system.[67]

China has developed an advanced kinetic anti-satellite capability, demonstrated by the intentional destruction of a Chinese weather satellite in 2007 using what is believed to be a vehicle based on a medium-range, two-stage, solid-fuelled ballistic missile, possibly the DF-21.[68] But China called the event an experiment, not an anti-satellite test.[69] China is not believed to currently have enough interceptors for a full ASAT system that could destroy multiple satellites in LEO, although it could produce more.[70] The UK, Israel, and India are also exploring techniques for exoatmospheric interceptors.[71]

Nuclear weapons

A nuclear weapon detonated in space generates an electromagnetic pulse that is highly destructive to unprotected satellites, as demonstrated by the US 1962 Starfish Prime test.[72] Given the current global dependence on satellites, such an attack could have a devastating and wide-ranging impact on society. As noted above, both the US and USSR explored nuclear-tipped missiles as missile defense interceptors and ASAT weapons. The Russian Galosh ballistic missile defense system surrounding Moscow employed nuclear-tipped interceptors from the early 1960s through the 1990s.[73]

China, the member states of ESA, India, Iran, Israel, Japan, Russia, and the US possess space launch vehicles capable of launching a nuclear warhead into orbit, although placing weapons of mass destruction in outer space is prohibited by the Outer Space Treaty. North Korea and Pakistan are among the 18 states that possess medium-range ballistic missiles that could launch a mass equivalent to a nuclear warhead into LEO without achieving orbit.

Eight states are known to possess nuclear weapons: China, France, India, Israel, Pakistan, Russia, the US, and the UK. North Korea has an ongoing nuclear program and attempted to detonate a nuclear device in 2006.[74] Iran reportedly ended its nuclear weapons program in 2003, but the International Atomic Energy Agency continues to investigate potentially illegal uranium enrichment activities.[75]

Directed energy weapons

All states have access to low-powered lasers, which could be used to "dazzle" unhardened satellites in LEO, and many may already have the capability to use low-power lasers to degrade unhardened sensors on satellites in LEO.[76] In 1997 a 30-watt laser used for alignment and tracking of a target satellite for the mega-watt US Mid-Infrared Advanced Chemical Laser (MIRACL) was directed at a satellite in a 420-km orbit, damaging the satellite's sensors.[77] This suggests that even a commercially available low-watt laser functioning from the ground could be used to "dazzle" or temporarily disrupt a satellite.[78] In addition, several actors are developing ground-based lasers, adaptive optics, and tracking systems that would allow laser energy to be accurately directed at a passing satellite. Low-power beams are useful for ranging and tracking satellites, while high-energy beams are known to cause equipment damage. Adaptive optics is a technology that enables telescopes to rapidly adjust their optical components to compensate for distortions. This technology could be applied to produce detailed images of satellites. Ground- and aircraft-based lasers could also use the same technologies to maintain the cohesion of a laser beam as it travels through the atmosphere, enabling more energy to be delivered on target at a greater distance. There is worldwide interest in adaptive optics research and development, and a number of industrial countries such as Canada, China, Japan, Russia, the US, and India are involved.[79] Actors that are developing laser satellite communications systems, such as France, Germany, and Japan, also inherently have the ability to track and direct a laser beam at a satellite.

Several actors have demonstrated the technical ability to generate relatively high-powered laser beams. Both Israel and the United States have developed prototypes of laser systems that are capable of destroying artillery shells and rockets at short ranges. The potential of high-energy lasers to be used against satellites has been extensively explored by the US, the USSR/Russia, and China. The megawatt-class MIRACL laser system is able to dazzle and blind sensors in GEO and heat to kill electronics on satellites in LEO — a significant ASAT capability. Similarly the USAF Starfire Optical Range at Kirtland Air Force Base in New Mexico is undertaking laser experiments under the Advanced Weapons Technology program that have been characterized as "experiments for application including antisatellite weapons" and called for a demonstration of "fully compensated beam propagation to Low-Earth orbit satellites" in the FY2007 budget request. Funding was only authorized after the USAF denied any intent to test Starfire against a satellite.[80] The Airborne Laser (ABL) currently under development in the US is central to plans for future Boost Phase Ballistic Missile Defense.[81] This technology is assessed by some experts to have ASAT capabilities; however, ongoing technical and cost challenges mean that it is far from being an operational weapon.[82] The ABL program was initiated in 1996 and took 12 years to reach first light, at a cost of $5-billion.[83] The first ballistic missile interception is planned for late 2009.[84] Other US High Energy Laser projects include the Joint High Power Solid State Laser (JHPSSL), intended to accelerate the development of solid state lasers for military use.[85]

China operated a high-power laser program as early as 1986 and is now believed to have multiple hundred-megawatt lasers.[86] The government is also devoting resources to high-power solid state laser research[87] and Chinese researchers are studying adaptive optics to maintain beam quality over long distances and the use of solid state lasers in space; both technologies could be used against satellites.[88] In 2006 China reportedly used a ground-based laser to illuminate an American reconnaissance satellite flying over Chinese territory.[89] It is difficult to verify from public sources the nature of the laser beam, the physical effects on the spacecraft, or the intent behind the illumination.[90] South Korea is also interested in developing laser systems for use against North Korean missiles and artillery shells, and hopes to begin deployment of a system in 2010.[91] Japan is interested in developing an air- and ground-based laser system for ballistic missile defense (BMD). The Japanese Ministry of Defense planned to request funding for research and development for a ground-based system in its FY2008 budget and it is also interested in participating in the US ABL program.[92] Indian defense scientists are also reportedly experimenting with “high-power laser weapons.”[93]

A summary of the technologies that are required to support the development of ground-based capabilities to attack satellites is provided in Figure 7.2 below.

Figure 7.2: Technologies required for the development of ground-based capabilities to attack satellites

Capabilities	Conventional			Directed energy			Nuclear
	Pellet cloud ASAT	Kinetic-kill ASAT	Explosive ASAT	Laser dazzling	Laser blinding	Laser heat-to-kill	HAND
Suborbital launch	☐	☐	☐				☐
Orbital launch	☐	☐	☐				☐
Precision position/ maneuverability		☐					
Precision pointing				☐	☐	☐	
Precision space tracking (uncooperative)	☐	☐			☐	☐	
Approximate space tracking (uncooperative)			☐	☐			☐
Nuclear weapons							☐
Lasers > 1 W				☐			
Lasers > 1 KW					☐		
Lasers > 100 KW						☐	
Autonomous tracking/ homing		☐					

Key:
☐ = Enabling capability

2008 Developments

US reconfigures anti-missile system to destroy a failed satellite as it de-orbits

On 20 February 2008 the US engaged a failed satellite in a decaying orbit as it descended toward Earth’s atmosphere using a modified Standard Missile-3 (SM-3) from the Aegis Ballistic Missile Defense system. The satellite, USA-193 operated by the US National Reconnaissance Office, had failed shortly after its 2006 launch and, according to the US government, posed a safety concern on Earth because of the large amount of toxic hydrazine fuel that it carried.[94] In what the US Navy called "a one-time event,"[95] modifications were made to the radar and other sensor networks to enable a Raytheon SM-3 missile to reach a greater vertical distance to destroy the satellite before it reentered Earth's atmosphere. Launched from the USS Lake Erie, the missile intercepted the satellite 247 kilometers above the surface of the Earth, igniting the fuel tank and shattering the satellite into small fragments, as confirmed by spectral analysis.[96] US government officials briefed other governments about their intentions prior to the event. The engagement demonstrated an ability to reconfigure the SM-3 missile for use against a satellite in LEO.[97] However, US government officials have stated that it was not part of an anti-satellite development and testing program, and that the system has returned to its original configuration.[98]

For additional information, see Space Environment Trend 1.1 and Space Laws, Policies, and Doctrines Trend 2.1.

2008 Developments

Ongoing efforts to improve missile technology globally may enable anti-satellite capabilities

The US continues to develop and test new technologies for ballistic missile defense that could enable a capability to intercept satellites in orbit. The MDA requested an increase of almost $700-million in funding for FY2009, in part because of more ambitious plans for the Kinetic Energy Interceptor (KEI) program.[99] However, the US Congress approved only $341.8-million of the $386.8-million requested for KEI, stipulating a need for an independent study of the feasibility and practicality of the system.[100] Tests of the KEI first-stage motor by contractor Northrop-Grumman in 2008 were reportedly successful, and a full test that includes the second-stage motor is planned for 2009.[101] Although originally intended to provide a boost-phase intercept capability, the program is now focused on midcourse intercepts,[102] potentially enabling use against objects in outer space.

Iran attempted three rocket launches in 2008, demonstrating its advancing rocket launch capabilities. The first launch of the Safir expendable launch vehicle in a test called Kavoshgar-1 on 4 February 2008 coincided with the inauguration of a new space center west of Tehran. Iran claimed that the rocket reached an altitude of 200 kilometers before returning to Earth[103] and that the two-stage rocket would be used to launch Iran's first scientific satellite in 2009.[104] The second firing of the rocket on 17 August 2008, with what appears to be an indigenously developed second-stage propulsion system, may have been an attempt to launch a satellite.[105] Western intelligence sources claim that the rocket broke apart shortly after launch.[106] A third launch called Kavoshgar-2 was conducted on 26 November 2008. Iranian state media claim that the rocket carried a space lab and a data monitoring and processing unit and that it "completed its mission and returned to earth with a special parachute after 40 minutes,"[107] but this has not been corroborated. The rocket did not achieve orbit. There are concerns that Iran's civilian space launch program is also contributing to its long-range ballistic missile program, which would use similar technology and likely shares the same launch site.[108] Currently Iran is only able to negate space systems by launching ballistic missiles.

Iran and North Korea have long cooperated on missile technology. In 2008 *Jane's Defence Weekly* analyzed commercial satellite imagery that indicated that North Korea has continued to pursue a ballistic missile and space launch program despite what was thought to have been a declining indigenous capability. Imagery revealed a second, previously unknown launch facility on North Korea's west coast, which is believed to have been under construction for the past eight years. The facility did not appear complete in these images, which showed a

Figure 7.3: Ballistic missiles with a range over 1,000 km by country[113]

COUNTRY	SYSTEM NAME	STATUS	RANGE (KM)	PAYLOAD (KG)
		Asia		
China	CSS-2 (DF-3/3A)	Operational	2,650/2,900	2,150
	CSS-3 (DF-4)	Operational	5,500	2,200
	CSS-4 (DF-5/5A)	Operational	12,000/13,000	
	CSS-5 (DF-21)	Operational	1,800	600
	DF-25	Operational	1,700	2,000
	CSS-9 (DF-31)	Operational*	8,000	700
	DF-31A	Operational**	12,000	800
	CSS-N-3 (JL-1) (SLBM)	Operational	2,500	500
	CSS-NX-5 (JL-2) (SLBM)	Operational?	2,000-8,000	1050-2,800
India	Agni-II	Operational	2,000/2,500	1,000
	Agni-III114	Testbed	3,200	?
North Korea	Nodong	Operational	1,300	700-1,000
	Taepodong I	Testbed? †	1,500-2,000	1,000
	Taepodong II115	Testbed	6,700	1,000
Pakistan	Ghauri I (Hatf V/Nodong)	Operational	1,300	500-750
	Ghauri II	Operational	1,500-2,000	700
	Shaheen II	Operational	2,000/2,500	750-1,000
		Russia and United States		
Russia	SS-18 (Satan, or R-36M)	Operational	9,000-11,000	8,800
	SS-19 (Stiletto, or UR-100N)	Operational	10,000	4,350
	SS-24 (Scalpel, or RT-23)	Operational	9,000-11,000	8,800
	SS-25 (Sickle, or Topol)	Operational	10,500	1,000-1,200
	SS-27 (Topol-M)	Operational	10,500	1,000-1,200
	SS-N-18 (Stingray, or Volna) (SLBM)	Operational	6,500	1,600
	SS-N-23 (Skiff, or Shtil) (SLBM)	Operational	8,300	2,800
United States	Minuteman III (MK-12/12A)	Operational	9,650+	1,150
	Trident II (D5) (SLBM)	Operational	7,360+	2,800
		Europe		
France	M-45 (SLBM)	Operational	6,000	?
	M-51116	Operational	6,000	?
United Kingdom	Trident II (D5) (SLBM)	Operational	7,360+	2,800
		Middle East		
Iran	Shahab III	Operational	1,300	750-800
	Ashoura	Operational?	2,000?	?
Israel	Jericho III	Operational?‡	3,000-6,500	1,000-1,300
Saudi Arabia	Dong Feng-3 (CSS-2)Ω	Operational	2,500	2,150
	Dong Feng 3A117	Operational	2,800	2,150

* Limited deployment according to DOD Report to Congress on PRC military power
** Limited deployment according to DOD Report to Congress on PRC military power
† Possible testbed for multistage missile technologies. Involved in the satellite launch attempt in 1998
‡ Not explicitly mentioned in newspaper article http://www.haaretz.com/hasen/spages/945859.html
Ω Imported from China

moveable launch pad, a static engine test stand, a vehicle-process building for pre-launch preparations, a high bay processing building, and 17 support buildings.[109] According to *Jane's*, the site will be able to support launches of both ballistic missiles and space launch vehicles. Previous satellite launch attempts in 1998 and 2006 failed.[110]

On 17 December 2007 Japan conducted its first successful test of the midcourse Aegis Ballistic Missile Defense System, acquired from the US, against a ballistic missile target.[111] The test was followed in November 2008 by a second, unsuccessful test.[112] This system was modified by the US to intercept a failed, de-orbiting satellite (see above).

2008 Developments

US laser program for missile defense continues, but feasibility not proven

Initiated in 1996, the ABL for boost-phase missile defense reached "first light" on 8 September 2008, when it was fired from the nose of a grounded Boeing 747-400F aircraft following $5-billion in development costs.[118] Another test on 1 December 2008 marked the first test of the entire integrated weapon system, including the beam control/fire control system, against a simulated ballistic missile.[119] In February 2008 Northrop Grumman, Lockheed Martin, and BAE Systems were each awarded $1-million contracts over four months for phase one in the development of the Advanced Tracked Illuminator Laser, part of the targeting assistance system for the ABL, and Northrop Grumman was awarded a contract for phase two.[120] Although $401.2-million in funding was authorized for the ABL for FY2009, the program was subjected to an independent study of its feasibility and practicality.[121]

In a separate development, Northrop Grumman Space Technology test fired its solid-state laser at a power of 30-kilowatts in 2008. The laser is being developed as part of the Joint High-Power Solid-State Laser (JHPSSL) program along with one designed by Textron. The laser is intended to be capable of firing at 100-kilowatts, a milestone anticipated in 2008 but delayed to 2009.[122] The program is developing lasers to be used across ground, air, and sea military services and is a candidate for the US Army's High-Energy Laser Technology Demonstrator program, which will mount a laser system to a vehicle for use against rockets and artillery.[123] A power of 100 kilowatts is generally viewed as the threshold for a 'weapons grade' laser, although lasers as low as 30-watts in power have been known to damage satellites.

Work on lasers is ongoing at the USAF Starfire Optical Range, which received $44.5-million for 2009.[124] Indicators suggest that the facility is researching the development of ground-based lasers that could be used against satellites.[125] Attempts to create laser weapons systems for missile defense have been ongoing since 1976 and continue to face challenges.[126]

2008 Space Security Impact

The US engagement of the de-orbiting USA-193 satellite demonstrates the ability to reconfigure an interceptor missile, even if only for a one-time event, for use against a satellite, raising the prospect of greater insecurity in space as more actors research and develop anti-missile systems. Increased global interest in missile and anti-missile capabilities has an uncertain effect on the security of outer space. While it is potentially threatening and destabilizing and could trigger an arms race targeting space, some assess it as a valuable deterrent against the use of force in space because it creates mutual vulnerabilities. The development of high-energy lasers can have the same uncertain impact, but this uncertainty is aggravated by the fact that lasers can be used in a wide range of space activities, including tracking objects in space, and they can be much more easily used covertly or without warning.

Trend 7.4: Increased access to space-based negation enabling capabilities

Deploying space-based ASATs, whether using kinetic-kill, directed energy, or conventional explosive techniques, would require enabling technologies somewhat more advanced than the fundamental requirements for orbital launch. Many of these technologies could be advantageous for a variety of civil, commercial, or non-negation military programs, but microsatellites, maneuverability, and other autonomous proximity operations are essential building blocks for a space-based negation system. A summary of the existing capabilities of key space actors that are considered enabling technologies for the development of space-based ASATs is provided in Figure 7.4.

Space-based weapons targeting satellites with conventional explosives, referred to as “space mines,” could employ microsatellites to maneuver near a satellite and explode within close range. Relatively inexpensive to develop and launch and with a long lifespan, a microsatellite’s purpose would be difficult to determine until detonation and, because of its small size, a space-mine microsatellite would be hard to detect, particularly if launched discreetly.

Microsatellite technology has become widespread, involving an array of civil, military, commercial, and academic actors. In 2000 the partnership between China and Surrey Satellite Technology Ltd. of the UK saw the launch of the Tingshua-1 microsatellite and companion Surrey Nanosatellite Application Platform to test on-orbit rendezvous capabilities.[127]

A variety of ongoing US programs are developing advanced technologies that would be foundational for a space-based conventional anti-satellite program, including maneuverability, docking, and onboard optics. The USAF Experimental Spacecraft System (XSS) employs microsatellites to test proximity operations, including autonomous rendezvous, maneuvering, and close-up inspection of a target. XSS-11 was launched in 2005 and flew successful repeat rendezvous maneuvers. The fact that the program is linked to the Advanced Weapons Technology element of the budget suggests that it could evolve into an ASAT program.[128]

The MDA Near-Field Infrared Experiment (NFIRE), designed to provide support to ballistic missile defense, at one point was planning to employ a kill vehicle to encounter a ballistic missile at close range, with a sensor to record the findings. However, in 2005 MDA cancelled the kill vehicle experiment after Congress expressed concerns about its applicability to ASAT development.[129] In 2006 the US launched a pair of Micro-satellite Technology Experiment (MiTEx) satellites into an unknown geostationary transfer orbit. The MiTEx satellites are technology demonstrators for the Microsatellite Demonstration Science and Technology Experiment Program (MiDSTEP) sponsored by DARPA, the USAF, and the US Navy. A major goal of the MiTEx demonstrations is to assess the potential of small satellites in GEO for defense applications.[130] Another missile defense technology that could enable space systems negation would be the space-based interceptor (SBI) (see Space-Based Strike Capabilities Trend 8.1).[131]

Figure 7.4: Enabling capabilities of key actors for space-based kinetic-energy ASATs*

Capability	China	EU/ESA	France	UK	India	Israel	Japan	Russia	Ukraine	US
Space launch vehicles										
Land – Fixed[132]	X	X	X		X	X	X	X	X	X
Land – Mobile[133]	L		L	L	L	L		X	L	X[134]
Sea	L[135]							X[136, 137]	X[138]	X[139]
Air								D[140]		X[141]
Space tracking (uncooperative)										
Optical (passive)	X[142]	X	X[143]	X[144]			X[145]	X[146]		X[147]
Radar	X[148]		X[149]	X[150]			X[151]	X[152]		X[153]
Laser[154]	X	X	X	X		X	X	X	X	X
Autonomous rendezvous										
Cooperative		D[155]						X[156]		D[157]
Uncooperative		D[158]						F[159]		D
Proximity operations										
Cooperative		D[160]								X[161]
Uncooperative		D[162]								X[163]
High-g, large-△V upper stages	X	X	X	L	D		X	X	X	X
Microsatellite construction	X	X	X	X	X	X	X	X	X	X

Key:
X = Existing capability
F = Flight-tested capability
D = Under development
L = Latent capability

* This figure highlights enabling technologies for space-based kinetic-kill negation capabilities. It does not imply that these actors have such negation systems or even programs to develop them, merely that they have prerequisite technologies that would make acquisition of such a system a shorter-term possibility.

Autonomous rendezvous capacity was also the objective of NASA's Demonstration of Autonomous Rendezvous Technology (DART) spacecraft, relying on the Advanced Video Guidance Sensor and GPS to locate its target.[164] In 2005 the ASAT capability of maneuverable microsatellites was demonstrated when the DART unexpectedly collided with the target satellite and bumped it into a higher orbit.[165] The DARPA Orbital Express program is developing capabilities for on-orbit refueling and reconfiguring, which would also be necessary to maneuver a space-based anti-satellite weapon.

Other US programs developing a range of space-based, dual-use maneuvering, autonomous approach, and docking capabilities include the DARPA/NASA Orbital Express program. In 2007 it demonstrated the feasibility of conducting automated satellite refueling and repair, which would also be necessary to maneuver a space-based anti-satellite weapon.[166] DARPA and the Naval Research Laboratory (NRL) are also developing a space tug capable of physically maneuvering another satellite in orbit under a program called Front-end Robotics Enabling Near-term Demonstration (FREND). It is "designed to allow interaction with geosynchronous orbit (GEO)-based military and commercial spacecraft, extending their service lives and permitting satellite repositioning or retirement."[167] The NRL has developed and ground tested the guidance and control algorithms to enable a spacecraft-mounted robotic arm to autonomously grapple another satellite not designed for docking.[168] And DARPA's Tiny Independent Coordinated Spacecraft (TICS) program was intended to develop 10-pound satellites that could be quickly air launched by fighter jets to form protective formations around larger satellites to shield them from direct attacks. Using advanced robotic technologies, these satellites could potentially be used against non-cooperative satellites. However, this program was cancelled in the FY2009 budget.[169] Although these developing technologies could potentially support space-based anti-satellite systems, many of them also enable space-based means for protecting satellites and are covered more extensively in Space Systems Protection Trend 6.3.

On-orbit servicing is also a key research priority for several civil space programs and supporting commercial companies. Germany is developing the Deutsche Orbitale Servicing Mission, which "will focus on Guidance and Navigation, capturing of non-cooperative as well as cooperative client satellites, performing orbital maneuvers with the coupled system and the controlled de-orbiting of the two coupled satellites."[170] Germany's Spacecraft Life Extension System project plans a satellite "tugboat" to keep satellites in orbit beyond their intended lifespans.[171] The ConeXpress Orbital Life Extension Vehicle being developed by Orbital Recovery is set to be the first commercial satellite specifically designed to rendezvous with a target satellite in GEO. Sweden is developing Europe's first automated rendezvous and proximity operation mission.[172] As well, the mission of Sweden's PRISMA satellite project is to demonstrate technologies for autonomous formation flying, approach and rendezvous, proximity operations, and final approach and recede operations.[173] There is no evidence to suggest that these programs are intended to support space systems negation, but the technologies could conceivably be modified for such an application.

Researchers at Chinese universities are analyzing on-orbit homing and rendezvous methods, although it is unclear whether the research is original and Chinese-initiated or merely a review of previously conducted foreign research.[174]

2008 Developments

A broad range of dual-purpose space-based technologies continue to be developed

A variety of military and civil space programs — particularly maneuverable microsatellites, docking technologies, and rapid launch capabilities — are developing advanced capabilities that could enable space-based activities against other satellite systems. These capabilities can serve many purposes, however, including support of space protection measures (see Trend 6.3 and 6.4). While there is no evidence that the programs outlined below are directed toward weapons capabilities, it is important to understand how they might enable space negation.

Maneuverability and proximity operations

In 2008 China demonstrated a growing capacity for proximity operations when the 35-kilogram BinXiang-1 (BX-1) microsatellite was maneuvered around the Shenzhou spacecraft to take photographs of it during China's human spaceflight mission.[175] Part of the purpose of this maneuver was to test the BX-1's ability to rendezvous and fly in formation with other spacecraft, and to assess its potential use for inspecting larger satellites.[176] However, the BX-1 could not come closer than a few kilometers to another satellite because it did not have the ability to determine relative distances between it and other spacecraft.[177] Analysis does not support claims that BX-1 was intended to simulate a co-orbital anti-satellite capability.[178]

Other programs that are developing maneuverability and proximity operations include DARPA's Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange (System F6) program, which is developing a satellite architecture in which the functionality of a single satellite is replaced by a cluster of satellites that wirelessly communicate with each other.[179] In some ways it is similar to the DARPA TICS program, which was funded in the 2008 budget but cancelled in the 2009 budget.[180] There were concerns that the program's objective to create small satellites that are "hard to detect" can be inserted into "any common operational orbit" with "little or no warning" and include "advanced robotic technologies" that could potentially be used against non-cooperative spacecraft.[181] It is not clear if System F6 would have the same capabilities. Funding for the program was increased in 2008 to $37.3-million from $21-million in 2007.[182] Similarly, DARPA's Fast Access Spacecraft Testbed (FAST) under the Tactical Technology Office, intended to demonstrate a High Power Generation Subsystem combined with electric propulsion systems for "light weight, high-power, highly mobile spacecraft"[183] able to transfer from low Earth to geostationary orbits, could also provide the basis for negation activities against other satellites. The program has been allocated $12-million in the FY2009 defense budget.[184]

The Canadian Advanced Nanospace Experiment 4 and 5 nanosatellites are also designed to demonstrate formation flying.[185] The Swedish PRISMA satelite is expected to be launched in 2009 into low, sun-synchronous orbit to test new technologies for formation flying and rendezvous.[186]

Docking and servicing

The DARPA/NRL's FREND program is developing on-orbit service technology that can grapple and tug objects to salvage inoperable space assets via an autonomous rendezvous satellite, as well as reposition operating satellites that do not have the ability to maneuver on their own.[187] This capability could conceivably be used against other, non-cooperative spacecraft.[188] The ESA also demonstrated its capability to autonomously dock in April 2008 when its Jules Verne Automated Docking Transfer Vehicle (ATV) docked with the International Space Station.[189]

Rapid launch

There is a possibility that small, quick satellite launchers could support the covert deployment of anti-satellite capabilities. Air Launch, which is under contract from DARPA and NASA, has claimed that its QuickReach rocket is now capable of placing a 454-kg satellite into orbit from a C-17 airplane in less than 24 hours. New launch technologies being researched in the US include a magnetic ring launcher and a combination of air launch and magnetic technologies called a railgun for nanosatellites.[190] China is working to develop more capable microsatellites for military and other space missions, and a classified "Shenlong air-launched booster designed for drop from a Chinese H-6 badger bomber for smallsat launch operations."[191] France is considering the use of the Rafale strike fighter to launch small satellites into orbit;[192] this is reminiscent of the Russian MiG-31S's capability to deliver a small payload into LEO.[193]

2008 Developments

US weapons technology programs developing proximity and maneuverability capabilities

The Experimental Spacecraft System (XSS) program uses microsatellites in proximity operations, including autonomous rendezvous, maneuvering, and close-up inspection of a target in LEO. Funding for a third XSS mission was provided in the FY2009 budget at $29.-3-million.[194] The program is linked to the Advanced Weapons Technology element of the budget, suggesting that it could evolve to support an anti-satellite program.[195]

The two MiTEx satellites launched in 2007 as part of MiDSTEP[196] were used in 2008 to inspect and characterize non-cooperative satellites and potential abnormalities following the failure of the US DSP-23 early-warning satellite in geostationary orbit in September 2008.[197] Maneuvering vast distances and conducting up-close rendezvous and inspection of a satellite is a new capability demonstration for the US military. The two MiTEx satellites had been maneuvering around and inspecting each other in GEO when they were dispatched to the failing DSP satellite. The first satellite reached the failed DSP component on 23 December 2008 and the second on 1 January 2009.[198] The MiTEx satellites' significant maneuvering capability and low detection threshold are key features for a co-orbital anti-satellite weapon.[199]

2008 Space Security Impact

The duality of many of the technologies outlined here is clear from their presence in both Space Systems Protection and Space Systems Negation chapters. While microsatellites were initially created to protect space systems, much of their development has been in a range between passive protection and active negation. The largest danger is in the capacity to conduct proximity maneuvers, since the size of such satellites implies that they are difficult to detect and track. However, these capabilities are still very much under development, and the ability of one satellite to approach an uncooperative satellite without notice to conduct an offensive operation is still several years away.

Space-Based Strike Capabilities

This chapter assesses trends related to the research, development, testing, and deployment of capabilities that could support space-based strike systems. Space-based strike systems operate from Earth orbit with the capability to damage or destroy either terrestrial targets (land, sea, or air) or terrestrially launched objects passing through space (e.g., ballistic missiles), via the projection of mass or energy. Earth-to-space and space-to-space strike capabilities, often referred to as anti-satellite (ASAT) weapons, are addressed in the Space Systems Negation chapter. Space systems that support Earth-based strike capabilities, such as reconnaissance satellites, are addressed in Space Support for Terrestrial Military Operations.

Mass-to-target strike systems collide with a target, damaging it through the combined mass and velocity impact of the weapon, or hit a target with inert or explosive devices. One mass-to-target concept is the US missile defense Space-Based Interceptor (SBI), which is designed to accelerate toward and collide with a ballistic missile in its boost phase. Another mass-to-target concept is the hypervelocity rod bundle — an orbital uranium or tungsten rod that would be decelerated from orbit and reenter the Earth's atmosphere at high velocity to attack ground targets.

Energy-to-target strike systems, often called directed energy weapons, transfer energy through a beam designed to generate sufficient heat or shock to disable or destroy a target. This beam could be generated using lasers, microwaves, or neutral particle beams. An example is the US Space-Based Laser (SBL) concept for missile defense. An SBL would attempt to use a satellite to direct an intense laser beam at a missile during its launch phase, heating it to the explosion point. An SBL satellite would require an energy source to power the laser, optical systems to generate the laser, and precise attitude control to point the laser beam accurately at the target for a relatively sustained period of time. The US Missile Defense Agency (MDA) canceled the SBL program in 2000, although some classified work on the concept may be ongoing. [1]

While no space-based strike systems have yet been tested or deployed, the US and the former USSR devoted considerable resources to developing them during the Cold War. The US continues to research supporting technologies within the context of its missile defense program and a vocal minority continues to argue for deployment of such systems. In addition to assessing the status of these dedicated space-based strike programs, this chapter also assesses efforts of space actors to develop key technologies required for space-based strike capabilities, even if they are not being pursued for that purpose. It is generally accepted that only the most advanced spacefaring states could overcome the technical hurdles to deploy space-based strike systems in the foreseeable future, and it is questionable whether they would be effective.[2]

Space Security Impact

Space-based strike systems can have a direct impact on all aspects of space security. An actor with a space-based strike capability, such as an SBI, could use such a system to deny or restrict another actor's ability to access space by attacking its space launch vehicles. Moreover, since some space-based strike systems may also be capable of attacking satellites, they could be used to restrict or deny the use of space assets and could generate additional space debris or electromagnetic interference.

The deployment of a space-based strike system would enable an actor to threaten and even attack actors on Earth with very little warning and would constitute a departure from current practice regarding the military use of space. The psychological effects of such a "Sword of

Damocles" could be far-reaching. It would also raise questions regarding the interpretation of the "use of outer space for peaceful purposes" as enshrined in the preamble of the Outer Space Treaty, which remains a point of contention in space law.[3] It would directly threaten space security since actors would no longer enjoy freedom from space-based threats.

Because actors may seek to offset space-based threats, the deployment of space-based strike systems would most likely encourage the development of anti-satellite weapons and legitimize attacks on space assets in self-defense. Certain normative restrictions and moratoria upon such attacks could be undermined. For rapid response times, strike systems would have to be placed in low earth orbit, making them vulnerable to attack.[4] Further, the testing and deployment of ASAT systems in response to space-based strike installations could generate space debris, undermining the sustainable use of space for all actors over the longer term (see The Space Environment Trend 1.1).

Some argue that space-based strike capabilities may be necessary to protect space systems from attack.[5] Indeed, the protection of satellites and the missile defense potential of space-based strike systems are two of the most commonly cited justifications for their development. As noted in Space Systems Negation, these systems could be used to protect the security of space assets against space negation attacks that might inflict long-term and disproportionate damage to the space environment or otherwise deny access to space. However, it is likely that the concentration of more assets in space will likely result in increased incentive to attack such systems.

Trend 8.1: While no space-based strike systems have been tested or deployed, the US continues to develop technologies behind space-based interceptors for its missile defense system

No known integrated space-based strike systems have been tested or deployed.[6] The most advanced space-based strike effort during the Cold War focused primarily on the development of mass-to-target weapons. In the 1960s the USSR developed the Fractional Orbital Bombardment System (FOBS) to deliver a nuclear weapon by launching it into a low Earth orbit (LEO) at 135-150 kilometers in altitude; it would de-orbit after flying only a fraction of one orbit, destroying Earth-based targets.[7] FOBS was not a space-based strike system, although it demonstrated capabilities that could be used in the development of an orbital bombardment system. A total of 24 launches — 17 successful — were undertaken between 1965 and 1972 to develop and test FOBS.[8] It was phased out in January 1983 to comply with the Strategic Arms Limitation Treaty II, under which deployment of FOBS was prohibited. It is not publicly known whether nuclear weapons were orbited through the FOBS efforts.

The US and USSR both pursued development of energy-to-target space-based strike systems in the 1980s, although today these programs have largely been halted. In 1985 the US held underground tests of a nuclear-pumped X-ray laser for the SBL under the Strategic Defense Initiative, although the effort proved unsuccessful and was abandoned. In 1990 the US also performed a Relay Mirror Experiment, which tested ground-based laser re-directing and pointing capabilities for the SBL.[9] In 1987 the USSR's heavy-lift Energiya rocket launched a 100-ton payload named Polyus, which by some reports included a neutral particle beam weapon and a laser. Due to a failure of the attitude control system, the payload did not enter orbit.[10]

The USSR's neutral particle beam experiments were reportedly halted in 1985. The US SBL program was cancelled in 2000 and the SBL office closed in 2002.[11] Although indirect research and development continue through the US MDA, the technology for the SBL does not exist.[12] Approximately $50-million was allocated to both the Department of Defense (DOD) Directed Energy Technology and High Energy Laser Research programs in FY2007; however, Congress cut funding for Laser Space Technology development.[13] Other larger classified budgetary programs are suspected of continuing work on space-based directed energy technologies.[14]

Under Strategic Defense Initiative in the 1980s the US invested several billion dollars in research and development of a space-based strike concept called Brilliant Pebbles. While the program never developed or deployed a fully operational system, the US did test some propulsion and targeting subsystems for Brilliant Pebbles. Research and development efforts in the US for space-based strike capabilities declined in the 1990s, but have been revived since 2000 through the SBI. SBI continues to be the most substantial space-based strike research and development program. The current SBI concept was developed to contribute to missile defense by providing a capability to intercept missiles as they pass through space.

One of the first key tests of US SBI-enabling technologies was the 1994 Clementine lunar mission to test lightweight spacecraft designs "at realistic closing velocities using celestial bodies as targets."[15] It has been succeeded by the US Air Force's Experimental Spacecraft System (XSS) with the objective to develop and demonstrate the capabilities of various microsatellite technologies, although the program has no direct relationship to MDA's SBI program (see Space Systems Negation Trend 7.4). The US Near-Field Infrared Experiment (NFIRE) is designed to include many of the key capabilities required for an SBI, including appropriate sensors, propulsion, and guidance units.[16] However, the US Congress denied the NFIRE system the ability to launch an independent "kill vehicle" to intercept a missile.[17] The US has also completed a phase-one study for the Microsatellite Propulsion Experiment (MPX), which would include two two-stage, anti-missile propulsion units — a key requirement for an SBI capability.[18]

Longer-term US plans include the potential deployment of an SBI testbed.[19] While such a system would have limited operational utility, it could constitute the first deployment of a space-based strike system. A summary of completed and planned US space-based strike-related missions is provided in Figure 8.1.

Figure 8.1: Recent and planned US space missions testing SBI technologies or integrated systems

Mission	Stage	Launch	Agency	Description
Clementine	Complete	1994	DOD & NASA	Tested lightweight sensors at realistic closing velocities using the moon and asteroids as targets
NFIRE	Ongoing	2007	MDA	Testing space-based plume detection and early-warning and tracking capabilities, and missile defense models and simulations[20]
MPX	Planned	N/A	MDA	Two two-stage anti-missile propulsion units
SBI testbed	Planned	2010-2012	MDA	Three to six integrated SBIs as a testbed for a full SBI system

Since its first appearance on the budget request in FY2004 under the Ballistic Missile Defense Interceptor Program, plans for the Space Test Bed have been scaled back financially and the timeline has been extended. The budget request in FY2004 was $14-million with initial tests scheduled for 2008. By FY2005 initial experiments had been pushed back to 2010-

2011. The amount of funding requested has dropped sharply, from $1.5-billion for FY2003 — 2007 to $290-million for FY2007-FY2013, but goals and timelines have remained stable in recent years.[21] The meaning of these budget cuts is not clear. It is possible that the Space Test Bed is receiving more funds from classified accounts or that funding is being diverted to other classified programs. While the program remains on the books, the FY2007 authorization bill prohibited the DOD from using funds for the "testing or deployment of space-based interceptors" until 90 days after submitting to Congress a detailed report on the project, including, inter alia, "an analysis of implication on foreign policy and national security, as well as probable responses from other countries."[22]

While the development of an integrated space-based strike vehicle may be possible within years rather than decades, building a militarily effective strike system with global coverage remains a significant challenge. A truly global system would require hundreds or even thousands of vehicles in orbit, and thus a launch capacity about five to 10 times greater than the current US launch capacity.[23] An examination of the technical feasibility of such a system for missile defense, conducted by the American Physical Society, estimated that launch costs alone for a system covering latitudes that include Iran, Iraq, and North Korea would likely exceed $44-billion.[24] The US Congressional Budget Office estimated the full cost of a system with a similar coverage of the globe, but with the capability to intercept only liquid-fueled ballistic missiles with longer launch timelines, at between $27-billion and $40-billion. Such a system presumed considerable advances in kill vehicle components. Without these advances, coverage would cost between $56-billion and $78-billion.[25]

In summary, no space-based strike systems have been tested or deployed to date, although Cold War-era programs did support considerable development and testing of key technologies. Prohibitive costs and reduced perceived needs led Russia and, to a lesser degree, the US to drastically cut funding for space-based strike programs. More recently the US has pursued the development of SBI in the context of its ballistic missile defense program, although both political and financial challenges to its completion remain.

2008 Development

Funding cut for US Space Test Bed but feasibility study approved

For the second year in a row, the US Missile Defense Agency (MDA) requested $10-million for the Space Test Bed in the FY2009 budget to evaluate the potential for adding a space-based layer to missile defense. The MDA budget request released in February 2008 contained an additional $260-million in planned requests for the Space Test Bed through FY2013.[26] As in previous years, the US Congress did not authorize any funds for the project in the FY09 Defense Authorization Act, citing opposition to the project.[27] However, Congress did authorize $5-million for a space-based interceptor feasibility study to be completed by an independent organization.[28]

2008 Development

Experimental missile defense satellite conducts second successful test of rocket sensor technology

The second major test of NFIRE was conducted on 23 September 2008.[29] The primary Track Sensor Payload is designed to collect both high- and low-resolution imagery from a missile plume using long-, medium-, and short-wave infrared to test a sensor system to observe and differentiate a missile plume from its rocket — a critical piece of data to enable space-based missile defense.[30] Similar to the first test in August 2007, this second test involved the launching of a Chimera missile as a test target from Vandenberg Air Force Base in California. The Chimera, a modified Minuteman II Intercontinental Ballistic Missile, was flown "as close as possible" to the NFIRE satellite, according to the NFIRE project manager for the 1st Air and Space Test Squadron.[31]

The goal of this test was the same as the first: to collect high- and low-resolution images of a rocket under thrust. These images will lead to improved understanding of missile exhaust plumes and, specifically, improved ability to distinguish between the plume and the rocket body itself.[32] While the NFIRE is not a space-based strike vehicle and does not have an interceptor on board, this test was another important milestone in developing the capability of a sensor to discriminate a rocket body from the surrounding exhaust plume, which is needed to enable targeting by such a weapon.

2008 Development

Multiple Kill Vehicle contract awarded

In November 2008 Raytheon was awarded a $441.9-million contract to develop the Multiple Kill Vehicle (MKV), with a contract completion date of 2011.[33] This was in part a response to the FY2008 Defense Appropriations Act in which the US Congress eliminated all funding for the Multiple Engagement Payload (MEP) and directed the Missile Defense Agency to focus on the MKV.[34] Lockheed Martin also has a competing version called the MKV-1 under development, but without a contract from the US military.[35]

In contrast to the MEP, which was being developed for the US Navy's Standard Missile-3, the MKV is being developed for both the midcourse Ground-Based Interceptor (GBI) and boost-phase Kinetic Energy Interceptor (KEI). While the MKV is not a direct component of a space-based strike system, MDA officials in the past have acknowledged that it would be a technology enabler for SBI.[36]

2008 Space Security Impact

The absence of space-based strike systems and infrastructure continued to support the security of outer space in 2008. While precursor technology development continued in the Near-Field Infrared Experiment Test and the Multiple Kill Vehicle program, restraint by US policymakers is positive and indicates concern for space security and the challenges of balancing terrestrial missile defense requirements with the need to maintain freedom from space-based threats.

Trend 8.2: More countries are developing advanced space-based strike-enabling technologies through civil, commercial, and military programs

Due to the potentially significant effects of space-based strike systems on space security dynamics, it is important to assess research into advanced enabling technologies that could support the development of space-based strike capabilities. Of concern here are purely technological capabilities, not the intentions of actors. The enabling technologies described below are multi-purpose. None are related to dedicated space-based strike programs, but are part of other civil, commercial, or military space programs. However, they do bring actors technologically closer to developing such a capability.

The advanced enabling technologies listed in Figure 8.2 are those required for each of the major space-based strike concepts over and above basic space access and use capabilities, such as orbital launch capability, satellite manufacturing, satellite telemetry, tracking and control, mission management, and Earth imaging. This analysis is based on the characteristics of these weapons systems as widely described in open source literature.[37]

Figure 8.2: Advanced space-based strike enabling capabilities*

Capability	Conventional			Nuclear	Directed energy	
	Interceptor	Hypervelocity rod bundle	Munitions delivery	Munitions delivery	Laser	Neutral particle beams
Precision position maneuverability	■	■	■	■		
High-G thrusters	■					
Large Δ-V thrusters	■	■	■	■		
Global positioning	■	■	■	■	■	■
Missile homing sensors	■				■	
Global missile tracking	▲				▲	▲
Global missile early warning	▲				▲	▲
Launch on demand	■	■	■	■	■	■
Microsatellite construction	■					
High-power laser systems					■	
High-power generation					■	■
Large aperture deployable optics					■	
Precision attitude control					■	■
Precision reentry technology		■	■	■		
Nuclear weapons				■		

Key
■ = Required
▲ = Needed but not necessarily on the primary Space-Based Strike Weapon

* This figure highlights enabling technologies for space-based strike. It does not imply that these actors have such strike capabilities or even programs to develop them, merely that they have prerequisite technologies that would make acquisition of such a system a shorter-term possibility.

A **precision position maneuverability** capability to ensure that an object can be moved to a specific location with an accuracy of less than 10 meters has been demonstrated by only a few actors. Both the US and Russia have performed a large number of space dockings that require such capability. The European Space Agency has completed the development of this capability for its Automated Transfer Vehicle, which docked at the International Space Station in 2008. The Chinese manned spacecraft, the Shenzhou series, is also equipped with a docking mechanism.[38]

The US is developing **high-G thrusters** that provide the large acceleration required for the final stages of missile homing for the SBI. No other state is currently assessed to have such a capability. A large delta (Δ)-V thruster capability, which enables the change in velocity required to maneuver in orbit or to de-orbit to reach the target, is fundamental for several space-based strike concepts. This is a relatively common capability that has been demonstrated by all actors with rocket technology, including the states that have demonstrated orbital or suborbital space access.

Accurate **global positioning** capabilities required for all space-based strike concepts are possessed primarily by the US (GPS) and Russia (GLONASS), although the GLONASS system is not fully operational at present. All other actors with space access have some involvement in the development of navigation systems — for example, the planned EU Galileo system, the Chinese Beidou constellation, and the Japanese Quazi-Zenith Satellite System (see Civil Space Programs and Global Utilities Trend 3.4). It is also noteworthy that many actors could make use of the global positioning afforded by the US and Russian systems.

Missile homing sensors, which provide real-time directional information during the missile homing phase required for SBI, are a capability common to most advanced military powers, including the US, Russia, and Israel, which have developed such systems for their ground-based missile defense capabilities. India and Japan are also developing this capability.[39]

Relatively extensive **global missile warning and missile tracking capabilities**, required for SBI and SBL, were developed by the US and the USSR during the Cold War (see Space Systems Protection Trend 6.1). Early warning of missile launches is currently provided by the US Defense Support Program satellites and the Russian Oko and Prognoz satellites; both states are working on upgrades and/or replacements for these systems. The designs for the US Space-based Infrared System-High and Space Tracking and Surveillance System will be more advanced, although both systems are behind schedule.[40] No other states currently have space-based early-warning capabilities, but France is developing two early-warning satellites, Spirale-1 and -2.[41]

Launch vehicles with an operational readiness of less than one week are necessary to provide the launch-on-demand capabilities to maintain an effective global space-based strike system. Russia's capability currently has the shortest average period between launches, but no state yet possesses a launch-on-demand capability. The US is developing a responsive launch capability through its Falcon program.[42] Some commercial actors, in particular Space-X, aim to provide more responsive and less expensive space launches (see Space Systems Protection Trend 6.4).[43] Although US concepts for a military space plane envision launch-on-demand capabilities, physical constraints would limit its utility.[44]

Microsatellite construction, which allows for reduced weight and increased responsiveness of space-based interceptors, is also a key enabling capability for an effective SBI system. China, ESA, France, Israel, Russia, the UK, the US, Canada, and India have developed microsatellites.

The **high-power laser systems** envisioned for an SBL have only been developed to any extent by the US, initially through its SBL effort and more recently through its Airborne Laser, MIRACL, Joint High Power Solid-State Laser (JHPSSL), and Starfire programs (see Space Systems Negation Trend 7.3). All of these efforts face continuing technical challenges. China has also operated a high-power laser program since 1986 and now has multiple hundred-megawatt lasers.[45] The technology does not yet exist to build a high-power space-based laser.[46]

High-power generation systems for space, necessary to power the SBL concept and for high thrust propellants for kinetic strike capabilities, have been developed and deployed both by the US and former Soviet Union, particularly with the use of nuclear power. The US System for Nuclear Auxiliary Power-10A mission launched in 1965 had a 45-kilowatt thermonuclear reactor. NASA is working on several nuclear projects under Project Prometheus.[47] Between 1967 and 1988 the USSR launched 31 low-powered reactors in Radar Ocean Reconnaissance Satellites.[48] While no other states have developed such capabilities for space, all states with a launch capability also have nuclear power programs.

Large deployable optics and precision attitude control — both needed for the SBL concept, and the latter applicable for all space-based strike concepts — have been developed by actors that include China, ESA, France, Japan, Russia, and the US for military reconnaissance or civil astronomical telescope missions.[49] India and Israel are currently developing such capabilities (see Civil Space Programs and Global Space Utilities). China has announced plans for a civilian telescope that will demonstrate precision attitude control capabilities.[50]

Precision reentry technology, needed to prevent burn-up and lateral lift when reentering the atmosphere, for kinetic space-to-Earth strike concepts, has been developed by those states with a human spaceflight capability — China, Russia, and the US. The ESA is developing this capability in its Applied Re-entry Technology program and the joint NASA-ESA Crew Return Vehicle (X-38).[51] France's Centre National d'Etudes Spatiales (CNES) has announced the development of a new reentry vehicle program for civil space purposes.[52] The Japan Aerospace Exploration Agency has some experimental reentry vehicle programs.[53] States with nuclear weapons have also developed precision reentry technologies for their nuclear warhead reentry vehicles. The capabilities needed for a rapid strike from space are more advanced, however, due to the higher speed at which reentry would occur.[54]

Figure 8.3 provides an overview of the space-based strike enabling technologies possessed or under development by key space actors. Included are only those actors that have developed orbital space access, a prerequisite for all space-based strike systems.

2008 Development

Development of the US Prompt Global Strike program continues, but its long-term implications unclear

In the FY2008 Defense Appropriations Act, the US Congress canceled the Conventional Trident intercontinental ballistic missile program and called for the DOD to establish a Prompt Global Strike (PGS) program,[55] the definition of which remains vague. Having received $100-million in FY2008, the US military planned to ask for $118-million for the program in FY2009. Although the DOD continued its plans for implementing PGS in 2008, a report issued by the Government Accounting Office in April 2008 found no comprehensive approach to the PGS mission and cited conflicting studies and interpretations of PGS requirements by different defense stakeholders.[56]

The DOD plans to use the funds allocated for PGS to concentrate on four major areas of research and development: hypersonic glide, alternative reentry systems, test range, and conventional prompt global strike.[57] Although all the military services will participate in these programs, in April 2008 the commander of US Strategic Command assigned coordination of the PGS effort to the US Air Force.[58] In November 2008, the same US official who developed the April 2008 report publicly questioned the national security value of using conventional weapons for PGS and the cost of acquiring such systems.[59]

The US Army's plan for PGS is the Advanced Hypersonic Weapon, a glider that is boosted into orbit by rocket engines. It is projected to be able to deliver a roughly 400-kilogram payload over a distance of 6,000 kilometers.[60] The US Air Force's renamed Falcon program, the Conventional Strike Missile, will serve as its element of PGS.[61] Consisting of a Minotaur commercial space launch booster, modified stages from the retired Peacekeeper ICBM, and a maneuvering vehicle, the CSM will launch like a ballistic missile and then the payload will use hypersonic flight to reach its target.[62]

Although funding for the Conventional Trident Program was cancelled in 2008, in April 2008 the DOD notified Congress that the US Navy plans to conduct a flight test of the Conventional Trident Program in FY2009, while also stating that it plans to abide by the demands of Congress to cancel the program.[63] Some have suggested that the technologies resulting from the testing might not be fielded on the Trident missile.[64]

While it is unlikely that the PGS program will result in the development of a space-based weapon system, several advanced enabling technologies will be developed, including "advanced propulsion, payload delivery and dispensing mechanisms, weapon system command and control, and advanced non-nuclear, kinetic, and other enabling capabilities,"[65] which would be required to support a space-based strike system.[66]

2008 Development

Key actors continue to develop a range of space-based strike enabling capabilities

The developments described above, while not linked to dedicated space-based strike programs, illustrate specialized military space capabilities. However, due to the potentially significant effects of space-based strike systems on space security dynamics, it is important to assess research into advanced enabling technologies that could support the development of space-based strike capabilities that are found in a range of civil, commercial, and military space programs. The enabling technologies described below can support multiple uses although none are related to dedicated space-based strike programs. But, based on the characteristics of weapons systems as widely described in open source literature, it can be judged that these advances bring actors closer to being able to develop such a strike capability.[67]

Figure 8.3: Space-based strike enabling capabilities of key space actors[68]

Advanced capabilities	China	EU/ ESA	France	UK	India	Israel	Japan	Russia	Ukraine	US
Precision position maneuverability	■	■						■		■
High-G thrusters										□
Large Δ-V thrusters	■	■	■	■	■	■	■	■	■	■
Accurate global positioning[69]	□	□			□	□	□	□	□	■
Anti-missile homing sensors			■	■	□	■	■	■		■
Global missile tracking								■		■
Global missile early warning			□					■		■
Launch on demand								□		□
Microsatellite construction	■	■	■	■	■	■	■	■	■	■
High-power laser systems	■									■
High-power generation								(■)		□
Large deployable optics	■	■	■		□	□	□	■		■
Precision attitude control	□	■	■		□	■	■	■		■
Precision reentry technology	■	□	■	■	□			■		■
Nuclear power	■		■	■	■	■	■	■	■	■
SBSW										
Space-based laser								(□)		(□)
Space-based interceptors								(□)		□
Hypervelocity rod bundle										
SB munitions delivery (conventional)										
Neutral particle beam								(□)		(□)

Key
■ = Some capability[70]
□ = Capability under development
(□) = Past development
(■) = Past capability

2008 Space Security Impact

Space-based weapons designed to strike terrestrial targets will require sophisticated technological developments that, at present, few spacefaring states seem able or willing to exploit. The development of dual-use capabilities that also provide enabling technologies for space-based strike systems continued in 2008, although there is no evidence that states are developing such capabilities for strike purposes. Nonetheless, the potential for space-to-Earth strike systems will continue to pose a challenge to the international community as advanced space-based technologies continue to be developed. While some enabling technologies for space-based strike are discrete and include significant technology barriers, many are advanced technologies associated with other space applications and have been developed for a variety of purposes by several different actors. If one actor were to pursue a space-based strike capability, others could follow.

Space Security Working Group Meeting

Institute of Air and Space Law, McGill University
Montreal, Quebec, Canada
5-6 May 2009

Participants

Gerard Brachet
Académie de l'Air et de l'Espace/Air and Space Academy (France)

Richard Bruneau
Foreign Affairs and International Trade Canada

Jasmin Cheung-Gertler
Foreign Affairs and International Trade Canada

Paul Dempsey
McGill University (Canada)

Karl Doetch
Doetch International Space Consultants (Canada)

Jamie Gibson
National Defence (Canada)

Peter Hays
Eisenhower Center for Space and Defense Studies (US)

Niklas Hedman
United Nations Office for Outer Space Affairs

Lars Hostbek
Ministry of Defence (Sweden)

Feng Jiehan
Wuhan University (China)

Catherine Marchetti
National Defence (Canada)

Jonathan McDowell
Harvard College Observatory (US)

Philip Meek
United States Air Force, Ret.

Sridhara Murthi
Antrix Corporation (Department of Space)

Xavier Pasco
Fondation pour Recherche Strategique (France)

Claudio Portelli
Italian Space Agency

Audrey Schaffer
US National Security Space Office

Lucy Stojak
M.L. Stojak Consultants/Faculty, International Space University (Canada)

Mike Taylor
US Air Force Space Command

Richard Tremayne-Smith
NTL World (UK)

Carsten Wiedemann
Institute of Aerospace Systems (Germany)

Pearl Williams
Foreign Affairs and International Trade Canada

Jaisha Wray
US Department of State

Spacesecurity.org Members

Taylor Binnington
University of Guelph

Catherine Doldrina
McGill University

Wade Huntley
University of British Columbia

Ram Jakhu
McGill University

William Marshall
NASA-Ames Research Center

Eugene Miakinkov
University of Waterloo

Amanda Mowle
McGill University

Kshama Nargund
McGill University

John Siebert
Project Ploughshares

Brian Weeden
Secure World Foundation

Jessica West
Project Ploughshares

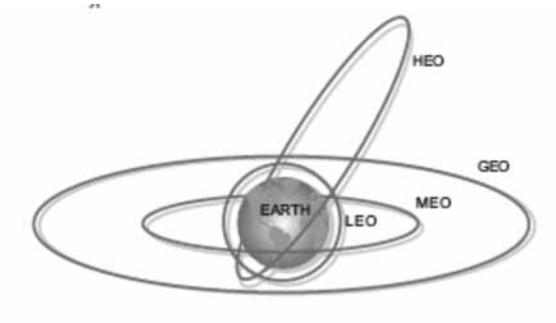
Observers

K.C. Gandhi
Centre for Aviation Studies (India)

Anne-Marie Hébert
McGill University

Diane Howard
McGill University

Types of Earth Orbits*



Low Earth Orbit (LEO) is commonly accepted as below 2000 kilometers above the Earth's surface. Spacecraft in LEO make one complete revolution of the Earth in about 90 minutes.

Medium Earth Orbit (MEO) is the region of space around the Earth above LEO (2,000 kilometers) and below geosynchronous orbit (36,000 kilometers). The orbital period (time for one orbit) of MEO satellites ranges from about two to 12 hours. The most common use for satellites in this region is for navigation, such as the US Global Positioning System (GPS).

Geostationary Orbit (GEO) is a region in which the satellite orbits at approximately 36,000 kilometers above the Earth's equator. At this altitude, geostationary orbit has a period equal to the period of rotation of the Earth. By orbiting at the same rate, in the same direction as Earth, the satellite appears stationary relative to the surface of the Earth. This is very useful for communications satellites. In addition, geostationary satellites provide a 'big picture' view of Earth, enabling coverage of weather events. This is especially useful for monitoring large, severe storms and tropical cyclones.

Polar Orbit refers to spacecraft at near-polar inclination and an altitude of 700-to-800 kilometers. The satellite passes over the equator and each latitude on the Earth's surface at the same local time each day, meaning that the satellite is overhead at essentially the same time throughout all seasons of the year. This feature enables collection of data at regular intervals and consistent times, which is especially useful for making long-term comparisons.

Highly Elliptical Orbits (HEO), are characterized by a relatively low altitude perigee and an extremely high-altitude apogee. These extremely elongated orbits have the advantage of long dwell times at a point in the sky; visibility near apogee can exceed 12 hours. These elliptical orbits are useful for communications satellites.

GEO transfer orbit (GTO) is an elliptical orbit of the Earth, with the perigee in LEO and the apogee in GEO. This orbit is generally a transfer path after launch to LEO by launch vehicles carrying a payload to GEO.

Apogee and Perigee refer to the distance from the Earth to the satellite. Apogee is the furthest distance to the Earth, and perigee is the closest distance to the Earth.

* From the Space Foundation, *The Space Report 2008* ((Colorado Springs: Space Foundation 2008), at 52.

Worldwide launch vehicles[1]

Vehicle	First Launch	Reliability*	Active Sites	LEO kg	GTO kg
Europe					
Ariane 5 (G, G+, GS, ECS)	1996	42/44	Kourou	16,000-21,000	6,200-10,500
China					
Long March 2C (SD, CTS,SMA)	1975	31/31	Jiuquan, Taiyuan, Xichang	3,200	1,000
Long March 2D	1992	10/10	Jiuquan	3,500	1,250
Long March 2F	1999	7/7	Jiuquan		
Long March 3A	1994	16/16	Taiyuan, Xichang	6,000	2,600
Long March 3B	1996	10/11	Xichang	13,562	4,491
Long March 4B	1999	11/11	Taiyuan	2,800	N/A
Long March 4C	2007	4/4	Taiyuan	4,200	1,500
India					
PSLV	1993	14/15	Satish Dhawan	3,700	800
GSLV	2001	4/5	Satish Dhawan	5,000	2,500
Japan					
H-2A	2001	15/15	Tanegashima	11,730	5,800
Israel					
Shavit 1	1988	5/7	Palmachim	225	N/A
US					
Atlas 5	2002	15/15	CCAFS, VAFB	12,500 (402) 20,520 (552)	4,950 (400) 8,670 (500)
Delta 2	1990	67/68	CCAFS	6,100	2,170
Delta 4	2002	9/9	CCAFS, VAFB	9,150 (M) 13,360 (M+) 22,560 (H)	4,300 (M) 8,670 (M+) 12,980 (H)
Falcon-1	2008	1/4	Omelek Island	470	N/A
Minotaur	2000	8/8	VAFB, MARS	640	N/A
Pegasus XL	1994	28/30	CCAFS, Kwajalein, MARS, VAFB	443 (XL) 500 (HAPS)	N/A
Taurus XL	1994	6/8	VAFB	1,275	445
Russia					
Dnepr	1999	11/12	Baikonur, Dombarovskiy	3,700	N/A
Kosmos 3M	1967	421/444	Plesetsk	1,350	N/A
Molniya	1960	331/342	Baikonur, Plesetsk	1,800	N/A
Proton K	1967	315/341	Baikonur	19,760	4,430
Proton M	2000	28/30	Baikonur	21,000	5,500
Rockot	1994	9/11	Baikonur, Plesetsk	1,850	N/A

[1] Space Foundation, The Space Report 2008 (Colorado Springs: Space Foundation 2008), at 53-57; FAA, “Year in Review 2008;” Gunter de Krebs, Gunter’s Space Page, http://www.skyrocket.de/space/; Phil Smith, Communications Director, Secure World Foundation (June 2009).

Vehicle	First Launch	Reliability*	Active Sites	LEO kg	GTO kg
			Russia (cont'd.)		
Soyuz	1958	1314/1366	Baikonur, Plesetsk	6,708	1,350
Tsiklon 2/3 (retired in January 2009)	1965	242/259	Baikonur	3,000	N/A
Zenit 2/2M	1985	31/37	Baikonur	12,030	N/A
			Iran		
Safir	2008	1/2	Semnan	?	?
			Sea Launch		
Zenit 3SL	1999	30/32	Pacific Ocean	N/A	6,100
			Land Launch		
Zenit 3SLB	2008	2/2	Baikonur	N/A	3,750

* As of June 2009

ANNEX 4:
Spacecraft Launched in 2008

Spacecraft Launched in 2008

COSPAR	Date Launched	Satellite Name	Actor Type	Primary Function	Owning State	Launch Vehicle	Launch State	Orbit
2008-029A	6/11/2008	Fermi Gamma-ray Space Tel.	Civil	Astronomy	USA	Delta 2	USA	LEO/C
2008-051A	10/19/2008	IBEX	Civil	Astronomy	USA	Pegasus-XL	USA	DHEO
2008-018A	4/18/2008	Vinasat	Civil	Communications	Vietnam	Aiane-5ECA	France	GEO/S
2008-019A	4/25/2008	Tian Lian 1A	Civil	Communications	China	Chang Zheng 3C	China	GEO/S
2008-055A	10/29/2008	Simon Bolivar	Civil	Communications	Venezuela	Chang Zheng 3B	China	GEO/S
2008-005A	2/7/2008	Atlantis (STS-122)	Civil	Human spaceflight	USA	Space Shuttle	USA	LEO/I
2008-009A	3/11/2008	Endeavour (STS-123)	Civil	Human spaceflight	USA	Space Shuttle	USA	LEO/I
2008-015A	4/8/2008	Soyuz TMA-12	Civil	Human spaceflight	Russia	Soyuz-FG	Russia	LEO/I
2008-027A	5/31/2008	Discovery (STS-124)	Civil	Human spaceflight	USA	Space Shuttle	USA	LEO/I
2008-047A	9/25/2008	Shenzhou 7	Civil	Human spaceflight	China	Chang Zheng 2F	China	LEO/I
2008-050A	10/12/2008	Soyuz TMA-13	Civil	Human spaceflight	Russia	Soyuz-FG	Russia	LEO/I
2008-059A	11/15/2008	Endeavour (STS-126)	Civil	Human spaceflight	USA	Space Shuttle	USA	LEO/I
2008-041A	9/6/2008	Huan Jing 1A	Civil	Imaging	China	Chang Zheng 2C	China	LEO/S
2008-041B	9/6/2008	Huan Jing 1B	Civil	Imaging	China	Chang Zheng 2C	China	LEO/S
2008-049A	10/1/2008	THEOS	Civil	Imaging	Thailand	Dnepr	Russia	LEO/S
2008-026A	5/27/2008	Feng Yun 3A	Civil	Meteorological	China	Chang Zheng 4C	China	LEO/S
2008-056B	11/5/2008	Chuangzin-1 02	Civil	Meteorological	China	Chang Zheng 2D	China	LEO/S
2008-066A	12/23/2008	Feng Yun 2E	Civil	Meteorological	China	Chang Zheng 3A	China	GTO
2008-020A	4/26/2008	Giove-B	Civil	Navigation Ω	ESA	Soyuz-FG	France	MEO
2008-032A	6/20/2008	Jason-2	Civil	Oceanography	USA	Delta 7320-10C	USA	LEO/I
2008-052A	10/21/2008	Chandrayaan 1	Civil	Planetary	India	PSLV-XL	India	CLO
2008-064A	12/10/2008	Yaogan Weixing 5	Civil	Radar Imaging	China	Chang Zheng 4B	China	LEO/S
2008-053A	10/25/2008	SJ-6/3A	Civil	Science	China	Chang Zheng 4B	China	LEO/S
2008-053B	10/25/2008	SJ-6/3B	Civil	Science	China	Chang Zheng 4B	China	LEO/S

COSPAR	Date Launched	Satellite Name	Actor Type	Primary Function	Owning State	Launch Vehicle	Launch State	Orbit
2008-004A	2/5/2008	Progress ISS 28P	Civil	Space station supply	Russia	Soyuz-U	Russia	LEO/I
2008-008A	3/9/2008	Jules Verne (ATV-1)	Civil	Space station supply	ESA	Ariane 5ESV	France	LEO/I
2008-023A	5/14/2008	Progress M-64	Civil	Space station supply	Russia	Soyuz-U	Russia	LEO/I
2008-043A	9/10/2008	Progress M-65	Civil	Space station supply	Russia	Soyuz-U	Russia	LEO/I
2008-060A	11/26/2008	Progress M-01M	Civil	Space station supply	Russia	Soyuz-U	Russia	LEO/I
2008-047G	9/25/2008	Shenzhou 7 subsatellite	Civil	Technology development	China	Chang Zheng 2F	China	LEO/I
2008-007A	2/23/2008	Kizuna (Winds)	Civil	Technology development	Japan	H-IIA 2024	Japan	GEO/D
2008-021B	4/28/2008	CanX-6 NTS	Civil private	AIS	Canada	PSLV	India	LEO/S
2008-021D	4/28/2008	IMS-1 (TWSAT)	Civil private	Imaging	India	PSLV	India	LEO/S
2008-021C	4/28/2008	Cute-1.7 + APD 2	Civil private	Technology development	Japan	PSLV	India	LEO/S
2008-021E	4/28/2008	Compass-1	Civil private	Technology development	Germany	PSLV	India	LEO/S
2008-021F	4/28/2008	AAUSat-II	Civil private	Technology development	Denmark	PSLV	India	LEO/S
2008-021G	4/28/2008	Delfi-C3	Civil private	Technology development	Netherlands	PSLV	India	LEO/S
2008-021J	4/28/2008	SEEDS 2	Civil private	Technology development	Japan	PSLV	India	LEO/S
2008-021L	4/28/2008	CanX-2	Civil private	Technology development	Canada	PSLV	India	LEO/S
2008-021A	4/28/2008	Cartosat 2A	Civil Ω	Imaging	India	PSLV	India	LEO/S
2008-054A	10/25/2008	COSMO 3	Civil Ω	Radar Imaging	Italy	Delta 7420-10	USA	LEO/S
2008-061A	12/1/2008	Yaogan Weixing 4	Civil*	Imaging	China	Chang Zheng 2D	China	LEO/S
2008-056A	11/5/2008	Shiyan Weizing 3	Civil *	Science	China	Chang Zheng 2D	China	LEO/S
2008-021K	4/28/2008	Rubin-8	Commercial	AIS	Germany	PSLV	India	LEO/S
2008-001A	1/15/2008	Thuraya 3	Commercial	Communications	UAE	Zenit-3SL	USA	GEO/I
2008-003A	1/28/2008	Express AM-33	Commercial	Communications	Russia	Proton-M/ Briz-M	Russia	GEO/S
2008-006A	2/11/2008	Thor 2R	Commercial	Communications	Norway	Proton-M/ Briz-M	Russia	GEO/D
2008-011A	3/14/2008	AMC-14	Commercial	Communications	USA	Proton-M/ Briz-M	Russia	GEO/I
2008-013A	3/19/2008	DirecTV-11	Commercial	Communications	USA	Zenit-3SL	USA	GEO/ NS

COSPAR	Date Launched	Satellite Name	Actor Type	Primary Function	Owning State	Launch Vehicle	Launch State	Orbit
2008-016A	4/14/2008	ICO-G1	Commercial	Communications	USA	Atlas-V-421	USA	GEO/I
2008-018B	4/18/2008	Star One C2	Commercial	Communications	Brazil	Ariane 5ESV	France	GEO/S
2008-024A	5/21/2008	Galaxy 18	Commercial	Communications	Bermuda	Zenit-3SL	USA	GEO/S
2008-028A	6/9/2008	Zhongxing-9	Commercial	Communications	China	Chang Zheng 3B	China	GEO/S
2008-030B	6/12/2008	Turksat 3A	Commercial	Communications	Turkey	Ariane 5ECA	France	GEO/S
2008-031A	6/19/2008	Orbcomm FM38	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-031B	6/19/2008	Orbcomm FM41	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-031C	6/19/2008	Orbcomm FM29	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-031D	6/19/2008	Orbcomm FM39	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-031E	6/19/2008	Orbcomm FM37	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-031F	6/19/2008	Orbcomm FM40	Commercial	Communications	USA	Kosmos-11k65m	Russia	LEO/I
2008-034A	7/7/2008	Protostar 1	Commercial	Communications	USA	Ariane 5ECA	France	GEO/D
2008-034B	7/7/2008	Badr 6	Commercial	Communications	Saudi Arabia	Ariane 5ECA	France	GEO/D
2008-035A	7/16/2008	Echostar 11	Commercial	Communications	USA	Zenit-3SL	USA	GEO/D
2008-038A	8/14/2008	Superbird C2	Commercial	Communications	Japan	Ariane 5ECA	France	GEO/D
2008-038B	8/14/2008	AMC 21	Commercial	Communications	USA	Ariane 5ECA	France	GEO/D
2008-039A	8/19/2008	Inmarsat 4 F3	Commercial	Communications	UK	Proton-M/ Briz-M	Russia	GEO/ID
2008-044A	9/19/2008	Nimiq 4	Commercial	Communications	Canada	Proton-M/ Briz-M	Russia	GEO/D
2008-045A	9/24/2008	Galaxy 19	Commercial	Communications	Bermuda	Zenit-3Sl	USA	GEO/D
2008-057A	11/5/2008	Astra 1M	Commercial	Communications	Luxembourg	Proton-M/ Briz-M	Russia	GEO/S
2008-063A	12/10/2008	Ciel 2	Commercial	Communications	Canada	Proton-M/ Briz-M	Russia	MEO
2008-065A	12/10/2008	Hot Bird 9	Commercial	Communications	France	Ariane 5ECA	France	GTO
2008-065B	12/10/2008	Eutelsat W2M	Commercial	Communications	France	Ariane 5ECA	France	MEO
2008-040A	8/29/2008	RapidEye 1	Commercial	Imaging	Germany	Dnepr	Russia	LEO/S
2008-040B	8/29/2008	RapidEye 2	Commercial	Imaging	Germany	Dnepr	Russia	LEO/S
2008-040C	8/29/2008	RapidEye 3	Commercial	Imaging	Germany	Dnepr	Russia	LEO/S
2008-040D	8/29/2008	RapidEye 4	Commercial	Imaging	Germany	Dnepr	Russia	LEO/S
2008-040E	8/29/2008	RapidEye 5	Commercial	Imaging	Germany	Dnepr	Russia	LEO/S
2008-042A	9/6/2008	GeoEye-1	Commercial	Imaging	USA	Delta 7420-10	USA	LEO/S
2008-048A	9/28/2008	Ratsat	Commercial	Technology development	USA	Falcon 1	USA	LEO/E
2008-025A	5/23/2008	Gonets DIM 2	Commercial †	Communications	Russia	Rokot	Russia	LEO/I

COSPAR	Date Launched	Satellite Name	Actor Type	Primary Function	Owning State	Launch Vehicle	Launch State	Orbit
2008-025B	5/23/2008	Gonets DIM 3	Commercial †	Communications	Russia	Rokot	Russia	LEO/I
2008-025C	5/23/2008	Gonets DIM 4	Commercial †	Communications	Russia	Rokot	Russia	LEO/I
2008-025D	5/23/2008	Yubileyniy	Commercial †	Communications	Russia	Rokot	Russia	LEO/I
2008-022A	4/28/2008	Amos 3	Commercial §	Communications	Israel	Zenit-3SLB	Russia	GEO/D
2008-030A	6/12/2008	Skynet 5C	Commercial §	Communications	UK	Ariane 5ECA	France	GEO/D
2008-033A	6/26/2008	Kosmos-2440	Military	Early warning	Russia	Proton-K/ DM-2	Russia	GEO/ID
2008-062A	12/2/2008	Kosmos 2446	Military	Early warning	Russia	Molniya 8K78M	Russia	HEO/M
2008-037A	7/26/2008	Kosmos 2441	Military	Imaging	Russia	Soyuz-2-1B	Russia	LEO/S
2008-058A	11/14/2008	Kosmos 2445	Military	Imaging	Russia	Soyuz-U	Russia	LEO/I
2008-012A	3/15/2008	USA-201	Military	Navigation	USA	Delta-7925-9.5	USA	MEO
2008-046A	9/25/2008	Kosmos 2434	Military	Navigation	Russia	Proton-M/ DM-2	Russia	MEO
2008-046B	9/25/2008	Kosmos 2435	Military	Navigation	Russia	Proton-M/ DM-2	Russia	MEO
2008-046C	9/25/2008	Kosmos 2436	Military	Navigation	Russia	Proton-M/ DM-2	Russia	MEO
2008-067A	12/25/2008	Kosmos 2447	Military	Navigation	Russia	Proton-M/ Briz-M	Russia	MEO
2008-067B	12/25/2008	Kosmos 2449	Military	Navigation	Russia	Proton-M/ Briz-M	Russia	MEO
2008-067C	12/25/2008	Kosmos 2448	Military	Navigation	Russia	Proton-M/ Briz-M	Russia	MEO
2008-002A	1/21/2008	TECSAR	Military	Radar Imaging	Israel	PSLV	India	LEO/I
2008-014A	3/27/2008	SAR-Lupe-4	Military	Radar Imaging	Germany	Kosmos-11k65m	Russia	LEO/S
2008-036A	7/22/2008	SAR-Lupe 5	Military	Radar Imaging	Germany	Kosmos-11k65m	Russia	LEO/S
2008-017A	4/16/2008	C/NOFS (P00-2)	Military	Science	USA	Pegasus-XL	USA	LEO/E
2008-010A	3/13/2008	USA-200	Military	Signals Intelligence	USA	Atlas V 411	USA	GTO
2008-059B	11/15/2008	Picosat Solar Cell Testbed	Military	Technology	USA	Space Shuttle	USA	LEO/I

† Providing civil and military services to government
§ Providing military services to government
Ω Dual civil and military use
* Possible dual civil and military

Endnotes

Chapter One Endnotes

[1] D. Wright, "Space Debris," *Physics Today* (October 2007) at 36.

[2] J. James, Testimony before the Subcommittee on Space and Aeronautics, House Committee on Science and Technology, 28 April 2009 (at 2), online: http://gop.science.house.gov/Media/hearings/space09/april28/james.pdf.

[3] N. Johnson, Testimony before the Testimony before the Subcommittee on Space and Aeronautics, House Committee on Science and Technology, 28 April 2009 (at 1), online: http://gop.science.house.gov/Media/hearings/space09/april28/johnson.pdf.

[4] William J. Broad, "Orbiting Junk, Once a Nuisance, Is Now a Threat," *New York Times* (6 February 2007), online: http://www.nytimes.com/2007/02/06/science/space/06orbi.html?ei=5070&en=52e4fd924f69b8b9&ex=1179374400.

[5] D. Mehrholz, L. Leushacke, W. Flury, R. Jehn. H. Klinkrad. M. Landgraf, "Detecting, Tracking and Imaging Space Debris" (February 2002), 109 *ESA Bulletin* at 128.

[6] J. Singer, "Space-Based Missile Interceptors Could Pose Debris Threat," *Space News* (13 September 2004).

[7] NASA Orbital Debris Program Office, Orbital Debris, Photo Gallery, online: http://orbitaldebris.jsc.nasa.gov/photogallery/photogallery.html (date accessed: 24 April 2009).

[8] US National Research Council, *Orbital Debris: A Technical Assessment* at 4.

[9] US National Research Council, *Orbital Debris: A Technical Assessment* at 2.

[10] Nicholas L. Johnson, "Space Debris, Its Causes and Management," Presentation to Congress in Washington, DC, sponsored by Representative Adam Schiff, D-CA and organized by the Monterey Institute of International Studies (24 July 2002).

[11] D. Wright, "Colliding Satellites: Consequences and Implications," Union of Concerned Scientists (February 26, 2009), online: http://www.ucsusa.org/assets/documents/nwgs/SatelliteCollision-2-12-09.pdf.

[12] A. Shalal-Esa, "USA-193: reboot problems," Reuters, 7 March 2007, online: SciTech Archive http://sci.tech-archive.net/Archive/sci.space.policy/2007-03/msg00261.html.

[13] J. Locker, "Re: USA 193……Further image," post to See-sat mailing list, 24 December 2007, online: http://www.satobs.org/seesat/Dec-2007/0194.html.

[14] Associated Press, "DoD Prepares for Spy Satellite Crash," 30 January 2008, online: http://www.military.com/NewsContent/0,13319,161057,00.html?wh=wh; MSNBC News Service, "U.S. downplays threat from falling satellite," Today, January 28, 2008, online: http://www.msnbc.msn.com/id/22857051/; David A. Fulghum, "US Considering Shooting Down Satellite," *Aviation Week and Space Technology* (12 February 2008).

[15] http://www.defenselink.mil/releases/release.aspx?releaseid=11691.

[16] Data compiled from the public satellite catalog, online: Space Track, http://www.space-track.org (date accessed: 1 February 2009).

[17] Data compiled from the public satellite catalog, online: Space Track, http://www.space-track.org (date accessed: 1 February 2009).

[18] http://thebulletin.org/files/NASA_White_Paper.pdf.

[19] http://www.thebulletin.org/web-edition/features/technical-comments-the-us-satellite-shootdown.

[20] *Orbital Debris Quarterly News* (January 2008) at 11, online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i1.pdf.

[21] *Orbital Debris Quarterly News* (January 2007) at 11, online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i1.pdf.

[22] *Orbital Debris Quarterly News* (April 2008), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i2.pdf.

[23] http://russianforces.org/blog/2006/07/problems_with_cosmos2421.shtml.

[24] *Orbital Debris Quarterly News* (January 2009), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv13i1.pdf.

25 J. McDowell, personal email conversation, 8 May 2009.

26 S. Clark, “Proton rocket suffers launch failure,” *Spacelfight Now* (15 March 2008), online: http://www.spaceflightnow.com/proton/amc14/.

27 *Orbital Debris Quarterly News* (April 2007) at 3, online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i2.pdf.

28 “Proton Breeze M Cleared for Return to Flight,” International Launch Services (16 June 2008), online: http://www.ilslaunch.com/news-061608.

29 Data compiled from the public satellite catalog, online: Space Track, http://www.space-track.org (date accessed: 1 February 2009).

30 *Orbital Debris Quarterly News* (January 2009), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv13i1.pdf.

31 *Orbital Debris Quarterly News* (October 2008), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i4.pdf.

32 *Orbital Debris Quarterly News* (October 2008), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i4.pdf.

33 T. Malik, “NASA: Space Debris a Higher Risk for Hubble Shuttle Flight,” Space.com (8 Sept 2008), online: Space.com http://www.space.com/missionlaunches/080908-sts125-toprisk.html; personal conversation with Eugene Stansberry, NASA Orbital Debris Program Office, 17 September 2008.

34 *Space News,* “French Satellite Force to Avoid Chinese Debris” (10 November 2008).

35 “CloudSat: Revealing the Inner Secrets of Clouds,” NASA, online: NASA website, http://www.nasa.gov/mission_pages/cloudsat/multimedia/a-train.html (date accessed: 3 March 2009).

36 Peter B. de Selding, “FCC Enter Orbital Debris Debate,” *Space News* (28 June 2004); “Mitigation of Orbital Debris,” 70 *Federal Register* (12 October 2005).

37 *Orbital Debris Quarterly News* (October 2008), online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i4.pdf.

38 *ESA Space Debris Mitigation Handbook* (Noordwijk, NE, 19 February 1999); R. Walker et al., *Update of the ESA Space Debris Mitigation Handbook* (European Space Agency, QinetiQ, July 2002), online: European Space Agency, http://www.esrin.esa.it/gsp/completed/execsum00_N06.pdf.

39 “European Space Debris Safety and Mitigation Standard,” Issue 1, Revision 0 (27 September 2000); F. Alby et al., “A European Standard for Space Debris,” 1999.

40 Peter B. de Selding, “China Says Work Underway to Mitigate Space Junk,” *Space News* (3 September 2007).

41 United Nations Committee on the Peaceful Uses of Outer Space, 511th Meeting, unedited transcripts (17 June 2003) at 5, online: United Nations Office for Outer Space Affairs, online: http://www.oosa.unvienna.org/Reports/transcripts/copuos/2003/COPUOS_T511E.doc.

42 Inter-Agency Space Debris Coordination Committee, “Support to the IADC Space Debris Mitigation Guidelines” (5 October 2004) at 3, 13, online: http://www.iadconline.org/docs_pub/IADC.SD.AI20.3.10.2004.pdf.

43 Inter-Agency Space Debris Coordination Committee, “Support to the IADC Space Debris Mitigation Guidelines” at 3, 13.

44 *Orbital Debris Quarterly News,* “Space Debris Mitigation Guidelines at the UN” (July 2005) at 1, online: NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv9i3.pdf.

45 “Report of the Committee on the Peaceful Uses of Outer Space, Sixty Second Session,” at 17.

46 “Report of the Scientific and Technical Subcommittee on its forty-fourth session,” at 43-45.

47 Technovelgy.com, “Electrodynamic Tethers: Clean Up Debris – Power or Boost Spacecraft” (11 May 2004), online: http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=252; Technovelgy.com, “The Terminator Tether Aims to Clean up Low Earth Orbit” (5 November 2004), online: http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=252; Technovelgy.com, “Terminator Tether — EDT Solution To Space Debris Update” (17 November 2004),

online: http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=264; Orbital Recovery Ltd., "Orbital Recovery Fact Sheet," online: http://www.orbitalrecovery.com/images/fact_sheet_v1_5.pdf; Tariq Malik, "Orbital Assistance: ConeXpress Spacecraft Could Extend Satellite Missions," Space.com (2 June 2004), online: http://www.space.com/businesstechnology/technology/conexpress_techwed_040602.html; Gunter Dirk Krebs, "ConeXpress-OLEV (CX-OLEV)," online: Gunter's Space Page, http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/conexpress-ors.htm.

48 Carmen Pardini, Toshiya Hanada, Paula H. Krisko, "Benefits and Risks of Using Electrodynamic Tethers to De-Orbit Spacecraft," IAC-06-B6.2.10, online: Inter-Agency Space Debris Coordination Committee, http://www.iadc-online.org/index.cgi?item=docs_pub.

49 NASA, "Space Debris Assessment for USA-193," Presentation to the 45th Session of the Scientific and Technical Subcommittee, Committee on the Peaceful Uses of Outer Space, United Nations (February 2008), online: http://www.oosa.unvienna.org/pdf/pres/stsc2008/tech-16.pdf.

50 NASA, "Space Debris Assessment for USA-193," at 4.

51 NASA, "Space Debris Assessment for USA-193," at 18.

52 J.-C. Liou and N. Johnson, "A Sensitivity Study of the Effectiveness of Active Debris Removal in LEO," Acta Astronautica, Volume 64, Issues 2-3, Pp. 236-243, January-February 2009, online: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070013702_2007011170.pdf.

53 *Orbital Debris Quarterly News* (October 2008), online: NASA Orbital Debris Program Office http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i4.pdf.

54 Federation of American Scientists, "Joint Data Exchange Center (JDEC)," online: http://www.fas.org/nuke/control/jdec/index.html.

55 "Improving Our Vision: Approaches for Shared Space Situational Awareness," Report of the Sept. 15-16, 2006 Conference, The Antlers Hotel, Colorado Springs, CO, The World Security Institute's Center for Defense Information and The U.S. Air Force Academy's Center for Space and Defense Studies (2007) at 10. The Space Based Visible (SBV) Sensor ceased operations in 2008. Amy Butler, "Space-Based Visible Sensor Ceases Ops," *Aerospace Daily and Defense Report* (10 June 2008), online: http://www.aviationnow.com/aw/generic/story_generic.jsp?channel=space&id=news/Spacey061008.xml&headline=Space-Based%20Visible%20Sensor%20Ceases%20Ops.

56 Peterson Air Force Base, 20th Space Control Squadron, Detachment 1, "Fact Sheet," online: www.peterson.af.mil/library/factsheets/factsheet.asp?id=4729 (date accessed: 10 July 2008).

57 "Bureaucracy Threatens Sat Protection Project," *Aviation Week and Space Technology* (4 April 2008).

58 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108–136—24 (November 2003), online: CelesTrack http://www.celestrak.com/Norad/elements/Section913.pdf.

59 SOCRATES, online : http://celestrak.com/SOCRATES.

60 *Jane's Space Directory,* "The SSS Space Surveillance System" (23 December 2003); Center for Defense Information, "Improving Our Vision" at 10.

61 Sourcebook on the Okno Space Surveillance Site, Version of 28 September 2006, online: Federation of American Scientists, http://www.fas.org/spp/military/program/track/okno.pdf.

62 *Jane's Space Directory,* "The SSS Space Surveillance System" (23 December 2003).

63 *Jane's Space Directory,* "The SSS Space Surveillance System" (23 December 2003).

64 Pavel Podvig, "Strategic Defense" (May 2006), online: Russian Strategic Forces, http://russianforces.org/eng/defense.

65 *France ST Special Reports,* "Imminent Delivery of the French Surveillance System" 75 (24 August 2005), online: France-Israel Teamwork in Science, http://www.fitscience.org/media/upload/FranceST_075.pdf; Onera, "Graves Le système français de surveillance de l'espace" (4 May 2006), online: http://www.onera.fr/dprs/graves/index.php; Federation of American Scientists, "A GRAVES Sourcebook" (29 October 2006), online: http://www.fas.org/spp/military/program/track/graves.pdf.

66 Jacques Bouchard as quoted in "Imminent Delivery of the French Surveillance System," *France ST Special Reports* 75 (24 August 2005).

[67] GlobalSecurity.org, "German Space Agencies," online: http://www.globalsecurity.org/space/world/germany/agency.htm#ref21 (date accessed: 10 July 2008); W. Flury, "Agenda Item 8: Space Debris, European Space Agency," Presentation to the 41st session of UN Scientific and Technical Subcommittee on the Peaceful Uses of Outer Space (UNCOPUOS) (16-27 February 2004) at 7, online: UN Office for Outer Space Affairs, http://www.oosa.unvienna.org/COPUOS/stsc/2004/presentations/flury2.ppt.

[68] SpaceWar, "Successful Trial for BNSC-funded Space Surveillance Project" (9 November 2006), online: Spacewar.com, http://www.spacewar.com/reports/Successful_Trial_For_BNSC_funded_Space_Surveillance_Project_999.html.

[69] Walter Flury et al., "Searching for Small Debris in the Geostationary Ring – Discoveries with the Zeiss 1-metre Telescope," 104 *ESA Bulletin* (November 2000), online: European Space Agency, http://www.esa.int/esapub/bulletin/bullet104/flury104.pdf.

[70] Heiner Klinkrad, "Monitoring Space – Efforts Made by European Countries," presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France (27-28 November 2002), online: Federation of American Scientists, http://www.fas.org/spp/military/program/track/klinkrad.pdf.

[71] European Space Agency, "Spacecraft Operations, Space Debris Avoidance," online: http://www.esa.int/spacecraftops/ESOC-Article-fullArticle_idBanner-1092735449782_item_selected-19_5_00_par-47_1091629030048.html (date accessed: 10 July 2008).

[72] Peter B. de Selding, "ESA Places Priority on Space Surveillance," *Defense News* (27 March 2006), online: http://www.defensenews.com/story.php?F=1639067&C=airwar.

[73] *Xinhua,* "China Reports Progress in Space Debris Research" (14 August 2003), online: Xinhuanet English, http://news.xinhuanet.com/english/2003-08/14/content_1113433.htm.

[74] *China Daily,* "Alarm System Warns of Space Debris" (11 August 2003).

[75] *People's Daily,* "China First Space Debris Monitoring Center Settles PMO," (11 March 2005); *People's Daily,* "CAS Sets up the First Space Debris Monitoring Center in China" (16 March 2005).

[76] Globalsecurity.org, "Chinese Space Facilities" (last modified 19 October 2005), online: http://www.globalsecurity.org/space/world/china/facility.htm.

[77] *Japan Times,* "Space Debris Radar Station Operational" (9 April 2004).

[78] IADC Observation Campaigns, Inter-Agency Space Debris Coordination Committee presentation to 43rd Session of COPUOS Science and Technology Sub-Committee (February 2006), online: http://www.iadc-online.org/docs_pub/UN_Presentation_2006_final.pdf.

[79] University of British Columbia, "MOST, Canada's First Space Telescope," online: Astronomy at the University of British Columbia, http://www.astro.ubc.ca/MOST/milestones.html (date accessed: 10 July 2008).

[80] *Space News,* "Canada Considers Military Microsatellites" (1 September 2003); W. Harvey et al., "The Near Earth Object Surveillance Satellite (NEOSSAT) Mission Enables an Efficient Space-based Survey (NESS Project) of Interior-to-Earth-Orbit (IEO) Asteroids," 38 *Lunar and Planetary Science* (2007), at 2372.

[81] Analysis by Brian Weeden, Technical Consultant, Secure World Foundation.

[82] D. Fulghum, "USAF Eyes Spaceborne Optics," *Aviation Week* (14 March 2008), online: Aviation Week, http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/optics031408.xml.

[83] SpaceWar, "LM Receives Contract for USAF Self-Awareness Space Situational Awareness Program" (30 October 2008), online: Spacewar.com, http://www.spacewar.com/reports/LM_Receives_Contract_For_USAF_Self_Awareness_Space_Situational_Awareness_Program_999.html.

[84] A. Butler, "DOD Looks to Sped Up Haystack Effort," *Aviation Week* (28 July 2008), online: AviationWeek, http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/HAYSTACK072808.xml&headline=DOD%20Looks%20To%20Speed%20Up%20Haystack%20Effort.

[85] K. Marren, "Mission Complete: APL-Operated Midcourse Space Experiment Ends," John Hopkins APL (16 July 2008), online: Johns Hopkins APL, http://www.jhuapl.edu/newscenter/pressreleases/2008/080716_2.asp.

86 SpaceWar, "Air Force Space Command Celebrates MSX 10th Anniversary," (21 April 2006), online: Spacewar.com http://www.spacewar.com/reports/Air_Force_Space_Command_Celebrates_MSX_10th_Anniversary.html.

87 Global Security, "Space Based Space Surveillance (SBSS)," online: Globalsecurity.com, http://www.globalsecurity.org/space/systems/sbss.htm (date accessed: 12 Feb 2009)

88 J Hodges, "Space Fence Reinvented," *C4ISR Journal* (1 October 2008), online: C4ISRJounal.com, http://www.c4isrjournal.com/story.php?F=3677126.

89 Peter B. de Selding, "ESA Space Surveillance Effort of Little Interest to French Military," *Space News* (8 December 2008) at 11.

90 See Tony Skinner, "Europe pursues space network," *Jane's Defence Weekly* (24 September 2008) at 18.

91 *Space News*, "French Satellite Force to Avoid Chinese Debris," (10 November 2008).

92 Okno Sourcebook, Federation of American Scientists, online: http://www.fas.org/spp/military/program/track/okno.pdf (accessed: 10 February 2009).

93 Secure World Foundation, "CSST's SOCRATES-GEO Adds 100th Satellite" (4 August 2008), http://www.secureworldfoundation.org/siteadmin/images/files/file_202.pdf.

94 Theresa Hitchens, "OpEd: Building Transparency in Space," *Space News* (29 July 2008).

95 V. Agapov and I. Molotov, "International scientific observation network (ISON) for the near-Earth space surveillance – results of the first years of work and plans for the future," presentation for the 45th session of the COPUOS STSC (19 February 2008), online: http://lfvn.astronomer.ru/report/0000029/index.htm.

96 R. Choc and R. Jehn, Classification of Geosynchronous Objects, 10th Edition.

97 R. Choc and R. Jehn, Classification of Geosynchronous Objects, 10th Edition.

98 J. James, Testimony before the Subcommittee on Space and Aeronautics, House Committee on Science and Technology, 28 April 2009, online: http://gop.science.house.gov/Media/hearings/space09/april28/james.pdf

99 Tim Bonds et al., Employing Commercial Satellite Communications: Wideband Investment Options for DoD (Santa Monica, CA: RAND Corporation, 2000) at 17.

100 Michael Calabrese and J.H. Snider, "Up in the Air," *Atlantic Monthly* (September 2003) at 46-47; Albert "Buzz" Merill and Marsha Weiskopf, "Critical Issues in Spectrum Management for Defense Space Systems," *Crosslink* (Winter 2002) at 14-19, online: Aerospace Corporation http://www.aero.org/publications/crosslink/winter2002/02.html.

101 Albert Merill and Marsha Weiskopf, "Critical Issues in Spectrum Management for Defense Space Systems" at 18.

102 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Plenipotentiary Conference* (Marrakesh, 2002). For an excellent description of the role of ITU see Francis Lyall, "Communications Regulations: The Role of the International Telecommunication Union" (1997), 3 *Journal of Law and Technology*, online: The University of Warwick, http://www2.warwick.ac.uk/fac/soc/law/elj/jilt/1997_3/lyall.

103 Constitution and Convention of the International Telecommunication Union, Art. 45 para. 197.

104 M.Y.S. Prasad, "Space-Based Telecommunications including Tele-Education & Telemedicine – Implications to the Area of Space Law," in Proceedings of the Space Law Conference 2005: Bringing Space Benefits to the Asian Region, Bangalore, India (26-29 June 2005).

105 Philip McAlister, "Follow the Money: Satellite Opportunities with the US Government" Futron Corporation (17 November 2003).

106 Theresa Hitchens, *Future Security in Space: Charting a Cooperative Course* (Washington, DC: Center for Defense Information, September 2004) at 49.

107 *Asia Satellite News*, "Satellite interference: still a problem" (7 March 2006), online: Telecom Asia, http://www.abu.org.my/public/documents/Satellite_ISOG-%20Telecom%20Asia7mar06.pdf.

108 John C. Tanner, "SPACE JAM: Fighting Satellite Interference from the Ground up," Telecom Asia (1 November 2003) at 16-22, online: Look Smart, Find Articles, http://findarticles.com/p/articles/mi_m0FGI/is_11_14/ai_111694639.

[109] John C. Tanner, “Space JAM.”

[110] US Department of Defense, Office of the Assistant Secretary of Defense, News Release, “DoD Moves Forward With Next Steps For Spectrum Relocation” (16 July 2007), online: DefenseLink, http://www.defenselink.mil/releases/release.aspx?releaseid=11131.

[111] Ravi Visvesvaraya Prasad, “The Great Indian Spectrum Dispute,” *The Financial Express* (13 August 2007), online: http://www.financialexpress.com/news/The-Great-Indian-Spectrum-Dispute/210194/.

[112] European Commission, Press Release, “EU and US a Step Further to Agreement over Galileo Satellite Navigation following Brussels Negotiating Round” (25 February 2004), online: European Union, http://www.eurunion.org/news/press/2004/20040030.htm.

[113] *EU Business,* “EU, US to Make GPS and Galileo Satellite Networks Compatible” (26 July 2007) online: http://www.eubusiness.com/Telecoms/1185465602.28/; Reuters, “US says to reach GPS-Galileo agreement this week” (16 July 2007), online: http://www.reuters.com/article/scienceNews/idUSL1674424620070716.

[114] Gibbons Media and Research LLC, “Compass: And China’s GNSS Makes Four,” *Inside GNSS* (November/December 2006), online: http://www.insidegnss.com/node/115.

[115] Gibbons Media and Research LLC, “Compass: And China’s GNSS Makes Four.”

[116] Union of Concerned Scientists, “Satellite Quick Facts,” online: http://www.ucsusa.org/assets/documents/nwgs/quick-facts-and-analysis-4-13-09.pdf.

[117] Joel D. Scheraga, “Establishing Property Rights in Outer Space,” 6 *Cato Journal* (1987) at 891.

[118] Joel D. Scheraga, “Establishing Property Rights in Outer Space,” at 891.

[119] Col. John E. Hyten, USAF, “A Sea of Peace or a Theater of War? Dealing with the Inevitable Conflict in Space,” 16 *Air and Space Power Journal* (Fall 2002) at 90, note 11. Current US FCC policies require US direct broadcast satellites (DBS) to be spaced nine degrees apart, placing greater constraint on the availability of orbital slots in GEO. US Federal Communications Commission, “DBS Spacing,” online: Federal Communications Commission, http://www.fcc.gov/ib/sd/dbs_spacing/ (date accessed: 10 July 2008).

[120] Constitution and Convention of the International Telecommunication Union Art. 33 para. 2.

[121] Ram Jakhu, “Legal Issues of Satellite Telecommunications, the Geostationary Orbit, and Space Debris,” 5(2) *Astropolitics* (2007) at 182.

[122] Attila Matas, “Cost Recovery for Satellite Network Filings,” ITU Regional Radiocommunication Seminar, Abu Dhabi (22-26 April 2007), online: http://www.itu.int/ITU-R/space/support/workshop/doc_presentation_en/Cost%20recovery_AM.pdf.

[123] Ram Jakhu, “Legal Issues of Satellite Telecommunications,” at 182-183.

[124] Report by the Secretary-General, “Implementation of Cost Recovery for Satellite Network Filings,” ITU Council 2007 (4-14 September 2007).

[125] *Space News*, 6 March 2008.

[126] Peter B. de Selding, “China Satellite Navigation System Planned for 2010,” *Space News* (5 May 2008).

[127] B. Potter, “Satellite Interference: Tech To The Rescue,” *Satellite Magazine* (June 2008), online: SatMagazine.com, http://www.satmagazine.com/cgi-bin/display_article.cgi?number=848918337.

[128] A. Sennitt, “Satellite interference growing worse, forum told,” Radio Netherlands Worldwide (13 June 2008), online: Radio Netherlands Worldwide, http://blogs.rnw.nl/medianetwork/satellite-interference-growing-worse-forum-told.

[129] *Satnews Daily,* “We Need Our Space, Say Satellite Users Interference Reduction Group” (18 July 2008), online: Satnews.com, http://www.satnews.com/cgi-bin/story.cgi?number=555683468.

[130] *Satnews Daily,* “We Need Our Space, Say Satellite Users Interference Reduction Group” (18 July 2008), online: Satnews.com, http://www.satnews.com/cgi-bin/story.cgi?number=555683468.

[131] A. Sennitt, “Satellite interference growing worse, forum told,” Radio Netherlands Worldwide (13 June 2008), online: Radio Netherlands Worldwide, http://blogs.rnw.nl/medianetwork/satellite-interference-growing-worse-forum-told.

[132] B. Potter, "Satellite Interference: Tech To The Rescue," *Satellite Magazine* (June 2008), online: SatMagazine.com, http://www.satmagazine.com/cgi-bin/display_article.cgi?number=848918337.

[133] International Telecommunication Union, "Confirmation of a Decision to Cancel Frequency Assignments of Satellite Networks Eutelsat 3-44E, EUTELSAT 3-48E< and EUTELSAT E-48E from MFIR," Director, Radiocommunications Board, Radio Regulations Board (27 April 2009).

Chapter Two Endnotes

[1] *Charter of the United Nations*, 26 June 1945, Can. T.S. 1945 No. 7, 59 Stat. 1031, 145 U.K.T.S. 805, 24 U.S.T. 2225, T.I.A.S. No. 7739.

[2] UN General Assembly, *Historical Summary on the Consideration of the Question on the Definition and Delimitation of Outer Space, Report of the Secretariat,* Committee on the Peaceful Uses of Outer Space, A/AC.105/769 (18 January 2002).

[3] Frans von der Dunk, "The Sky is the Limit — But Where Does It End?" *Proceedings of the Forty-Eighth Colloquium on the Law of Outer Space* (2006) at 84-94.

[4] Ivan A. Vlasic, "The Legal Aspects of Peaceful and Non-Peaceful Uses of Outer Space," in Bupendra Jasani, ed., *Peaceful and Non-Peaceful Uses of Space: Problems of Definition for the Prevention of an Arms Race in Outer Space* (London: Taylor and Francis, 1991).

[5] The US interpretation of "peaceful" as synonymous with "non-aggressive" was a logical extension of the US effort to gain international recognition of the permissibility of reconnaissance satellites while simultaneously discouraging military space activities that threatened these assets — two major goals of US policy during the period predating the Outer Space Treaty (1957-67). See Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945-84* (Ithaca, NY: Cornell University Press, 1988) at 59-71.

[6] SpaceWar.com. "China Says Anti Satellite Test Did Not Break Rules," 12 February 2007, online: http://www.spacewar.com/reports/China_Says_Anti_Satellite_Test_Did_Not_Break_Rules_999.html.

[7] Elizabeth Waldrop, "Weaponization of Outer Space: U.S. National Policy," *High Frontier* (Winter 2005) at 37, online: The University of Michigan Law School, www.law.umich.edu/curriculum/workshops/governance/WkshpPaper2006_Waldrop.pdf.

[8] Ram Jakhu, "Legal Issues Relating to the Global Public Interest in Outer Space", 32 *Journal of Space Law* (2006) at 41.

[9] Lucy Stojak, "Key Concepts in Space Arms Control," Report to Foreign Affairs Canada (February 2005) at 11.

[10] *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, 27 January 1967, 610 U.N.T.S. 205, 18 U.S.T. 2410, T.I.A.S. No. 6347, 6 I.L.M. 386 (hereafter *Outer Space Treaty*) (entered into force on 10 October 1967).

[11] "Convention on International Liability for Damage Caused by Space Objects," Article II; convention opened for signature 29 March 1972, entered into force 1 September 1972.

[12] Peter Haanappel, "Enforcing the Liability Convention: Ensuring the Binding Force of the Award of Claims Commission," in Marietta Benko and Kai-Uwe Schrogl, eds., *Space Law: Current problems and perspectives for future regulation* (Utrecht: Eleven International Publishing, 2005) at 115.

[13] United Nations Office for Outer Space Affairs, "Convention of Registration of Objects Launched into Outer Space" (2006), online: http://www.unoosa.org/oosa/en/SORegister/nat_reg_notif_idx.html (date accessed: 16 June 2008).

[14] Kai-Uwe Schrogl and Niklas Hedman, "The results of the UNCOPUOS Legal Subcommittee Working Group on 'Practice of States and international organizations in registering space objects' 2005-2007," International Astronautical Congress (2007) at 3.

[15] Bernhard Schmidt-Tedd and Michael Gerhard, "Registration of Space Objects: Which are the Advantages for States Resulting from Registration?" in Marietta Benko and Kai-Uwe Schrogl, eds., *Space Law: Current problems and perspectives for future regulation,* at 122. For details see Jonathan McDowell, "Adherence to the 1976 Convention on Registration of Objects Launched into Outer

Space" (11th Ed., Revised July 15, 2007), online: Jonathan's Space Page, http://www.planet4589.org/space/un/un_paper1.html#Tab1; United Nations Office for Outer Space Affairs, "Convention of Registration of Objects Launched into Outer Space."

16 Reuters, "Large Nations Fail to Register Satellites" (17 August 2001).

17 COPUOS Legal Subcommittee, *Practice of States and international organizations in registering space objects: Working paper submitted by the Chairman of the Working Group on the Practice of States and International Organizations in Registering Space Objects*, 46th Sess., UN Doc. A/AC.105/C.2/L.266 (2007); COPUOS Legal Subcommittee, *Report of the Legal Subcommittee of the Committee on Peaceful Uses of Outer Space on its Forty-Sixth Session held in Vienna from 26th March to 5th April 2007*, 46th Sess., UN Doc. A/AC.105/891 (2007) at 20; UNGAOR, *Report of the Committee on Peaceful Uses of Outer Space*, 62nd Sess., Supp. No. 20, UN Doc. A/62/20 (2007) at 30-31; UNGAOR, *Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects*, GA Res. A/RES/62/101, 62nd Sess. (2007).

18 *Agreement Governing the Activities of States on the Moon and other Celestial Bodies*, 5 December 1979, 1363 U.N.T.S. 3, 18 I.L.M. 1434 (hereafter *Moon Agreement*) (entered into force 11 July 1984), Article 3(4).

19 *Moon Agreement*.

20 Union of Concerned Scientists, "Backgrounder: International Legal Agreements Relevant to Space Weapons," (February 2004), online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1157.

21 United Nations General Assembly Resolution Database, online: http://www.un.org/documents/resga.htm (date accessed: 10 July 2008).

22 UNGA, "UNGA First Committee Voting Record on Prevention of an Arms Race in Outer Space," A/C.1/60/L.27 (25 October 2005), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/1com/1com05/votes/L.27.pdf .

23 Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control* (Washington, DC: US Government Printing Office, September 1985) at 93.

24 *Outer Space Treaty*, Article III.

36 Given the usefulness of some space technologies in the development of missiles, MTCR export controls are perceived by some countries, notably those outside the regime, as a restrictive cartel impeding access to space.

37 See Missile Technology Control Regime Website, online: http://www.mtcr.info/english/index.html.

38 Brought into effect on 25 November 2002.

39 Michel Bourbonnière, "LOAC and the Neutralization of Satellites or IUS in Bello Satellitis" in *International Security Research and Outreach Programme Report* (Department of Foreign Affairs and International Trade, Canada, May 2003) at 17-23.

40 Ambassador Thomas Graham Jr., "The Law and the Military Uses of Outer Space," Speech delivered at the Naval War College, Newport, Rhode Island (1 May 2003), online: Eisenhower Institute, http://www.eisenhowerinstitute.org/programs/globalpartnerships/fos/newfrontier/grahambriefing.htm.

41 Dr. Peter Van Fenema, interview by author, McGill University, Montreal, 25 February 2005.

42 UNGA, "Review of the Implementation of the Recommendations of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space," A/59/174 (23 July 2004); UNISPACE III Conference, "Vienna Declaration on Space and Human Development Adopted by UNISPACE III, as it Concludes Two-Week Session," Press Release (30 July 1999), online: http://www.un.org/events/unispace3/.

43 Detlev Wolter, *Common Security in Outer Space and International Law*, UNIDIR/2005/29 (Geneva: United Nations Institute for Disarmament Research) at 132.

44 Detlev Wolter, *Common Security in Outer Space and International Law,* at 131-136.

45 CD, "Possible Elements of the Future International Legal Instrument on the Prevention of the Weaponization of Outer Space," CD/1645 (6 June 2001).

[46] United Nations General Assembly, "Transparency and confidence-building measures in outer space activities," Resolution A/Res/60/66 (6 January 2006), online: http://disarmament.un.org/vote.nsf/5063335733dce716852570c200516189/479505242538e0d5852570a1004a6bd8/$FILE/60-66.pdf.

[47] Union of Concerned Scientists, "A Treaty Limiting Anti-Satellite Weapons" (May 1983), online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1153.

[48] The Henry L. Stimson Center, "Model Code of Conduct for the Prevention of Incidents and Dangerous Military Practices in Outer Space" (2004), online: http://www.stimson.org/wos/pdf/codeofconduct.pdf.

[49] The Henry L. Stimson Center website, endorsements page, online: http://www.stimson.org/space/?SN=WS200701191170 (date accessed: 10 July 2008). The concept of a Code of Conduct has been endorsed by representatives from US Strategic Command, the EU, Canada, France, Intelsat, the US Congress, as well as by publications including *The Economist, Space News*, and *Aviation Week and Space Technology*.

[50] United Nations Institute for Disarmament Research, "Building the Architecture for Sustainable Space Security," Conference Report, Geneva (30-31 March 2006).

[51] UNGAOR, *Report of the UNGA First Committee, Prevention of an Arms Race in Outer Space,* 63rd Sess., A/C.1/63/L.4 (2008).

[52] Karen E. House, Statement to the 63rd Session of the United Nations General Assembly Delivered in the Debate on Outer Space (Disarmament Aspects) of the General Assembly's First Committee, 20 October 2008, online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/1com/1com08/statements/20OctUS.pdf.

[53] *Draft Resolution on transparency and confidence-building measures in outer space activities*, 63rd Sess., UN Doc. A/C.1/63/L..44/Rev.1, http://rescommunis.wordpress.com/2008/11/02/russian-draft-resolution-on-space-weapons-endorsed-by-the-first-committee/.

[54] Reaching Critical Will, "First Committee Monitor, final edition 2008," online: http://www.reachingcriticalwill.org/political/1com/FCM08/final.html#space.

[55] *Report of the Secretary-General, Transparency and confidence-building measures in outer space activities,* UNGAOR, 63rd Sess., UN Doc. A/63/136/Add.1 (2008); P.J. Blount, "First Committee Approves Resolution on the Prevention of an Arms Race in Outer Space," *Space Law*, 30 October 2008.

[56] NASA, *Space Debris Assessment for USA-193*. Presentation to the 45th Session of the Scientific and Technical Subcommittee Committee on the Peaceful Uses of Outer Space United Nations, 11-22 February 2008, http://www.oosa.unvienna.org/pdf/pres/stsc2008/tech-16.pdf.

[57] UNGA, *Report of the Scientific and Technical Subcommittee on its forty-fifth session, held in Vienna from 11 to 22 February 2008*, http://www.oosa.unvienna.org/pdf/reports/ac105/AC105_911E.pdf, at 4.

[58] Ambassador Christina Rocca, Statement to the Conference on Disarmament, 15 February 2008, online: http://www.unog.ch/80256EDD006B8954/(httpAssets)/DE7EEEEB629D982FC12573F0004A1E07/$file/Statement+by+Ambassador+Rocca.pdf.

[59] Ambassador Christina Rocca, Statement to the Conference on Disarmament, 15 February 2008, online: http://www.unog.ch/80256EDD006B8954/(httpAssets)/DE7EEEEB629D982FC12573F0004A1E07/$file/Statement+by+Ambassador+Rocca.pdf.

[60] Noah Shachtman, "Experts Scoff at Sat Shoot-Down Rationale (Updated), *Wired*, 15 February 2008, online: http://www.wired.com/dangerroom/2008/02/fishy-rationale/; Marc Kaufman and Josh White, "Satellite Fuel's Risks Are Disputed," *Washington Post* (21 February 2008) at 3; WMD Insights, "U.S. Satellite Shoot-Down Evokes International Concern and Criticism," Issue 24 (April 2008), online: http://www.wmdinsights.org/I24/I24_G1_US_Satellite.htm.

[61] AFP, "US satellite shoot-down part of space 'arms race: Russia," 17 February 2008, online: Google News, http://afp.google.com/article/ALeqM5glO8NOCFzDgV7U_hdEkpXxjgrx8Q; WMD Insights, "U.S. Satellite Shoot-Down Evokes International Concern and Criticism," Issue 24 (April 2008).

[62] Tom Bowman, "China Protests after U.S. Shoots Down Satellite," NPR, 21 February 2008, online: http://www.npr.org/templates/story/story.php?storyId=19246330; WMD Insights, "U.S. Satellite Shoot-Down Evokes International Concern and Criticism," Issue 24 (April 2008); Ministry of Foreign Affairs of the People's Republic of China, "Foreign Ministry Spokesperson Liu Jianchao's

Remarks on the US Plan to Destroy Malfunctioning Satellite," 18 February 2008, online: http://www.fmprc.gov.cn/eng/ewfw/s2510/2511/t409230.htm.

63 Council of the European Union, *Council conclusions and draft Code of Conduct for outer space activities,* 3 December 2008, online: http://register.consilium.europa.eu/pdf/en/08/st16/st16560.en08.pdf.

64 Council of the European Union, *Council conclusions and draft Code of Conduct for outer space activities,* 3 December 2008, online: http://register.consilium.europa.eu/pdf/en/08/st16/st16560.en08.pdf;

65 Jeff Abramson, "EU Issues Space Code of Conduct," *Arms Control Today* (January/February 2009), online: http://www.armscontrol.org/act/2009_01-02/eu_issues_space_code_conduct.

66 UNGA, Agenda Item 89, First Committee, *General and complete disarmament*, 63rd Sess., UN Doc. A/C.1/63/L.38 (2008), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/1com/1com08/res/L38.pdf.

67 Wade Boese, "Russia Halts Missile Launch Notices," *Arms Control Today* (March 2008), online: http://www.armscontrol.org/act/2008_03/RussiaHalts.

68 7th Regular Meeting of the Hague Code of Conduct against Ballistic Missile Proliferation, "Statement of the Republic of Slovenia on behalf of Mr. Bojan Bertoncelj (Vienna, 29 May 2008), online: http://74.125.113.132/search?q=cache:D4VeJX96b6wJ:www.eu2008.si/en/News_and_Documents/Statements_in_International_Organisations/May/0529hague.html+HAGUE+code+of+conduct+2008+implementation&hl=en&ct=clnk&cd=1.

69 Wade Boese, "Russia Halts Missile Launch Notices," *Arms Control Today* (March 2008), online: http://www.armscontrol.org/act/2008_03/RussiaHalts; Representative of Brazil, "Explanation of Vote – (After the Vote) – Resolution L.38, Online: http://www.reachingcriticalwill.org/political/1com/1com08/EOV/BrazilL38.pdf.

70 Representative of India, "Explanation of Vote — Resolution contained in L38: The Hague Code of conduct against Ballistic Missiles," 28 October 2008, online: http://www.reachingcriticalwill.org/political/1com/1com08/EOV/IndiaL2L5L28L38L40L58.pdf.

71 UNGA, "Missiles," A/RES/63/55 (2008), online: http://daccess-ods.un.org/access.nsf/Get?Open&DS=A/RES/63/55&Lang=E; UNGA. "Missiles," A/RES/61/59 (2006), online: http://daccess-ods.un.org/access.nsf/Get?Open&DS=A/RES/61/59&Lang=E; UNGA, "Missiles," A/RES/59/67 (2004), online: http://daccess-ods.un.org/access.nsf/Get?Open&DS=A/RES/59/67&Lang=E.

72 UNGA, "The issue of missiles in all its aspects: Report of the Secretary General," UN Doc. A/63/176 (2008), online: http://www.unidir.ch/pdf/activites/pdf2-act367.pdf; UNGA, "The issue of missiles in all its aspects: Report of the Secretary General," UN Doc. A/59/278 (2004), online: http://www.unidir.ch/pdf/activites/pdf2-act397.pdf; UNGA, "The issue of missiles in all its aspects: Report of the Secretary General," UN Doc. A/57/229 (2002), online: http://daccess-ods.un.org/access.nsf/Get?Open&DS=A/57/229&Lang=E.

73 UNGA, Vote Count, 1st Committee, "Missiles," A/C.1/63/L.27 (2008), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/1com/1com08/votes/L27.pdf; UNGA, Vote Count, 1st Committee, "Hague Code of Conduct Against Ballistic Missile Proliferation," A/C.1/63/L.38 (2008), online: http://www.reachingcriticalwill.org/political/1com/1com08/votes/L38.pdf.

74 UNGA, *United Nations Report of the Committee on the Peaceful Uses of Outer Space,* A/60/20 (2005).

75 *Orbital Debris Quarterly News,* " Space Debris Mitigation Guidelines at the UN," 9 (July 2005) at 1.

76 See "Working Paper on the Prevention of an Arms Race in Outer Space," submitted by the Mongolian People's Republic to the Committee on Disarmament, CD/272 (5 April 1982).

77 UNGA, "Prevention of an Arms Race in Outer Space," A/RES/40/87 (12 December 1985). See also CD, "Mandate for the Ad Hoc Committee under item 5 of the agenda of the Conference on Disarmament entitled Prevention of an Arms Race in Outer Space," CD/1059 (14 February 1991) and previous documents under the same title.

78 These recommendations included improved registration and notification of information, the elaboration of a code of conduct or of rules of the road as a way to reduce the threat of possible incidents in space, the establishment of "keep-out zones" around spacecraft, the elaboration of

an agreement dealing with the international transfer of missile technology and other sensitive technology, and widening the protection offered to certain satellite systems under US-USSR/Russia arms control agreements.

79 Reaching Critical Will, "Conference on Disarmament Adopts Annual Report to General Assembly and Closes 2008 Substantive Session," (9 September 2008), online: http://www.reachingcriticalwill.org/political/cd/press08/3session/Sept9.html.

80 Conference on Disarmament, "Draft Decision by the Presidents of the 2008 Session of the Conference on Disarmament," CD/1840; *Disarmament Diplomacy*, "The Conference on Disarmament in 2008: Still in Denial," No. 88 (Summer 2008).

81 United Nations Office at Geneva, "*Conference on Disarmament Hears Address by Foreign Minister of Russia and Message by Chinese Minister for Foreign Affairs,"* 12 February 2008; Peter Brookes, "Marking the boundaries of weapon use in space," *Jane's Defence Weekly* (30 July 2008); WMD Insights, "U.S. Satellite Shoot-Down Evokes International Concern and Criticism," Issue 24 (April 2008).

82 CD, *Working Paper Presented by the Delegations of China, the Russian Federation, Vietnam, Indonesia, Belarus, Zimbabwe and Syria, Possible Elements for a Future International Legal Agreement on the Prevention of the Deployment of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects,* 27 June 2002, online: http://www.reachingcriticalwill.org/political/cd/speeches02/chiruswp_062702cd.html.

83 Marus Grinius, "General Statement by Marius Grinius Ambassador and Permanent Representative of Canada to the Conference on Disarmament" (12 February 2008), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/papers08/1session/Feb12%20Draft%20PPWT.pdf.

84 Marius Grinius, "General Statement by Marius Grinius Ambassador and Permanent Representative of Canada to the Conference on Disarmament" (12 February 2008), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/papers08/1session/Feb12%20Draft%20PPWT.pdf.

85 See statements under "PAROS" at Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/speeches08/topics.html#paros.

86 Marius Grinius, "General Statement by Marius Grinius Ambassador and Permanent Representative of Canada to the Conference on Disarmament" (12 February 2008), online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/speeches08/1session/Feb12Canada_english.pdf.

87 Ambassador Christina Rocca, "Letter dated 19 August 2008 from the permanent representative of the United States of America addressed to the Secretary-General of the conference transmitting comments on the draft 'Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects (PPWT)' as contained in document CD/1839 of 29 February 2008," CD/1847, 26 August 2008, online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/papers08/3session/CD1847.pdf.

88 Ray Acheson, *CD Report* (12 February 2008) online: Reaching Critical Will, http://www.reachingcriticalwill.org/political/cd/speeches08/reports.html#feb12.

89 UNCOPUOS, *Future role and activities of the Committee on the Peaceful Uses of Outer Space*, working paper submitted by the Chairman, 50th Sess., UN Doc. A/AC.105/L.268 (10 May 2007).

90 Presentation provided to the author. Gerard Brachet, "CD PAROS," Geneva (20 February 2008); Theresa Hitchens, "COPUOS wades into the next great space debate," *Bulletin of the Atomic Scientists* (26 June 2008).

91 Presentation provided to the author. Gerard Brachet, "CD PAROS," Geneva (20 February 2008).

92 H.R. 6063, "National Aeronautics and Space Administration Authorization Act of 2008," H.R. 6063 (Enrolled as Agreed to or Passed by Both House and Senate), Section 1102, Public Law no: 110-422; Office of Management and Budge, "Statement of Administration Policy H.R. 6063-National Aeronautics and Space Administration Authorization Act of 2008," (16 June 2008), online: SpaceRef.com http://www.spaceref.com/news/viewsr.html?pid=28315

93 Office of Science and Technology Policy, *US National Space Policy* (6 October 2006), online: http://www.ostp.gov/html/US%20National%20Space%20Policy.pdf.

94 *US National Space Policy*.

95 *Itar-Tass,* "Russia May Cooperate with US in Space Programs" (21 January 2004).

96 European Space Agency Permanent Mission in Russia, online: European Space Agency http://www.esa.int/SPECIALS/ESA_Permanent_Mission_in_Russia/index.html (date accessed: 10 July 2008).

97 Space.com, "Russia, China Discuss Joint Space Projects" (9 November 2006), online: http://www.space.com/news/061109_russia_china_missions.html; Vinay Shukla, "Putin Clears Space Pact with India," Rediff India Abroad (6 November 2006), online: http://www.rediff.com/news/2006/nov/06russia.htm.

98 Susan Eisenhower, Thomas Graham Jr., and Robert J. Lawson, *Space Security 2003* (Toronto: Northview Press, 2004) at 37.

99 *RIA Novosti,* "Russia to remain Leading Space Power — Head of Roscomosmos," (19 August 2005).

100 Information Office of the State Council of the People's Republic of China, "China's Space Activities in 2006" (October 2006), online: People's Daily Online, http://english.peopledaily.com.cn/20061012_311157.html.

101 Information Office of the State Council of the People's Republic of China, "China's Space Activities" (2000), online: People's Daily Online, http://english.peopledaily.com.cn/features/spacepaper/spacepaper.html.

102 Signatories include China, Iran, Republic of Korea, Mongolia, Pakistan, and Thailand.

103 "China's Space Activities" (2000).

104 Indian Space Research Organisation, "International Cooperation," online: http://www.isro.org/international.htm (date accessed: 10 July 2008).

105 David Long, "The Evolution and Shape of European Space Policy," Report to Foreign Affairs Canada (May 2004) at 18.

106 EC, *Communication from the Commission to the Council and the European Parliament: European Space Policy* at 8.

107 European Parliament, "European Parliament resolution of 10 July 2008 on Space and security," (2008/2030[1N1]), http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P6-TA-2008-0365.

108 ASI (Italy), BNSC (United Kingdom), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA, ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia). See NASA, *The Global Exploration Strategy: The Framework for Coordination,* online: http://www.nasa.gov/pdf/178109main_ges_framework.pdf .

109 *The Global Exploration Strategy: The Framework for Coordination* at 2.

110 *Government Gazette, Republic of South Africa*, South African National Space Agency Act, 2008. http://www.info.gov.za/view/DownloadFileAction?id=94358.

111 *Space Travel Exploration and Tourism,* "South Africa To Establish Space Agency" (21 January 2009) online: http://www.space-travel.com/reports/South_Africa_To_Establish_Space_Agency_999.html.

112 Joint Publication 3-14 is all but silent on the space strike mission, stating only that "currently there are no space force application assets operating in space." US Department of Defense, *Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations,* Joint Publication 3-1 (9 August 2002) at x.

113 US Department of Defense, *Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations,* at x.

114 US Air Force, Future Concepts and Transformation Division, *Transformation Flight Plan* (November 2003), online: http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf.

115 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1 (2 August 2004) at 2. This document represents the views of the USAF and not necessarily those of the US Government.

116 For a discussion of the spectrum of views regarding space weapons see Peter L. Hays, "Current and Future Military Uses of Space," *Outer Space and Global Security* (Geneva: UNIDIR, 2003) at 21-64.

117 US Department of Defense, S*pace Policy Directive 3100.10* (Updated 9 July 1999).

118 US Department of Defense*, Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations,* Joint Publication 3-14; US Air Force, *2004 USAF Posture Statement* (2003).

119 National Missile Defense Act of 1999, Public Law 106-38 (6 January 1999).

[120] US National Space Policy.

[121] See Government of the Russian Federation, "The Basic Provisions of the Military Doctrine of the Russian Federation," *FBIS-SOV* 19, no. 222 (1993), Section 3.1, first published *Rossiiskie vesti* (18 November 1992) at 1-2; Government of the Russian Federation, "Draft Russian Military Doctrine," *BBC Monitoring* (1999), Section 1.5, first published *Krasnaya Zvezda* (9 October 1999) at 3-4; Government of the Russian Federation, "Russian Federation Military Doctrine" *Nezavisimaya Gazeta* (22 April 2000), Section I.5; Russian Federation Ministry of Defence, "Russian Federation Ministry of Defence Brochure: Urgent Tasks of the Development of the Russian Federation Armed Forces," Moscow (2003), Section II at 13.

[122] Government of the Russian Federation, "Draft Russian Military Doctrine," *BBC Monitoring* (9 October 1999), Section 1.10.a.

[123] Government of the Russian Federation, "Russian Federation Military Doctrine," *Nezavisimaya gazeta* (22 April 2000), Section II.3; Russian Federation Ministry of Defence, "Russian Federation Ministry of Defence Brochure: Urgent Tasks of the Development of the Russian Federation Armed Forces," Moscow (2003), Section IV at 18-19.

[124] Interfax, "Putin Reiterates Priorities in Developing Space Forces" (7 April 2003).

[125] Interfax, "Svobodny Cosmodrome Has Special Role in Russia's Space Programs — Space Troops Chief" (14 April 2003).

[126] Andrew Gowers, Robert Cottrell, and Andrew Jack, "Transcript: Interview with Vladimir Putin, 13 December," *Financial Times* (15 December 2001) at 2.

[127] Steve Gutterman, "Reports: Russia threatens retaliatory steps if any country deploys weapons in space," Associated Press (2 June 2005); Rebecca Johnson, "PAROS Discussions at the 2004 UN First Committee" (20 October 2004), online: Acronym Institute for Disarmament Diplomacy, http://www.acronym.org.uk/un/2004paro.htm.

[128] "China's Space Activities in 2006."

[129] Government of China State Council Information Office, "China's National Defense in 2004" (27 December 2004), online: Federation of American Scientists, http://www.fas.org/nuke/guide/china/doctrine/natdef2004.html.

[130] Information Office of the State Council, People's Republic of China, "China's National Defense in 2006" (29 December 2006), online: FAS, http://www.fas.org/nuke/guide/china/doctrine/wp2006.html.

[131] K.K. Nair, *Space, the Frontiers of Modern Defence* (India: Centre for Air Power Studies, 2006) at 75. The author notes that China's PLA "has outlined its mission regarding military space as consisting of two categories. The first is information supporting, and the second, battlefield combating, which loosely corresponds to missions of force enhancement and counter-space operations in western parlance."

[132] Martin Staff, "China Officially Announces Anti-Satellite Test Successful," Spacewar (24 January 2007), online: http://www.spacewar.com/reports/China_Officialy_Announces_Anti_Satellite_Test_Successful_999.html.

[133] "Space: A New European Frontier for an Expanding Union: An Action Plan for Implementing the European Space Policy," White Paper, European Commission (2003) at 6-7, online: The European Union, http://europa.eu.int/comm/space/whitepaper/pdf/spwhpap_en.pdf.

[134] Dr. Thomas Beer, ESA HQ, Paris — Security Strategy and Partnership Development Office, "The European Space Agency: Enhancing the European Space and Defence Policy," Presentation at the International Space Security Conference, Scope and Prospects for Global Cooperation, Institute for Defence Studies and Analyses and Centre for Defence and International Security Studies, New Delhi (13-14 November 2007), online: Space Security Programme, http://www.spacesecurityprogramme.org/uploads/ssp/space_sec_session%201_Dr.%20Thomas%20Beer.pdf.

[135] European Commission, *Report of the Panel of Experts on Space and Security*, Project Number 200446 (1 March 2005) at 26, online: European Union http://europa.eu.int/comm/space/news/article_2262.pdf.

[136] Assembly of the Western European Union, *Space and the ESDP,* Assembly Fact Sheet No. 7 (December 2007), online: http://www.assembly-weu.org/en/documents/Fact%20sheets/Fact%20sheet%207E%20PESD%20et%20Espace.pdf?PHPSESSID =f3137d60.

[137] EC, *Communication from the Commission to the Council and the European Parliament: European Space Policy*, COM (2007) 212 final (26 April 2007) at 8.

[138] Michèle Alliot-Marie, "Discours de Madame le Ministre de la Défense: Lancement du satellite HELIOS II," Ministry of Defence (18 December 2004).

[139] *Convention for the Establishment of a European Space Agency*, open for signature 30 May 1975, entered into force 30 October 1980, 14 ILM 864, Article II.

[140] Barbara Opall-Rome, "Air Force to Lead Israel's Military Activities in Space," *Defense News* (27 February 2006), online: http://www.defensenews.com/story.php?F=1556062&C=mideast. See also Diganit Paikowsky, "Israel's space program as a national asset," 23 *Space Policy* (2007) at 90-96.

[141] Space War, "India Begins Work on Space Weapons Command" (12 April 2006), online: http://www.spacewar.com/reports/India_Begins_Work_On_Space_Weapons_Command.html.

[142] *The Indian Express,* "Army to unveil Space Vision 2020 at commanders' meet" (23 October 2007), online: http://www.indianexpress.com/story/231390.html.

[143] Rahul Bedi, "IAF draft defence doctrine envisages a broader role," *Jane's Defence Weekly* (22 August 2007) at 14; *The Indian Express,* "Army to unveil Space Vision 2020 at commanders' meet" (23 October 2007).

[144] Department of National Defence, Canada, *Strategic Vectors: Air Force Transformation Vision* (2004) at 14-16.

[145] *Space News,* "Japan's Improved Space Policy" (2 June 2008); Kazuto Suzuki, "A Brand New Space Policy or Just Papering Over a Political Glitch? Japan's New Space Law in the Making." *Space Policy*, 24:4 (November 2008) at 171-174.

[146] Res Communis, "Japan's Basic Space Law Enters into Force,",(29 August 2008), citing the Daily Yomiuri website in Japanese, online: http://rescommunis.wordpress.com/2008/08/29/japans-basic-space-law-enters-into-force/.

[147] Possible early applications could be missile warning and communications as described in the cited article. *Space News,* "Japan's Improved Space Policy" (2 June 2008).

[148] Setsuko AOKI, "Introduction to the Japanese Basic Space Law of 2008," 57:4 *Zeitschrift foer Luft-unt Weltraumrecht*, at 585-589.

[149] Keiji Tachikawa, "2009: A New Era for Japan's Space Program," JAXA, online: http://www.jaxa.jp/article/interview/vol44/index_e.html.

[150] Japan Ministry of Defense. *Defense of Japan 2008*, Chapter 2, Section 2, online: http://www.mod.go.jp/e/publ/w_paper/2008.html.

[151] Wendell Minnick, "Japan Issues Defense Paper Despite Leadership Gap," *Defense News* (8 September 2008), online: http://www.mod.go.jp/e/publ/w_paper/2008.html.

[152] *Xinhua,* "China to modernize military while pursuing peaceful development" (20 January 2009); the full text of the paper is available online: http://www.chinadaily.com.cn/china/2009-01/20/content_7413294.htm.

[153] *Chinese Government News,* "China's National Defense in 2008: White Paper on National Defense Published" (26 January 2009), online: http://www.defencetalk.com/news/publish/defence/China_s_National_Defense_in_2008_White_Paper_on_National_Defense_Published30016968.php.

[154] Chinese White Paper on National Defense 2008, online: http://www.china.org.cn/government/central_government/2009-01/20/content_17155577_4.htm; Trefor Moss, "Space Race," *Jane's Defence Weekly* (29 October 2008) at 28.

[155] Chinese White Paper on National Defense 2008, Section XIV, "Prevention of the Introduction of Weapons and an Arms Race in Outer Space," online: http://www.china.org.cn/government/central_government/2009-01/20/content_17155577_4.htm.

[156] Chinese White Paper on National Defense 2008, Section XI, online: http://www.china.org.cn/government/central_government/2009-01/20/content_17155577_4.htm.

[157] The French White Paper on Defense and National Security, Volume 3, No. 46 (December 2008), CSS Analyses in Security Policy.

[158] The French White Paper on Defense and National Security, Section 14.

[159] The French White Paper on Defense and National Security, Section 14.

160 The French White Paper on Defense and National Security, Section 14.

161 *Defense Industry Daily*, "French President Tries to Set French Defense on a New Course" (3 November 2008), online: http://www.defenseindustrydaily.com/French-President-Tries-to-Set-French-Defense-on-a-New-Course-04937/.

162 The French White Paper on Defense and National Security, Section 13.

163 The French White Paper on Defense and National Security, Section 14.

164 Ben Iannotta, "How far will America go to protect its satellites?" *C4ISR Journal* (1 June 2008), online: http://www.c4isrjournal.com/story.php?F=3502048.

165 Andew Palowitch quoted in *C4ISR Journal*, "U.S. space protection strategy emphasizes cooperation (2 October 2008), online: http://www.c4isrjournal.com/story.php?F=3754428.

166 European Parliament, European Parliament resolution of 10 July 2008 on Space and security, online: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P6-TA-2008-0365

167 Adopted on 26 September 2008. Council of the European Union. *Council Resolution Taking forward the European Space Policy,* Brussels (26 September 2008), online: http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/intm/103050.pdf

168 Peter B. de Selding, "European Leaders Endorse Military Role for Galileo," *Defence News* (6 October 2008) at 58; Peter B. de Selding, "European Defence Agency Has Growing Interest in Military Space," *Space News* (6 October 2008) at 12.

Chapter Three Endnotes

1 Data from Gunter Dirk Krebs, online: Gunter's Space Page, http://www.skyrocket.de/space/ (date accessed: 10 June 2009). Dark grey indicates an independent orbital launch capability and dots indicate launch sites.

2 Krebs, "Gunter's Space Page."

3 Surrey Satellite Technology Ltd., online: http://www.sstl.co.uk/Missions/Mission_Heritage (date accessed: 10 June 2009).

4 Indian Space Research Organisation, *Indian Space Research Organisation Annual Report 2005-2006* (2007), online: http://www.isro.org/rep2007/Earth%20Observation.htm; "Army's satellite based surveillance and intelligence program near completion," *India Defence* (18 September 2006), online: http://www.india-defence.com/reports/2519.

5 "Major US Civilian Satellites In Military Use," *Air Force Magazine* (1 August 1997) at 25, online: Milnet, http://www.milnet.com/pentagon/sats/cmsats.htm; "COSMO-Skymed," Defense-Update, online: http://defense-update.com/products/s/skymed.htm (date accessed: 10 June 2009).

6 PTI, "ISRO to Launch New Genre of Micro-Satellites," Space Daily (10 September 2007), online: http://www.spacedaily.com/reports/ISRO_To_Launch_New_Genre_Of_Micro_Satellites_999.html.

7 Jonathan's Space Report, "Satellite Catalogue and Launch Catalogue," online: http://planet4589.org/space/log/satcat.txt (date accessed: 10 June 2009).

8 See Annex 4. Information collected from FAA, "Year in Review 2008"; Dr. Jonathan McDowell; and Gunter's Space Page, http://www.skyrocket.de/space/.

9 T. Thanhvan, "Vietnam's First Satellite Launched After 13-Year Preparation," XNA (21 April 2008), online: Space Mart, http://www.spacemart.com/reports/Vietnam_First_Satellite_Launched_After_13_Year_Preparation_999.html.

10 A. Daniels, "Venezuela joins space club nations," *BBC World* (29 October 008), online: http://news.bbc.co.uk/2/hi/americas/7697130.stm; *China View,* "China launches telecom satellite for Venezuela" (30 October 2008), online: http://news.xinhuanet.com/english/2008-10/30/content_10276834.htm.

11 *Government Gazette,* "South African National Space Agency Act, 2008," No. 31729, Issue 522 (15 December 2008).

[12] SPX, "South Africa to Establish Space Agency," Space Travel (21 January 2009), online: http://www.space-travel.com/reports/South_Africa_To_Establish_Space_Agency_999.html.

[13] K. Campbell, "Russia to offer technical support to new SA space agency," *Engineering News* (16 January 2009), online: http://www.engineeringnews.co.za/article/russia-to-offer-technical-support-for-new-sa-space-agency-2009-01-16.

[14] Information from the website of the future agency available online: http://www.aexa.divaac.org/eng.html (date accessed: 10 June 2009). See also the information on the initiative at the Mexican Senate available online: http://www.senado.gob.mx/comisiones/LX/cyt/content/docs_discusion/index_docsdiscusion.htm (in Spanish, accessed: 10 June 2009).

[15] Reuters, "Russia to Help Cuba Build Space Center" (17 September 2008), online: http://www.reuters.com/article/scienceNews/idUSLH47851920080917.

[16] Satnews Daily, "Development of an Arab Space Agency Being Discussed" (30 October 2008), online: http://www.satnews.com/cgi-bin/story.cgi?number=1635810947.

[17] P. Hafezi and F. Dahl, "Iran tests rocket, plans to launch satellite," Reuters (4 February 2008), online: http://www.reuters.com/article/worldNews/idUSL0423337120080204; Space Travel, "Iran gives details on controversial space launch" (19 February 2008), online: http://www.space-travel.com/reports/Iran_gives_details_on_controversial_space_launch_999.html ; *BBC News,* "Iran launches satellite carrier" (17 August 2008), online: http://news.bbc.co.uk/2/hi/in_depth/7566804.stm; James Oberg, "Iran tried, but failed, to launch satellite," MSNBC (19 August 2008), online: http://www.msnbc.msn.com/id/26294174/; Geoffrey Forden, "Smoke and mirrors: Analysing the Iranian missile test," *Jane's Intelligence Review* (April 2008) at 47-51.

[18] Geoffrey Forden, "Smoke and Mirrors."

[19] Joseph S. Bermudez Jr. and Tim Brown, Briefing, "North Korea's New Missile Facility," *Jane's Defence Weekly* (17 September 2008) at 30-31.

[20] AFP, "Brazil Hopes to Launch Satellite Rocket in 2011: Report" (21 October 2008), online: Space Travel, http://www.space-travel.com/reports/Brazil_hopes_to_launch_satellite_rocket_in_2011_report_999.html.

[21] XNA,"South Korea's First Rocket Launch Might Be Put Off," Space Travel (24 July 2008), online: http://www.space-travel.com/reports/South_Korea_First_Rocket_Launch_Might_Be_Put_Off_999.html.

[22] Mark Wade, "KSLV-I," *Astronautix*, online: http://www.astronautix.com/lvs/kslvi.htm (date accessed: 10 June 2009).

[23] Kim Tong-hyung, "Rocket Launch Marks First Test for Korean Space Ambitions," *Korea Times* (20 October 2008), online: http://www.koreatimes.co.kr/www/news/nation/2008/10/133_33007.html.

[24] RIA Novosti, "Russia to Test Flight New-Generation Space Rocket In 2010," Space Daily (15 April 2008), online: http://www.spacedaily.com/reports/Russia_To_Test_Flight_New_Generation_Space_Rocket_In_2010_999.html; "A new engine is ready for Angara," (5 September 2008), online: http://www.vz.ru/society/2008/9/5/203826.print.html (in Russian).

[25] European Space Agency, "Successful Qualification Firing Test For Zefiro 23," Space Travel (1 April 2008), online: http://www.space-travel.com/reports/Successful_Qualification_Firing_Test_For_Zefiro_23_999.html.

[26] "China's New Carrier Rocket to Debut in 2014," *Xinhua News* (3 February 2008), online: http://news.xinhuanet.com/english/2008-03/02/content_7702780.htm.

[27] JAXA, "HTV (HT-II) Transfer Vehicle," (26 December 2008), online: http://www.jaxa.jp/projects/rockets/htv/index_e.html.

[28] European Space Agency, "Jules Verne Refuels The International Space Station," Science Daily (20 June 2008), online: http://www.sciencedaily.com/releases/2008/06/080618114613.htm.

[29] Fernand Verger, Isabelle Sourbès-Verger, Raymond Ghirardi and Xavier Pasco, *The Cambridge Encyclopedia of Space* (Cambridge: Cambridge University Press, 2003) at 73-77.

[30] Verger et al., *The Cambridge Encyclopedia of Space,* at 69.

[31] *Jane's Space Directory* (Surrey, UK: Jane's Information Group, 2001) at. 14; European Space Agency, "Annual Report 2006" (July 2007) at 110, online: http://www.esa.int/esapub/annuals/annual06/ESA_AR2006.pdf.

32 Verger et al., *The Cambridge Encyclopedia of Space,* at 96-97.

33 Verger et al., *The Cambridge Encyclopedia of Space,* at 81.

34 Verger et al., *The Cambridge Encyclopedia of Space,* at 68-69.

35 National Aeronautics and Space Administration, “FY 2007 Budget and 2006 Strategic Plan” (2006), online: http://www.nasa.gov/about/budget/index.htm. See annual increases under previous budget statements.

36 *Space News,* “ESA Gets 10 Percent Budget Hike for 2005” (26 January 2005).

37 *The Sunday Morning Herald,* “Top Official Deplores Decline of Russian Space Program” (12 December 2002), online: http://www.smh.com.au/articles/2002/12/11/1039379887168.html; Olga Zhdanovich, discussion with author (Montreal, Quebec, 26 February 2005).

38 *Aviation Week and Space Technology,* “The Government has Approved” (7 November 2005) at 28.

39 RIA, “Russia To Spend More on Space Over Next Decade,” Space Daily (10 April 2006), online: http://www.spacedaily.com/reports/Russia_To_Spend_More_On_Space_Over_Next_Decade.html; *RIA Novosti,* “Russia remains leader in spacecraft launches — space agency” (26 December 2006), online: http://en.rian.ru/russia/20061226/57833667.html. Law on the federal budget, all budget laws with annexes are accessible from Russian Federal Ministry of Finance, online: http://www1.minfin.ru/ru/budget/federal_budget/.

40 K.S. Jayaraman, “Record-Setting Indian Space Budget Includes Funds for Large Satellites,” *Space News* (6 March 2006); “India Expands Human Space Launch Plans With One Third Increase in Space Budget” (28 February 2007), online: Space Ports, http://spaceports.blogspot.com/2007/02/india-funds-human-space-launch-plans.html; ISRO, *Outcome budget of the department of space, government of India 2008-2009,* online: http://www.isro.org/Accounts/OutcomeBudget2008-2009.pdf. Value in original currency is 4074 crores.

41 Dean Cheng, “Dragons in Orbit: China’s Space Program Merits Greater Attention,” *Space News* (21 August 2006). Figures quoted from members of China’s National Space Administration place its budget as high as $2-billion. *Xinhua,* “Chinese spends a 10th of NASA budget on space activities” (12 October 2006), online: http://news.xinhuanet.com/english/2006-10/12/content_5194441.htm. In 2006 Lou Ge, the vice-administrator of the China National Space Administration, estimated the Chinese space budget to be $500-million. Lou Ge quoted in Jeff Foust, “China, competition, and cooperation,” The Space Review (10 April 2006), online: http://www.thespacereview.com/article/599/1.

42 Eric Hagt, *Mutual Assured Vulnerabilities in Spac*e (Washington, DC: World Security Institute, 2006) at 87.

43 N. Peter, “Space Policy, Issues and Trends in 2006/2007” (6 September 2007) at 14, online: European Space Policy Institute, http://www.espi.or.at/images/stories/dokumente/studies/6th%20espi%20report.pdf.

44 Data from Verger et al., *The Cambridge Encyclopedia of Space.*

45 *CNN News,* “Russia Approves Space Funding” (26 October 2005).

46 NASA, Mission Archives, “Space Shuttle” (24 May 2009), online; http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/list_main.html.

47 Christian Science Monitor and Reuters, “Politician urges NASA to postpone shuttle’s retirement,” *Christian Science Monitor* (18 December 2007), online: http://space.newscientist.com/channel/human-spaceflight/space-shuttle/dn13098-politician-urges-nasa-to-postpone-shuttles-retirement.html.

48 CNN, “Bush Unveils Vision for Moon and Beyond” (15 January 2004), online: http://www.cnn.com/2004/TECH/space/01/14/bush.space/; NASA, Release 06-224, “NASA Set to Launch Lunar Reconnaissance Orbiter in 2008” (18 May 2006), online: http://www.nasa.gov/home/hqnews/2006/may/HQ_06224_LRO_update.html.

49 NASA, Release 06-361, “NASA Unveils Global Exploration Strategy and Lunar Architecture” (4 December 2006), online: http://www.nasa.gov/home/hqnews/2006/dec/HQ_06361_ESMD_Lunar_Architecture.html.

50 Verger et al., *The Cambridge Encyclopedia of Space,* at 68-69.

[51] Eiichiro Sekigawa, "Return Vision: Japan's Space Agency Counts ISS at Centre of 20-year Road Map," *Aviation Week and Space Technology* (April 2005) at 32.

[52] K.S. Jayaraman, "India's Space Agency Seeks Government Approval of Human Spaceflight Program," *Space News* (10 November 2006).

[53] Moon Daily, "Japan's Lunar Explorer Enters Observation Orbit" Moon(22 October 2007), online: http://www.Moondaily.com/reports/Japan_Lunar_Explorer_Enters_Observation_Orbit_999.html; "China and ESA Launch Moon Mission — Chang'e-1," Science Daily (25 October 2007), online: http://www.sciencedaily.com/releases/2007/10/071024115241.htm.

[54] As per Deputy Economy Minister P. Hintze, "Germans Shoot the Moon: Space Craft to Enter Lunar Orbit," *Deutsche Welle* (7 November 2007), online: http://www.dw-world.de/dw/article/0,2144,2880216,00.html; European Space Agency, "Chandraayan-1 Overview," online: http://www.esa.int/esaSC/SEM7YH2MDAF_index_0_m.html (date accessed: 10 July 2008); S. Ramachandran, "India Sets Its Sights on Mars," *Asia Times* (19 April 2007), online: http://www.atimes.com/atimes/South_Asia/ID19Df02.html; Reuters, "South Korea Eyes Moon Orbiter in 2020, Lander in 2025" (20 November 2007), online: http://www.reuters.com/article/scienceNews/idUSSEO24596320071120.

[55] Indian Space Research Organisation, "Milestones of the Indian Space Research Organisation (ISRO)," online: http://www.isro.org/mileston.htm (date accessed: 10 June 2009).

[56] Surrey Satellites Technologies Ltd., Press Announcement, "Surrey Launches Two More Satellites from Russia" (10 July 1998), online: http://www.ee.surrey.ac.uk/SSC/CSER/UOSAT/press/tmsat-fasat- pr3.html.

[57] European Commission, *Communication from the Commission to the Council and the European Parliament: European Space Policy*, COM (2007) 212 final (26 April 2007) at 5, online: http://ec.europa.eu/enterprise/space/doc_pdf/esp_comm7_0212_en.pdf.

[58] Space Mart, "China, Brazil give Africa free satellite land images" (28 November 2007), online: http://www.spacemart.com/reports/China_Brazil_give_Africa_free_satellite_land_images_999.html. This intention is also reflected in the Brazilian National Policy, as presented during the COPUOS legal subcommittee in February 2008.

[59] For information about this cooperation see *RIA Novosti,* "China Launches 3rd Earth Observation Satellite" (19 September 2007), online: http://en.rian.ru/world/20070919/79431180.html.

[60] *The Hindu Business Line,* "ISRO Offers Support for Disaster Management in Asia-Pacific" (23 November 2007), online: http://www.thehindubusinessline.com/2007/11/23/stories/2007112352081000.htm.

[61] Global Monitoring for Environment and Security, online: http://www.gmes.info/ (date accessed: 10 June 2009).

[62] OECD, *The Space Economy at a Glance*, International Futures Programme (2007) at 36. Originally sourced OECD/IFP Research (2007).

[63] L.G. Spires, "NASA budget likely to remain steady for 2010," *The Huntsville Times* (31 December 2008), online: http://www.al.com/news/huntsvilletimes/local.ssf?/base/news/1230718590170650.xml&coll=1; *National Aeronautics and Space Administration Authorization Act of 2008* (enrolled as agreed to or passed by both the House of Representatives and the Senate) H.R. 6063, sec. 101. Note the authorization bill does not provide funding, which is contained in the appropriations legislation. The actual figure appropriated for NASA will likely be lower.

[64] The issue raised a lot of controversy in the US. See Brian Berger, "New Push for Soyuz Waiver after Griffin E-mail Spotlights NASA Woes," 19(36) *Space News International* (15 September 2008) at 1, 6.

[65] *New Scientist,* "Politician urges NASA to postpone Shuttle's retirement" (17 December 2007), online: http://www.newscientist.com/article/dn13098-politician-urges-nasa-to-postpone-shuttles-retirement.html; T. Malik, "NASA studies changes in shuttle plan," MSNBC (29 August 2008), online: http://www.msnbc.msn.com/id/26461790/; Brian Berger, "Senators Ask Bush for Shuttle Stay of Execution," *Space News* (1 September 2008) at 10, 12.

[66] B. Iannota, "Space Shuttle Extension Options Carry High Cost," Space.com (6 January 2009), online: http://www.space.com/news/090106-sn-space-shuttle-extension-costs.html.

67 OMB Statement of Administration Policy H.R. 6063 — *National Aeronautics and Space Administration Authorization Act of 2008,* Spaceref.com (16 June 2008), online: http://www.spaceref.com/news/viewsr.html?pid=28315.

68 NASA, News Release, "NASA to Realign Constellation Program Milestones" (11 August 11, 2008), online: http://www.nasa.gov/home/hqnews/2008/aug/HQ_08-205_Constellation_realignment.html; *BBC News* "NASA Moonship Flight Target Slips" (12 August 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7555927.stm.

69 N. Greenfieldboyce, "Tensions with Russia May Hurt NASA Program," National Public Radio (15 August 2008), online: http://www.npr.org/templates/story/story.php?storyId=93644106; "Enter the Dragon," *The Economist* (21 August 2008), online: http://www.economist.com/science/displaystory.cfm?story_id=11959182; I. Klotz, "US Free to Buy Russia Space Seats," *BBC News* (26 September 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7638188.stm; Brian Berger, "Bush Signs NASA Budget, Soyuz Waiver into Law," Space.com (2 October 2008), online: http://www.space.com/news/081002-nasa-soyuz-waiver.html.

70 D. Barboza, "China Launches Spacewalk Mission," *New York Times* (25 September 2008); C. Moskowitz, "Liftoff! China Launches Third Manned Spaceflight," Space.com (25 September 2008), online: http://www.space.com/missionlaunches/080925-zhenzhou7-launch-wrap.html. For more information see Xinhua News Agency, Website, *China's Third Manned Space Mission*, online: http://www.chinaview.cn/shenzhou7/ (date accessed: 10 June 2009).

71 Leonard David, "China's Spacewalk: A Prelude of Things to Come," *Space News* (10 June 2008), at 10.

72 *Thaindian News,* "China to Mass Produce Shenzhou Spaceship" (26 September 2008), online: http://www.thaindian.com/newsportal/world-news/china-to-mass-produce-shenzhou-spaceship_100100270.html.

73 *Shanghai Daily,* "China's Next Target: Space Laboratory" (22 September 2008), online: http://www.chinadaily.com.cn/china/2008-09/22/content_7047390.htm; *China Daily,* "Space Lab, a Step-Stone to Grander Feats*"* (1 October 2008), online: http://www.china.org.cn/china/shenzhouVII_spacewalk/2008-10/01/content_16558166.htm.

74 J. Drew, "Space Inspires Passion ad Practicality in China," *Washington Post* (25 September 2008) at G7.

75 N. Mathews, "ISRO to Seek Human Spaceflight Funding," *Aerospace Daily and Defence Report* (1 May 2008); PTI, "The government is actively considering sending man into space: Chavan," *The Hindu* (16 April 2008), online: http://www.hindu.com/thehindu/holnus/001200804161442.htm.

76 *Hindustan Times,* "ISRO Eyes Manned Moon Mission by 2015, Awaiting Government Approval" (22 October 2008).

77 ISRO, *Outcome budget of the department of space, government of India 2008-2009,* online: http://www.isro.org/Accounts/OutcomeBudget2008-2009.pdf. Value in original currency is 4074 crores.

78 With $375-million funding for the development of the Polar Satellite Launch Vehicle in 2009-2012. B. Gopalaswamy, "Indian Space Policy: Aiming Higher," *Space News* (21 July 2008) at 21.

79 Federal Law of November 24, 2008 N 204-FZ regarding the Federal Budget for year 2009 and for the planned period of 2010-2011. With supplements. *Rossijskaja Gazeta* 4799 (26 November 2008), online: http://www.rg.ru/2008/11/26/budjet2009-dok.html (in Russian).

80 RIA, "Russian Space Program Still Plagued By Numerous Problems," Space Daily (4 March 2008), online: http://www.spacedaily.com/reports/Russian_Space_Program_Still_Plagued_By_Numerous_Problems_999.html. See the official report of the Russian Audit Chamber on the development of the high-tech industry of Russia, online: http://www.ach.gov.ru/news/show/?2526 (date accessed: 10 June 2009).

81 Federal Law of November 24, 2008 N 204-FZ regarding the Federal Budget for year 2009 and for the planned period of 2010-2011.

82 "India Launches First Moon Mission," *BBC News* (22 October 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7679818.stm.

83 ISRO, "Lunar Images from Chandrayaan-1," SpaceRef (16 November 2008), online: http://www.spaceref.com/news/viewsr.html?pid=29777; ISRO, "LASER Instrument on Chandrayaan-1 Successfully Turned ON," SpaceRef (16 November 2008), online: http://www.spaceref.com/

news/viewsr.html?pid=29776. China's Chang'e-1 lunar mission reportedly cost approximately $180-million; see Tariq Malik, "China's First Moon Probe Crashes to Lunar Surface," Space.com (2 March 2009), online: http://www.space.com/missionlaunches/090302-china-change1-crash.html. Japan's Lunar A mission has an estimated cost of $470-million; see Reuters, "Japan Plans Unmanned Mission to the Moon" (9 October 2007), online: http://www.reuters.com/article/topNews/idUST24708420071009.

84 NASA, Goddard Space Flight Center, "Lunar Reconnaissance Orbiter," online: http://lunar.gsfc.nasa.gov/mission.html (date accessed: 10 June 2009); SatNews Daily, "NASA's LCROSS To Moon Crash — On Purpose," online: http://www.satnews.com/cgi-bin/display_story.cgi?number=211448956 (date accessed: 10 June 2009); Tony Philips, "NASA's LCROSS Spacecraft to Crash into the Moon in 2009," (11 November 2008) online: http://www.space.gs/08/11-aug-2008-lcross.html (date accessed: 10 June 2009).

85 Johnson Space Center, "NASA Announces Study Proposal on Design of Human Lunar Lander," SpaceRef (15 January 2008), online: http://www.spaceref.com/news/viewsr.nl.html?pid=26686.

86 J. Amos, "NASA Committed to Mars Rover Plan," *BBC News* (12 October 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7664965.stm.

87 Tariq Malik, "China's First Moon Probe Crashes to Lunar Surface."

88 *People's Daily,* "Chang'e-2 to Launch in 2010" (7 November 2008), online: http://english.people.com.cn/90001/90776/6529655.html.

89 *People's Daily,* "China's Lunar Rover to Land on Moon in 2012" (8 November 2008), online: http://english.peopledaily.com.cn/200411/08/eng20041108_163090.html.

90 AFP, "China Plans Manned Trip to Moon after Successful Mission," Space Daily (28 September 2008), online: http://www.spacedaily.com/reports/China_plans_manned_trip_to_Moon_after_successful_mission_999.html.

91 J. Matson, "Moon Lust: Will International Cooperation or Competition Return Humans to the Moon," *Scientific American* (22 December 2008), online: http://www.sciam.com/article.cfm?id=will-man-return-to-Moon; Peter B. de Selding, "Japan, China to Extend Successful Lunar Missions," *Space News* (March 31, 2008) at 11.

92 Roy Gibson, "The history of international space programs," 23 *Space Policy* (2007) at 155.

93 John Krige, "The politics of European collaboration in space," 36 *Space Times: Magazine of the American Astronautical Society* (September — October 1997) at 6, cited in Roger D. Launius, "Notes from the Field," 2 *Comparative Technology Transfer and Society* (April 2004) at 28.

94 Dennis Overbye, "NASA to Cut Back Scientific Missions because of Budget," *New York Times* (1 March 2006).

95 Videocosmos, "Mir Station," online: http://www.videocosmos.com/mir.shtm (date accessed: 25 April 2007)

96 NASA, "History of Shuttle-Mir," online: http://spaceflight.nasa.gov/history/shuttle-mir/images/timeline.pdf (date accessed: 25 April 2007).

97 NASA, Missions, "International Space Station," (10 June 2009), online: http://www.nasa.gov/mission_pages/station/structure/isstodate.html.

98 European Space Agency, "How Much Does it Cost?" online: http://www.esa.int/export/esaHS/ESAQHA0VMOC_iss_0.html (date accessed: 25 April 2007).

99 As of January 2007 China, Israel, Ukraine, India, Morocco, Saudi Arabia, and South Korea had signed agreements to cooperate on Galileo.

100 Brian Berger, "Griffin Agrees to Explore Working with China in Several Areas of Space Science," *Space News* (26 September 2006); Warren Leary, "NASA Chief in China to Discuss Space Cooperation," *New York Times* (24 September 2006); "U.S. halts China space ventures," *Washington Times* (2 February 2007); New Scientist Space and AFP, "US rethinks cooperation with China in space," *New Scientist* (3 February 2007).

101 *People's Daily,* "China, Brazil to Co-Launch 2nd Satellite in Latter Half Year" (13 July 2002).

102 Chinese National Space Administration, White Paper, "China's Space Activities in 2006" (12 October 2006), online: http://www.cnsa.gov.cn/n615709/n620682/n639462/79381_1.html.

103 Satnews Daily, "NASA, 13 Space Agencies Join in Historic Space Cooperation Agreement" (5 June 2007), online: http://www.satnews.com/stories2007/4550/.

104 Ch. Bodeen (citing P. Zhaoyu, assistant director of the Lunar Exploration Program Centre), "China Insists There's No Asia Space Race," Space.com (1 November 2007), online: http://www.space.com/news/ap-071101-china-nospacerace.html.

105 Peter B. de Selding, "ATV Success Buoys Europe's Hope for Long-Term Human Presence in Space," *Space News* (7 April 2008) at 1, 12.

106 SPX, "US Congressional Subcommittee Examines The Status Of The ISS," Space Travel (28 April 2008), online: http://www.space-travel.com/reports/US_Congressional_Subcommittee_Examines_The_Status_Of_The_ISS_999.html.

107 RIA Novosti, "Russia Needs Billions More To Complete Its ISS Segment," Space Travel (14 April 2008) online: http://www.space-travel.com/reports/Russia_Needs_Billions_More_To_Complete_Its_ISS_Segment_999.html.

108 Satnews, "Combo ESA + ISRO Moon Mission Meeting Deadlines," online: http://www.satnews.com/cgi-bin/display_story.cgi?number=1413168760 (date accessed: 10 June 2009); P.J. *Blount,* "U.S. and India Sign Framework Agreement," *Space Law* (1 February 2008), online: Res Communis, http://rescommunis.wordpress.com/2008/02/01/us-and-india-sign-framework-agreement.

109 *New* Scientist, "Nations sign landmark lunar exploration agreement" (31 July 2008), online: http://www.newscientist.com/article/mg19926673.300-nations-sign-landmark-lunar-exploration-agreement.html; *The Economic* Times (India), "India signs agreement with U.S. to carry out lunar exploration" (27 July 2008), online: http://economictimes.indiatimes.com/PoliticsNation/India_signs_agreement_with_US_/articleshow/3286803.cms; NASA, Press Release, "NASA Hosts International Meeting For Lunar Science Discussions" (29 July 2008), online: http://www.nasa.gov/home/hqnews/2008/jul/HQ_08190_NASA_hosts_ILN.html.

110 AFP, "European-Japanese Mission to Mercury Clears Key Hurdle," Space Daily (18 January 2008), online: http://www.spacedaily.com/reports/European-Japanese_mission_to_Mercury_clears_key_hurdle_999.html.

111 NASA, Release 08-174, "Space Agencies Continue Talks on Global Space Exploration Strategy" (14 July 2008), online: http://www.nasa.gov/home/hqnews/2008/jul/HQ_08174_Montreal_meeting.html.

112 Craig Covault, "U.S. and China Resume Space Cooperation," *Aviation Week and Space Technology* (5 September 2008).

113 XNA, "China Hopes to Join Space Station Project," Space Travel (17 October 2008), online: http://www.space-travel.com/reports/China_Hopes_To_Join_International_Space_Station_Project_999.html.

114 Xingchao Li, China Centre for Resources Satellite Data and Application, PDF Presentation, "Chinese Earth Observation Missions," ESA (14 October 2008), online: http://dragon2.esa.int/landtraining2008/pdf/D1L2ab_ChineseEarthObservationMissions_Li.pdf.

115 XNA, "Brazil, Germany To Develop Night-Vision Radar Satellite," Space Mart (17 March 2008), online: http://www.spacemart.com/reports/Brazil_Germany_To_Develop_Night_Vision_Radar_Satellite_999.html.

116 "Current Event: Brazil, Argentina Agree to Build Hyperspectral Satellite," *Space News* (27 November 2007), online: Res Communis, http://rescommunis.wordpress.com/2007/11/27/current-event-brazil-argentina-agree-to-build-hyperspectral-satellite/.

117 Alfonso Daniels, "Venezuela Joins Space Club Nations," *BBC World* (29 October 2008), Online: http://news.bbc.co.uk/2/hi/americas/7697130.stm; Xinhua, "China Launches Telecom Satellite for Venezuela," China View (30 October 2008), online: http://news.xinhuanet.com/english/2008-10/30/content_10276834.htm.

118 Xinhua, "Asia-Pacific Space Cooperation Organization Starts Operation," China View (16 December 2008), online: http://news.xinhuanet.com/english/2008-12/16/content_10514901.htm.

119 Ria Novosti, "Ukraine, Indonesia Sign Space Cooperation Deal," Space Travel (10 November 2008), online: http://www.space-travel.com/reports/Ukraine_Indonesia_Sign_Space_Cooperation_Deal_999.html.

[120] US Department of Commerce, Office of Space Commercialization, "Trends in Space Commerce" (June 2001).

[121] Space Foundation, *The Space Report* (Colorado Springs: Space Foundation, 2006) at 77. From ABI Research, Table of Contents for *Satellite Positioning Systems and Devices: Global Markets for GPS, GALILEO, GLONASS, and Other Satellite-Based Positioning Technologies* (2005), online: http://www.abiresearch.com/products/market_research/Satellite_Positioning_Systems_and_Devices.

[122] *Economist,* "The Sky's the Limit" (8 March 2001); Giovanni Bisignani, Director, International Air Transport Association, "State of the Air Transport Industry," International Air Transport Association 64th General Meeting (2 June 2008), online: http://www.iata.org/pressroom/speeches/2008-06-02-01.htm.

[123] US Department of Commerce, Office of Space Commercialization, "Trends in Space Commerce" (June 2001).

[124] White House press secretary quoted in "Selective Availability: Completely Dead," *Inside GNSS* (19 September 2007), online: www.insidegnss.com/node/200.

[125] Russian Ministry of Defense, "Coordinational Scientific Information Center," online: Russian Space Agency http://www.GLONASS-center.ru/frame_e.html (date accessed: 25 April 2007).

[126] Pavel Podvig, "Russia and Military Uses of Space," from the working paper, "The American Academy of Arts and Sciences Project 'Reconsidering the Rules of Space'" (June 2004), online: Russian Strategic Nuclear Forces, http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml.

[127] European Union, "Satellite Navigation" (6 April 2006), online: http://europa.eu.int/comm/space/russia/sector/satellite_navigation_en.html; GPS Daily, "Russia to Lift GLONASS Restrictions for Accurate Civilian Use" (14 November 2006), online: http://www.gpsdaily.com/reports/Russia_To_Lift_GLONASS_Restrictions_For_Accurate_Civilian_Use_999.html.

[128] Pavel Felgenhauer, "Did GLONASS Failure Sink Ivanov's Chance at the Presidency?" *Eurasia Daily Monitor* (6 February 2008), online: Jamestown News, www.jamestown.org/edm/article.php?article_id+2372780.

[129] RIA Novosti, "GLONASS Navigation System Available to India — Russia" (21 January 2007), online: http://en.rian.ru/russia/20070122/59520011.html.

[130] European Commission, Press Release, "GALILEO: YES, at Last!" (26 March 2002), online: Europa, http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/02/478.

[131] T. Barnes and V. Samson, "Galileo Funding Approved," 11 *CDI Space Security Update* (5 December 2007), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4152#10.

[132] European Union, "Galileo Services" (1 March 2006), online: http://europa.eu.int/comm/dgs/energy_transport/galileo/programme/services_en.htm.

[133] "The Beidou System," Presentation to the Union of Concerned Scientists, Summer Symposium, Beijing, August 2004.

[134] "China Starts to Build Own Satellite Navigation System," GPS Daily (3 November 2006), online: http://www.gpsdaily.com/reports/China_Starts_To_Build_Own_Satellite_Navigation_System_999.html.

[135] K.S. Jayaraman, "India to Develop Regional Navigation System," *Space News* (22 May 2006).

[136] Interagency GPS Executive Board, "Joint Announcement, Second Japan-US GPS Plenary Meeting, 2002" (16 October 2002).

[137] *Asian Surveying and Mapping,* "QZSS-1 in 2010" (8 May 2009), online: http://www.asmmag.com/news/qzss-1-in-2010.

[138] Peter B. de Selding, "Disaster Response Imagery, but Distribution Still Tough," *Space News* (9 June 2008) at 14.

[139] Jeremy Singer, "NOAA Chief Seeks International Sources for Hurricane Data," *Space News* (3 March 2008) at 13.

[140] Jonathan's Space Report, "Satellite Catalog and Launch Catalog," online: http://planet4589.org/space/log/satcat.txt.

[141] WMO Space Programme, "Current Polar-Orbiting Satellites Coordinated within CGMS" (25 November 2005).

142 US Environmental Protection Agency, "Global Earth Observation System of Systems (GEOSS)," online: http://www.epa.gov/geoss/basic.html (date accessed: 25 April 2007).

143 Group on Earth Observations, "About GEO" (2008), online: http://www.earthobservations.org/about_geo.shtml.

144 Group on Earth Observations, "Declaration of the Earth Observation Summit" (31 July 2003); US Environmental Protection Agency, "Global Earth Observation System of Systems (GEOSS)."

145 Donald MacPhail, "Increasing the use of Earth observations in developing countries," 25 *Space Policy* (2009) at 6-8.

146 International Charter "Space and Major Disasters," "About the Charter" (18 March 2009), online: http://www.disasterscharter.org/about_e.html.

147 International Charter "Space and Major Disasters," "Charter Members and Space Resources" (17 April 2008), online: http://www.disasterscharter.org/participants_e.html.

148 Surrey Satellite Technologies, Press Release, "SSTL Readies First DMC Satellite for November Launch" (19 November 2002).

149 DMC International Imaging, online: http://www.dmcii.com/index.html (date accessed: 10 June 2009).

150 Cospas-Sarsat Secretariat, "Cospas-Sarsat System Data," No. 34 (December 2008), online: http://www.cospas-sarsat.org/DocumentsSystemDataDocument/SD34-DEC08.pdf.

151 Space.com, "Satellite Technology Helps Canada Patrol Waterways" (4 May 2009), online: http://www.space.com/businesstechnology/090504-busmon-radarsat-ships.html; Christer Aasen, Norwegian Space Center, News Archives, "Norway builds AIS satellite" (9 October 2008), online: http://www.spacecentre.no/?module=Articles;action=Article.publicShow;ID=51125.

152 Cospas-Sarsat Secretariat, "Cospas-Sarsat System Data," No. 34 (December 2008).

153 *BBC News,* "Contest to Build Galileo Begins" (1 July 2008), online: http://news.bbc.co.uk/1/hi/sci/tech/7483582.stm; J. Amos, "Firms Chosen for Galileo Run-Off," *BBC* (19 September 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7625357.stm.

154 SPX, "SSTL Completes Galileo In-Orbit Test Campaign," GPS Daily (10 September 2008), online: http://www.gpsdaily.com/reports/SSTL_Completes_Galileo_In_Orbit_Test_Campaign_999.html; Agence-France Press, "Europe's Galileo Network Continues to Evolve," Center for Defense Information (27 April 2008), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4298#10; Peter B. de Selding, "Second Satellite in Galileo Constellation Reaches Orbit," *Space News* (5 May 2008) at 7.

155 GPS Daily, "Venezuela, Cuba may join Russian military's navigation system" (17 September 2008), online: http://www.gpsdaily.com/reports/Venezuela_Cuba_may_join_Russian_militarys_navigation_system_999.html.

156 Russian Federal Space Agency, "Roskosmos launches database" (in Russian), online: http://www.federalspace.ru/StartsMain.asp?ShowYear=2008.

157 *RIA Novosti,* "Russia Launches Rocket with Three New GLONASS Satellites" (25 December 2008), online: http://en.rian.ru/russia/20081225/119169033.html.

158 AFP, "Cuba and Venezuela May Join GLONASS" (17 September 2008), online: http://afp.google.com/article/ALeqM5iVLtXkgoveLhIbRCRbAzE6_czGeg.

159 Peter B. de Selding, "China Satnav Ssytem Planned for 2010; Frequency Issue Still Unresolved," *Space News* (5 May 2008) at 7.

160 Peter B. de Selding, "China Satellite Navigation System Planned for 2010," *Space News* (5 May 2008).

161 SPX, "Contract Signed for ESA's Sentinel-3 Earth Observation Satellite," Space Mart (15 April 2008), online: http://www.spacemart.com/reports/Contract_Signed_For_ESA_Sentinel_3_Earth_Observation_Satellite_999.html.

162 European Space Agency, "Second Phase of GMES Gets Go-ahead at Ministerial Council" (9 December 2008), online: http://www.esa.int/esaLP/SEMHO6STGOF_LPgmes_0.html.

163 European Space Agency, "Extended Cyclone Relief Efforts Aided from Space" (3 July 2008), online: http://www.esa.int/esaEO/SEM68CSHKHF_environment_0.html; *US Geological Survey,* "Landsat

Satellite Imagery Used to Assess the Impact of Myanmar's Cyclone Nargis" (8 May 2008), online: http://www.usgs.gov/newsroom/article.asp?ID=1933&from=rss_home.

164 *Economic Times of India,* "China Asks ISRO, Other Space Agencies for Space-related Data" (14 May 2008).

165 *Space News,* "Taiwanese Satellite Aids China Disaster Relief Effort" (2 June 2008) at 3.

166 International Charter "Space and Major Disasters," "Recent Activations" (9 June 2009), online: http://www.disasterscharter.org/new_e.html.

167 J. Morgan, "A New 'Pair of Eyes' in Space," *BBC News* (19 January 2009), online: http://news.bbc.co.uk/2/hi/science/nature/7785662.stm.

168 NASA HQ, "NASA and USAID Bring Earth-Observation Benefits to Africa," SpaceRef (21 November 2008), online: http://www.spaceref.com/news/viewpr.html?pid=26998.

169 *Press Trust of India,* "India and France Joint Working Group Meet To Discuss Space" (9 July 2008), online: http://www.spacemart.com/reports/India_And_France_Joint_Working_Group_Meet_To_Discuss_Space_999.html.

170 Craig Covault, "Huanjing Sats Get Checkout," *Aviation Week & Space Technology* (11 September 2008), online: http://www.aviationweek.com/aw/generic/story.jsp?id=news/China091108.xml&headline=Huanjing%20Sats%20Get%20Checkout&channel=space.

171 Johnny A. Johannessen and Ming-Xia He, "Dragon in Support to Harmonizing European and Chinese Marine Monitoring for Environment and Security," ESA SP-655 (April 2008), online: http://earth.esa.int/dragon/symp2008/proceedings/2johanne.pdf.

Chapter Four Endnotes

1 Eurospace, "Facts & Figures: The European Space Industry in 2002" (2004) at 7, online: http://www.eurospace.org/.

2 Space Foundation, *The Space Report 2009* (Colorado Springs: Space Foundation 2009) at 5. The figures reported are based on those in the Space Foundation Report, but do not include the figures for government spending. The total industry figure cited here includes the following: commercial satellite manufacturing, commercial launches, ground stations and equipment, independent research and development, insurance, fixed satellite services, mobile satellite services, direct-to-home television, global positioning system equipment and chipsets, and orbital private human space flight. Futron Corporation, "2008 Satellite Industry Statistics," in *State of the Satellite Industry Report* (June 2009) at 10, 18, online: Satellite Industry Association, http://www.sia.org/news_events/2009_State_of_Satellite_Industry_Report.pdf.

3 Futron Corporation, *State of the Satellite Industry Report*, "2005 Satellite Industry Statistics" (June 2006) at 8, online: http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf; Futron Corporation, *State of the Satellite Industry Report*, "2006 Satellite Industry Statistics" (June 2007) at 6,7, online: http://www.sia.org/PDF/2007StateofSatelliteIndustryReport.pdf; *The Space Report 2007 Update* at 4,5. Estimates of satellite service revenues for 2006 vary, with the Futron Corporation citing $62.8-billion and the Space Foundation citing $111.1-billion, the latter based on data from a range of sources.

4 Futron Corporation, "State of the Satellite Industry Report" (June 2008) at 6, online: Satellite Industry Association, http://www.sia.org/files/2008SSIR.pdf.

5 US Federal Aviation Administration, "The Economic Impact of Commercial Space Transportation on the US Economy: 2002 Results and Outlook for 2010" (March 2004), at 3, online: http://ast.faa.gov/files/pdf/2004Economic_Impact.pdf.

6 Communications Satellite Corporation, or COMSAT, is a private communications satellite company organized and started by the US Congress. See Comsat International, "Comsat International History," online: http://www.comsatinternational.com/about/history.html (date accessed: 25 April 2007); President's National Security Telecommunications Advisory Committee (NSTAC), "Satellite Task Force Report, Factsheet" (March 2004) at 6.

7 John Higginbotham, "Private Possibilities in Space," in Edward L. Hudgins, ed., *Space: The Free Market Frontier* (New York: Cato Institute, 2002) at 146.

8 "Satellite Task Force Report, Factsheet," at 6.

9 Space Foundation, *The Space Report* (2006) at 52.

10 Data taken from annual commercial launch reports by the Futron Corporation, available online: http://www.futron.com/resource_center/friends_of_futron/report_archives/launch_report.htm (date accessed: 25 April 2007).

11 Peter B. de Selding, "Launch Price Increases Expected despite Overcapacity," *Space News* (19 September 2005).

12 FAA, "2006 Year in Review," at 7.

13 Futron Corporation, "State of the Satellite Industry Report" (June 2007) at 18, online: Satellite Industry Association, http://www.futron.com/pdf/resource_center/reports/SIA_2006_Indicators.pdf; Futron Corporation, "State of the Satellite Industry Report" (June 2009) at 16, online: Satellite Industry Association, http://www.sia.org/news_events/2009_State_of_Satellite_Industry_Report.pdf.

14 FAA, "2006 Year in Review," at 13.

15 Futron Corporation, "State of the Satellite Industry Report" (June 2007).

16 Michael A. Taverna and Robert Wall, "Pick and Choose: Buoyant demand and improving outlook seen for telecom satellite manufacturers," *Aviation Week & Space Technology* (10 September 2007) at 28.

17 Futron Corporation, "State of the Satellite Industry Report" (June 2008) at 13.

18 Futron Corporation, "State of the Satellite Industry Report" (June 2007) at 14; Futron Corporation, "State of the Satellite Industry Report" (June 2009) at 14.

19 AFP, "India launches Israeli satellite in boost to space business" (21 January 2008), online: Canada.com, http://www.canada.com/topics/technology/science/story.html?id=68e69c99-33d2-4106-b739-a891169539c2&k=11055; BBC News, "India commercial rocket takes off" (23 April 2007), online: http://news.bbc.co.uk/2/hi/south_asia/6582773.stm. For launch price comparisons see FAA Commercial Space Transportation, "2007 Year in Review" (2008) at 17-19.

20 K. Raghu, "India to build a constellation of 7 navigation satellites by 2012," *livemint.com/The Wall Street Journal* (5 September 2007), online: http://www.livemint.com/2007/09/05002237/India-to-build-a-constellation.html.

21 T.S. Subramanian, "ISRO entrenched in remote-sensing images market," *The Hindu* (23 September 2007), online: http://www.hindu.com/2007/09/23/stories/2007092360451200.htm.

22 Edward Cody, "China builds and launches a satellite for Nigeria," *The Washington Post* (14 May 2007), online: http://www.washingtonpost.com/wp-dyn/content/article/2007/05/13/AR2007051301264.html.

23 Jim Yardley, "Snubbed by US, China Finds New Space Partners," *New York Times* (24 May 2007), online: http://www.nytimes.com/2007/05/24/world/asia/24satellite.html.

24 AFP, "Arianespace warns US over Chinese space 'dumping'" (30 November 2007), online: http://afp.google.com/article/ALeqM5gRSPI2HxWsPwjfICbGanIw4VN0SQ.

25 US Federal Aviation Administration, *Commercial Space Transportation: 2008 Year in Review* (January 2009) at 11-12.

26 US Federal Aviation Administration, *Commercial Space Transportation: 2008 Year in Review* (January 2009) at 22.

27 Futron Corporation, Monthly Launch Report (January 2009), http://www.futron.com/pdf/friends_of_futron_reports/launch_reports/FutronLR2009-01.pdf.

28 US Federal Aviation Administration, *Commercial Space Transportation: 2008 Year in Review* (January 2009) at 14.

29 See FAA, "Year in Review 2008."

30 See Annex 4. Information collected from FAA, "Year in Review 2008"; Dr. Jonathan McDowell; and Gunter's Space Page, http://www.skyrocket.de/space/.

31 Futron Corporation, "Underlying demand continues to increase," Q & A Futron, *Satellite Evolution* (September/October 2008) at 30.

[32] Futron Corporation, "2008 Satellite Industry Statistics." in *State of the Satellite Industry Report* (June 2009) at 10, 18, online: Satellite Industry Association, http://www.sia.org/news_events/2009_State_of_Satellite_Industry_Report.pdf.

[33] Futron Corporation, "2008 Satellite Industry Statistics," in *State of the Satellite Industry Report* (June 2009) at 13, online: Satellite Industry Association, http://www.sia.org/news_events/2009_State_of_Satellite_Industry_Report.pdf.

[34] Marc Kaufman, "U.S. Finds It's Getting Crowded Out There," *The Washington Post* (9 July 2008) at A01; *The China Post*, "U.S. viewed as losing space markets, hobbled by own policy" (21 February 2008), online: http://www.chinapost.com.tw/business/2008/02/21/143919/U.S.-viewed.htm?loc=interstitialskip.

[35] Futron Corporation, Satellite Manufacturing Report (January 2009), http://www.futron.com/pdf/friends_of_futron_reports/satellite_manufacturing_reports/FutronSM2009-01.pdf.

[36] BBC News, "India launches Israeli satellite" (21 January 2008), online:, http://news.bbc.co.uk/2/hi/south_asia/7199736.stm.

[37] G. Madhavan Nair in AFP, "India launches Israeli satellite in boost to space business" (21 January 2008).

[38] K. Raghu, "India to build a constellation of 7 navigation satellites by 2012," *livemint.com/The Wall Street Journal* (5 September 2007), online: http://www.livemint.com/2007/09/05002237/India-to-build-a-constellation.html.

[39] SPX, "India-Built Satellite for International Market" (10 December 2008), online: Space Mart, http://www.spacemart.com/reports/India_Built_Satellite_For_International_Market_999.html.

[40] *The Economic Times*, "Indian space agency aims $60 mn revenue from satellite manufacturing" (20 October 2008), online: http://economictimes.indiatimes.com/News/News_By_Industry/ET_Cetera/Indian_space_agency_aims_60_mn_revenue_from_satellite_manufacturing/articleshow/3618689.cms.

[41] *The Economist,* "Space" (7 April 2008), online: http://www.economist.com/daily/chartgallery/displaystory.cfm?story_id=10976407.

[42] *The Economic Times*, "Indian space agency aims $60 mn revenue from satellite manufacturing" (20 October 2008), online: http://economictimes.indiatimes.com/News/News_By_Industry/ET_Cetera/Indian_space_agency_aims_60_mn_revenue_from_satellite_manufacturing/articleshow/3618689.cms.

[43] Olusola Balogun, "Nigeria: Consultants Blame Power Outage for Nigcomsat Failure," *Daily Independent* (Lagos) (13 November 2008), online: allAfrica.com http://allafrica.com/stories/200811141013.html.

[44] Peter J. Brown, "China lost in SE Asian space," *The Asia Times* (10 October 2008), online: http://www.atimes.com/atimes/Southeast_Asia/JJ10Ae01.html.

[45] Andy Pasztor, "Eutelsat to use Chinese launch services," *The Wall Street Journal* (28 April 2008), p. B3; Andy Pasztor, "China to Launch Satellite for France's Eutelsat," *The Wall Street Journal* (25 March 2009), online: http://online.wsj.com/article/SB123550142763361701.html.

[46] *Space News,* News Briefs, "Chinese rocket launches European-built satellites" (16 June 2008).

[47] *Space News*, "China to invest in Commercial Satellite Research City" (4 February 2008).

[48] AFP, "Japan's Mitsubishi Heavy aims to cut rocket launch costs: company," Space Travel (7 January 2008), online: http://www.space-travel.com/reports/Japans_Mitsubishi_Heavy_aims_to_cut_rocket_launch_costs_company_999.html; AFP, "Mitsubishi Targeting Foreign Satellite Launch Orders," Space Travel (25 February 2008), online: http://www.space-travel.com/reports/Mitsubishi_Targeting_Foreign_Satellite_Launch_Orders_999.html.

[49] Asian Surveying and Mapping, "Mitsubishi to launch Korea's Kompsat-3" (14 January 2009), online: http://www.asmmag.com/news/mitsubishi-to-launch-korea-s-kompsat-3.

[50] Futron Corporation, "Underlying demand continues to increase," Q & A Futron, *Satellite Evolution* (September/October 2008) at 30.

[51] Jayesh Limaye, "India's big plans in small satellite manufacturing," Techtree.com India (31 October 2008), online: http://www.techtree.com/India/Techtree_Notes/Indias_big_plans_in_small_satellite_manufacturing/551-94599-889.html.

52 *The Economic Times*, "Indian space agency aims $60 mn revenue from satellite manufacturing" (20 October 2008), online: http://economictimes.indiatimes.com/News/News_By_Industry/ET_Cetera/Indian_space_agency_aims_60_mn_revenue_from_satellite_manufacturing/articleshow/3618689.cms.

53 IANS, "India Poised To Be Major Player In Satellite Manufacturing," Space Mart (30 October 2008, online: http://www.spacemart.com/reports/India_Poised_To_Be_Major_Player_In_Satellite_Manufacturing_999.html.

54 Russia Today, "Nanotechnology to boost space industry" (7 April 2008), online: http://www.russiatoday.ru/Business/2008-04-07/Nanotechnology_to_boost_space_industry.html.

55 S. Pete Worden quoted in K.C. Jones, "NASA plans 'Nano' satellites to help commercialize space," InformationWeek (25 April 2008), online: http://www.informationweek.com/news/telecom/unified_communications/showArticle.jhtml?articleID=207402121.

56 Jeff Foust, "If you build it who will come? Identifying Markets for Low Cost Small Satellites," 22nd Annual AIAA/USU Conference on Small Satellites, 11 August 2008, online: http://www.futron.com/pdf/resource_center/conference_presentations/SSC08-I-1_Foust.pdf.

57 Futron Corporation, "Futron Launch Report" (January 2006). Effective 1 January 2006 commercial launches are defined by Futron as including launches where at least one payload procured launch services commercially. This definition differs from the standard used by the Federal Aviation Administration's Office of Commercial Space Transportation. Federal Aviation Administration, "Commercial Space Transportation: 2005 Year in Review" (January 2006), online: http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf.

58 Tamar H. Mehuron, "2004 Space Almanac," *Air Force Magazine* (August 2003), online: Air Force Association, http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf; Futron Corporation, "Futron Launch Report" (January 2008).

59 "Commercial Space Transportation: 2005 Year in Review," at 7.

60 US Senate, Senate Subcommittee on Science, Technology and Space, Testimony of Jerry Rising, Lockheed Martin Corporation (23 September 1998), online: http://www.senate.gov/~commerce/hearings/0923ris.pdf.

61 Futron Corporation, "Space Transportation Costs: Trends in Price per pound to Orbit 1990-2000" (6 September 2002) at 4-5, online: http://www.futron.com/pdf/FutronLaunchCostWP.pdf.

62 AFP, "China Eyes Commercial Space Flights in 20 Years" Space Daily (3 November 2004), online: http://www.spacedaily.com/2004/041103134440.5mxlxzjo.html.

63 All data derived from Federal Aviation Administration, "Commercial Space Transportation Year in Review" (1997 through 2008), online: http://ast.faa.gov/rep_study/yir.htm. This data differs from the figures provided by the Futron Corporation in Figure 4.2.

64 Frank Sietzen, Jr., "The H-II Failure: Japan's Commercial Launch Industry Take a Hit," Space.com (18 November 1999), online: http://www.space.com/missionlaunches/launches/hs_japan_991118.html.

65 Futron Corporation, "Futron Launch Report" (December 2006).

66 FAA, Associate Administrator for Commercial Space Transportation, *Commercial Space Transportation: 1999 Year in Review* (January 2000), online: http://www.faa.gov/about/office_org/headquarters_offices/ast/media/1999yir.pdf, at 7.

67 Futron Corporation, "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000" (6 September 2002) at 3, online: http://www.futron.com/pdf/FutronLaunchCostWP.pdf. Prices quoted in pounds and converted to kilograms by the author.

68 Futron Corporation, "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000."

69 Federal Aviation Administration Commercial Space Transportation, "Quarterly Launch Report, 2nd Quarter 2006" (2006) at 2; V. Brinda et al., "Mission Analysis of a Reusable Launch Vehicle Technology Demonstrator," AIAA/CIRA 13th International Space Planes and Hypersonics Systems and Technologies Conference, Capua, Italy, 16-20 May 2005.

70 Missy Frederick, "Internet Mapping Portal Competition Benefits Satellite Imagery Businesses," *Space News* (24 April 2006).

71 Futron Corporation, "2006 Satellite Industry Statistics," at 12.

[72] Scott Pace et al., "Appendix B: GPS History, Chronology, and Budgets," in *The Global Positioning System: Assessing National Policies* (RAND 1995) at 248.

[73] *GPS Daily,* "Russia to Lift GLONASS Restrictions for Accurate Civilian Use" (14 November 2006), online: http://www.gpsdaily.com/reports/Russia_To_Lift_Glonass_Restrictions_For_Accurate_Civilian_Use_999.html.

[74] *Xinhua,* "China to Launch 2 Satellites for Compass Navigation System" (13 November 2006), online: http://news.xinhuanet.com/english/2006-11/13/content_5322002.htm.

[75] Scott Pace et al., "Appendix B: GPS History, Chronology, and Budgets," at 248-249; Missy Frederick, "Commercial Use of GPS Expanding into More Markets."

[76] Daniel J. Marcus, "Commerce Predicts Big '92 Growth for US Space Business," *Space News* (6 January 1992).

[77] Kim Thomas, "Mobile Telephones Offer A New Sense of Direction," *Financial Times* (London) (17 November 2006) at 7.

[78] Space Foundation, *The Space Report 2008* at 21.

[79] *Commercial Space Launch Amendments Act of 2004,* H.R. 3752, 108th Congress (8 March 2004); Erica Werner, "Congress Passes Bill Allowing Space Tours," Associated Press (9 December 2004), online: redOrbit, http://www.redorbit.com/news/space/109773/congress_passes_bill_allowing_space_tours/; *Space News,* "No Waiting on Commercial Space Launch Bill" (25 October 2004), online: *Space News*, http://search.space.com/spacenews/archive04/editarch_102504.html.

[80] ESA, "ESA to Help Europe Prepare for Space Tourism" (20 July 2006), online: http://www.esa.int/SPECIALS/GSP/SEM2YABUQPE_0.html. As part of the initiative European private companies with plans for space tourism activities may submit proposals to ESA, which will select a maximum of three that will receive further study. Each company that submits a proposal selected by ESA will receive €150,000 to assist in development.

[81] Space Adventures, "Orbital Spaceflight," online: http://www.spaceadventures.com/index.cfm?fuseaction=orbital.welcome.

[82] Rita Delfiner, "Mogul has blast again," New York Post (27 March 2009), online: http://www.nypost.com/seven/03272009/news/nationalnews/mogul_has_blast_again_161555.htm.

[83] Scaled Composites, Press Release, "SpaceShipOne Makes History: First Private Manned Mission to Space" (21 June 2004), online: http://www.scaled.com/projects/tierone/062104-2.htm.

[84] Space.com, "Bigelow Aerospace Fast-tracks Manned Spacecraft" (14 August 2007), online: http://www.space.com/news/070814_bigelow_sundancer.html; Leonard David, "Bigelow Aerospace Sets a Business Trajectory," *Space News* (26 March 2007); Craig Covault, "Bigelow Aims High: Entrepreneur reveals near-term plan for commercial manned space infrastructure," *Aviation Week & Space Technology* (9 April 2007) at 24-25.

[85] US Government Accountability Office, "Commercial Space Launches: FAA Needs Continued Planning and Monitoring to Oversee the Safety of the Emerging Space Tourism Industry" (20 October 2006), online: http://www.gao.gov/new.items/d0716.pdf.

[86] FAA Commercial Space Transportation, "New Regulations Govern Private Human Spaceflight Requirements for Crew and Spaceflight Participants" (15 December 2006), online: http://www.faa.gov/about/office_org/headquarters_offices/ast/human_space_flight_reqs/. See also *Human Spaceflight Requirements for Crew and Spaceflight Participants, Final Rule*, 71 Fed. Reg. 75616 (2006).

[87] *Safety Approvals; Final Rule*, 71 Fed. Reg. 46847 (2006).

[88] Andy Pasztor, "Satellite Insurers See Flat Rates Ahead," *Wall Street Journal* (15 January 2008).

[89] *Space News*, "Capacity, not track record, drives launch, satellite insurance rates" (22 September 2008).

[90] Lisa Daniel, "Satellite Insurance: Operators Returning To Outside Providers," Satellite Today (1 November 2007), online: http://www.viasatellite.com/via/features/Satellite-Insurance-Operators-Returning-To-Outside-Providers_19461.html

[91] *Space News*, "Eutelsat Secutrehuge $2.5 billion insurance package" (28 April 2008).

[92] FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006",(2006) at SR-7; Michael A. Taverna, "Worsening Insurance Crunch Worries Space Industry," at 47; FAA,

"Commercial Space Transportation Quarterly Launch Report, 4th Quarter" (2002), at 10, online: http://ast.faa.gov/files/pdf/FourthQuarterFinal.pdf.

93 Vidya Ram, "Space: Insurance's new frontier," Forbes.com (13 February 2009), online: http://www.forbes.com/2009/02/13/space-insurance-collision-face-markets-0212_space_22.html.

94 Satellite Standard Blog, "Satellite Insurance" (26 March 2006), online: satellitestandard.blogspot.com/2006/03/satellite-insurance.html.

95 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006) at SR-8.

96 Tariq Malik, "SpaceX successfully launches Falcon 1 rocket into orbit," Space.com (28 September 2008), online: http://www.space.com/missionlaunches/080928-spacex-falcon1-fourthtest.html.

97 *Aviation Week*, "Falcon Force" (6 October 2008); SpaceX, "Falcon 1 Overview," online: http://www.spacex.com/falcon1.php

98 *Aviation Week*, "Falcon Force" (6 October 2008).

99 SpaceX, "Falcon 1" and "Falcon 9," online: http://www.spacex.com/index.php.

100 *Space News*, "United Launch Alliance to re structure Delta 2 program" (4 February 2008).

101 Michael A. Taverna, "Back and Better?" *Aviation Week & Space Technology* (2 April 2007) at 6.

102 Peter B. de Selding, 'Sea Launch rocket successfully returns to flight," *Space News* (15 January 2008), online: Space.com, http://www.space.com/missionlaunches/080115-sealaunch-thuraya3-liftoff.html.

103 Peter B. de Selding, "Israeli satellite reaches orbit in land launch debut," *Space News* (28 April 2008), online: Space.com, http://www.space.com/missionlaunches/080428-land-launch-debut.html.

104 FAA, *Commercial Space Transportation: 2008 Year in Review* (January 2009) at 19.

105 Yury Zaitsev, "Russia begins elbowing Ukraine out from Brazil's space program," RIA Novosti (17 September 2008), online: http://en.rian.ru/analysis/20080917/116874710.html.

106 Jeff Foust, "When Bad Launches Happen to Good Companies," The Space Review (9 April 2007), online: http://www.thespacereview.com/article/847/1.

107 David Bond, ed., "Washington Outlook: Seeding the Station," *Aviation Week & Space Technology* (22 October 2007), at 25; NASA, "NASA Signs Commercial Space Transportation Agreements"; SatNews Daily, "Also Working Toward COTS Award is t/Space," online: http://www.satnews.com/cgi-bin/display_story.cgi?number=212728659 (date accessed: 13 March 2008); Frank Morring Jr., Amy Butler, and Michael Mecham, "Orbital Collision Won't Be The Last," *Aviation Week and Space Technology* (15 February 2009), online: http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw021609p2.xml.

108 NASA, "NASA awards Space Station commercial resupply services contracts" (23 December 2008), online: (http://www.nasa.gov/home/hqnews/2008/dec/HQ_C08-069_ISS_Resupply.html; Frank Morring, Jr., "Space Station resupply contracts awarded," *Aviation Week* (24 December 2008), online: http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/Draggie122408.xml&headline=Space%20Station%20Resupply%20Contracts%20Awarded.

109 PlanetSpace, "PlanetSpace has filed with the GAO a protest to the selection decision of NASA under the ISS Commercial Resupply Services (CRS) Competition," SpaceRef.com (15 January 2009), online: http://www.spaceref.com/news/viewpr.html?pid=27372.

110 Chris Bergin, "Lockheed and Bigelow human-rated EELV deal," NASA Spaceflight.com (21 September 2006), online: http://www.nasaspaceflight.com/2006/09/lockheed-and-bigelow-human-rated-eelv-deal/.

111 *Aviation Week and Space Technology*, "A finer view" (15 September 2008); PRNewswire-FirstCall, "GeoEye -1 satellite launches into space from Vandenberg Air Force Base, California," GeoEye.mediaroom.com (6 September 2008), online: http://geoeye.mediaroom.com/index.php?s=43&item=304.

112 *Space News*, "GeoEye signs an exclusive deal with Google Earth" (1 September 2008).

113 German Aerospace Center, "German satellite fleet RapidEye is launched" (29 August 2008), online: http://www.dlr.de/en/desktopdefault.aspx/tabid-1/86_read-13366/.

114 Adam Keith, "Insight: Transformation of the Earth Observation Sector," *SatMagazine* (May 2008), online: http://www.satmagazine.com/cgi-bin/display_article.cgi?number=58249124.

[115] Space.com, "Satellite images help aid groups track atrocities" (10 November 2008), online: http://www.space.com/businesstechnology/081110-busmon-satellite-darfur.html; Amnesty International USA, "Georgia human rights" (2006-2009), online: http://www.amnestyusa.org/all-countries/georgia/page.do?id=1011157; *The Hindu*, "Satellite pictures reveal LTTE runways" (26 November 2008), online: http://www.hindu.com/2008/11/26/stories/2008112657751200.htm; Michael Evans, "Spy photos reveal 'secret launch site' for Iran's long-range missiles," *The Times* (11 April 2008), online: http://www.timesonline.co.uk/tol/news/world/middle_east/article3724048.ece; *Jane's Defence Weekly*, "Satellite Imagery confirms nuclear sub base in china" (16 April 2008).

[116] William Matthews, "GeoEye's new satellite offers unprecedentedly sharp images," *DefenseNews* (20 October 2008), online: http://www.defensenews.com/story.php?i=3778072&c=FEA&s=TEC.

[117] The Aerospace Corporation, "Study of the Liability Risk-Sharing Regime in the United States for Commercial Space Transportation" (1 August 2006), online: FAA/AST, http://www.faa.gov/about/office_org/headquarter_offices/ast/report_studies/media/Risk_Study(final).pdf.

[118] D. Dowd Muska, "Houston, We Have no Purpose," *Nevada Journal* (November 1998), online: http://nj.npri.org/nj98/11/cover_story.htm.

[119] Mark Wade, "USAF to subsidize EELVs," *Encyclopedia Astronautica*, online: http://www.astronautix.com/lvs/atlasv.htm (date accessed: 25 April 2007).

[120] US Space Transportation Policy Fact Sheet (6 January 2005); Brian Berger, "SpaceX Fighting for USAF Launches," *Space News* (31 October 2005).

[121] Office of the Press Secretary, "Fact Sheet: U.S. Commercial Remote Sensing Space Policy" (13 May 2003), online: The White House, http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html.

[122] Jeff Foust, "A Year-end Reality Check," Space Review (29 December 2003), online: http://www.thespacereview.com/article/78/1.

[123] European Commission Directorate-General for Research, "Space: A New European Frontier for an Expanding Union: An Action Plan for Implementing the European Space Policy," White Paper (2004).

[124] ESA Director General, *Resolution on the European Space Policy* (June 2007) at 11; online: http://www.esa.int/esapub/br/br269/br269.pdf.

[125] Russian Space Web, "Rockets: Angara Family," online: http://www.russianspaceweb.com/angara.html (date accessed: 10 July 2008); Government of the Russian Federation, "On Measures to Fulfill the Russian Federal Space Program and International Space Agreements, Decree No. 42, Selected Examples of National Laws Governing Space Activities: Russian Federation" (12 April 1996).

[126] Futron Corporation, *China and the Second Space Age* (15 October 2003), online: http://www.futron.com/pdf/resource_center/white_papers/China_White_paper.pdf.

[127] Craig Covault, "Resolution Revolution," *Aviation Week & Space Technology* (17 September 2007) at 30.

[128] MDA, "RadarSat2," Media Kit, online: http://www.radarsat2.info/about/mediakit/backgrounder_R2.pdf (date accessed: 13 March 2008); *National Defense and Canadian Forces,* "Polar Epsilon to assert Canada's Arctic sovereignty" (10 January 2008), online: http://www.forces.gc.ca/site/newsroom/view_news_e.asp?id=2547.

[129] German Aerospace Center, "TerraSAR-X goes into operation" (9 January 2008), online: http://www.dlr.de/en/desktopdefault.aspx/tabid-4219/6774_read-11191; *Aviation Week & Space Technology,* "News Breaks: Russia" (16 April 2007) at 24; J. Herrmann, N. Faller, M. Weber and A. Kern, "Infoterra GmbH Initiates Commercial Exploitation of TerraSar-X," Inforterra GmbH, online: GISDevelopment.net http://www.gisdevelopment.net/technology/sar/me05_062pf.htm (date accessed: 12 March 2007).

[130] Andrew Chuter, "New UK Milsat Follows Pattern of Private Ownership Defense Services," *Defense News* (21 May 2007) at 16.

[131] Peter B. de Selding, "Galileo Funding Solution Remains Elusive," *Space News* (17 September 2007).

[132] CBC News, "Federal government blocks sale of MDA space division" (10 April 2008), online: http://www.cbc.ca/money/story/2008/04/10/mdablock.html.

133 Missile Technology Control Regime, online: http://www.mtcr.info/english/ (date accessed: 10 July 2008).

134 Steven Pifer, "The US and Russia: Space Cooperation and Export Controls," Testimony before the House Science Committee, Subcommittee on Space and Aeronautics (11 June 2003), online: US Department of State, http://www.state.gov/p/eur/rls/rm/2003/21487.htm.

135 Official Journal of the European Communities, *Council Regulation (EC) No 2432/2001 of 20 November 2001 amending and updating Regulation (EC) No 1334/2000 setting up a Community regime for the control of exports of dual-use items and technology* (20 December 2001); Department of Foreign Affairs and International Trade Canada, "Definitions for Terms in Groups 1 and 2," online: http://www.dfait-maeci.gc.ca/trade/eicb/military/gr1-2-en.asp?#spac (date accessed: 10 July 2008); *Regulations of the People's Republic of China on Export Control of Missiles and Missile-related Items and Technologies* (August 2002), online: Center for Nonproliferation Studies, http://cns.miis.edu/research/china/chiexp/misreg.htm; Seema Galut and Anupam Srivastava, "Nonproliferation Export Controls in India" (June 2005), online: Center for International Trade and Security, www.uga.edu/cits/documents/pdf/EXEC%20SUMMARY%2020050616.pdf.

136 Satellite Industry Association, "Background: Satellite Export Controls."

137 "Satellite Task Force Report, Factsheet," at 5.

138 Satellite Industry Association, "Effects of Export Controls on the U.S. Satellite Industry: Anecdotal Evidence," at 2.

139 Peter B. de Selding, "China Launches Communications Satellite," Space.com (6 July 2007), online: http://www.space.com/missionlaunches/070706_chinasat6b_lnch.html.

140 The White House, Fact Sheet, "US Commercial Remote Sensing Space Policy" (13 May 2003), online: http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html; *Space News,* "Business Report" (27 May 2003).

141 Peter B. de Selding, "France Reviews Spot Imagery Policy," *Space News* (19 October 2001).

142 K.S. Jayaraman, "Russia Wants Access to Indian Satellite Imagery Market," *Space News* (27 January 2003).

143 John C. Baker, Ray A. Williamson, and Kevin M. O'Connell, *Commercial Observation Satellites — At the Leading Edge of Global Transparency* (Santa Monica: RAND Corporation, 2001) at 431; Parliament of Canada, "Proceedings of the Standing Senate Committee on Foreign Affairs, Issue 21 — Evidence — November 22 meeting" (22 November 2005), online: http://www.parl.gc.ca/38/1/parlbus/commbus/senate/Com-e/fore-e/21eva-e.htm?Languag. Bill C-25 fulfills Canada's international and bilateral obligations to regulate the remote sensing space activities of its nationals, as required pursuant to the 1967 Outer Space Treaty and the 2000 Canada-US Intergovernmental Agreement concerning the operation of commercial remote sensing satellite systems.

144 Jason Bates, "The Brave New World of Commercial Imagery," *Space News* (21 January 2003). Governments refer to "shutter-control" as "buy-outs" of sensitive imagery to prevent dissemination.

145 Philip McAlister, "Follow the Money: Satellite Opportunities with the US Government" (17 November 2003), online: Futron Corporation, http://www.futron.com/pdf/resource_center/conference_presentations/sat_oppor_with_us_govt.pdf.

146 Richard DalBello, interview with author (June 2009).

147 Patrick Chisholm, "Buying Time: Disconnects in Satcom Procurement" (29 November 2003), online: Military Information Technology, http://www.military-information-technology.com/article.cfm?DocID=285.

148 Bob Brewin, "Satellite Development Delays Cost DOD $1B," FCW.com (26 January 2007), online: http://www.fcw.com/article97492-01-26-07-Web.

149 David Cavossa, Satellite Industries Association Executive, cited in Jerome Bernard, "US Using Space Supremacy to Wage Combat in Iraq, Afghanistan," *Defense News* (23 June 2006), online: http://www.defensenews.com/story.php?F=1890797&C=airwar.

150 US Government Accountability Office, "Congressional Requesters, Subject: Department of Defense Actions to Modify its Commercial Communications Satellite Services Procurement Process" (17 April 2006), online: http://www.gao.gov/new.items/d06480r.pdf.

151 US General Accounting Office, *Satellite Communications — Strategic Approach Needed for DOD's Procurement of Commercial Satellite Bandwidth,* GAO-04-206 (December 2003); David Helfgott, "Satellite Communications Poised for Rebound," *SIGNAL (*April 2004), online: AFCEA International, http://www.afcea.org/signal/articles/anmviewer.asp?a=90&print=yes.

152 "Satellite Task Force Report, Factsheet," at 10.

153 ESA Director General, *Resolution on the European Space Policy* (June 2007), at 9.

154 Information Office of the State Council of the People's Republic of China, "China's Space Activities in 2006," (12 October 2006), online: People's Daily Online, http://english.people.com.cn/200610/12/eng20061012_311157.html.

155 David McGlade, "Commentary: Preserving the Orbital Environment," *Space News* (19 February 2007), at 27; Henry L. Stimson Center, "Space Security Program," online: http://www.stimson.org/space/?SN=WS200702131213 (date accessed: 13 March 2008).

156 Joseph Rouge, "The State of Space Security: Space Situational Awareness," Presentation at workshop on The State of Space Security, George Washington University, Washington, DC (24 January 2008), online: http://www.gwu.edu/~spi/Joseph%20Rouge.pdf.

157 Richard DalBello and Joseph Chan, "Linking Government and Industry Efforts to Increase Space Situational Awareness," Presentation at workshop on The State of Space Security, George Washington University, Washington, DC (24 January 2008), online: http://www.gwu.edu/~spi/Richard%20DalBello.pdf.

158 *Jane's Defence Weekly*, "DoD's UAV push may drive satellite market" (11 June 2008).

159 Jane's Information Group, "Space-saving devices: Militaries look to make the most of commercial satellites," Janes.com (8 October 2008), online: http://www.janes.com/news/defence/systems/idr/idr081008_1_n.shtml.

160 Joseph Rouge, Director of the National Security Space Office, quoted in Greg Berlocher, "Military continues to influence commercial operators," Satellite Today (1 September 2008), online: http://www.satellitetoday.com/via/supplement/Military-Continues-To-Influence-Commercial-Operators_24295_p2.html.

161 Jose del Rosario, Senior Consultant, NSR, "TSAT Delays and Budget Cuts Likely to Boost Commercial COTM Market," *Milsat Magazine* (March 2008), online: http://www.milsatmagazine.com/cgi-bin/display_article.cgi?number=616323761.

162 Peter B. de Selding, "Europe Studies Military Demand for Commercial SATCOM," *Space News* (10 November 2008).

163 *Aviation Week and Space Technology*, "Radar Love" (29 September 2008).

164 Brian X. Chen, "Google's super satellite captures first image," *Wired* (8 October 2008), online: http://blog.wired.com/wiredscience/2008/10/geoeye-1-super.html; William Matthews, "GeoEye's new satellite offers unprecedentedly sharp images," *DefenseNews* (20 October 2008), online: http://www.defensenews.com/story.php?i=3778072&c=FEA&s=TEC.

165 Greg Berlocher, "Military continues to influence commercial operators," Satellite Today (1 September 2008), online: http://www.satellitetoday.com/via/supplement/Military-Continues-To-Influence-Commercial-Operators_24295_p2.html; *Space News*, "USAF sees surveillance potential in commercial comsats" (7 April 2008).

166 Greg Berlocher, "Military continues to influence commercial operators."

167 Brian X. Chen, "Google's super satellite captures first image"; William Matthews, "GeoEye's new satellite offers unprecedentedly sharp images;" German Space Center, "German satellite fleet RapidEye is launched" (29 August 2008), online: http://www.dlr.de/en/desktopdefault.aspx/tabid-1/86_read-13366/.

168 *The China Post*, "U.S. viewed as losing space markets, hobbled by own policy" (21 February 2008), online: http://www.chinapost.com.tw/business/2008/02/21/143919/U.S.-viewed.htm?loc=interstitialskip.

169 Marc Kaufman, "U.S. Finds It's Getting Crowded Out There," *The Washington Post* (9 July 2008) at A01; *The China Post*, "U.S. viewed as losing space markets, hobbled by own policy."

170 Ann Calvaresi Barr, Director Acquisition and Sourcing Management, Testimony Before the Subcommittee on Oversight of Government Management, the Federal Workforce, and the District

of Columbia, Committee on Homeland Security and Governmental Affairs, U.S. Senate, (24 April 2008), online: GAO, http://www.gao.gov/new.items/d08710t.pdf.

171 Sandra I. Erwin, "Obama advisor: ITAR is a Cold War relic," *National Defense* (November 2008), online: http://www.nationaldefensemagazine.org/ARCHIVE/2008/NOVEMBER/Pages/ObamaAdvisorITARIsaColdWarRelic.aspx.

172 *Space News*, "Bigelow Aerospace advances work on full scale space habitat" (25 August 2008); *Space News*, "U.S. eyes removing some satellite components from munitions list" (7 April 2008).

173 New Scientist and Reuters, "China denies attempting to get U.S. space data, " *New Scientist* (18 November 2008), online: http://www.newscientist.com/article/dn16074-china-denies-attempting-to-get-us-space-data.html; Mark K. Matthews and Robert Block, Mark K. Matthews and Robert Block, "Experts see spying case at NASA as wake-up call," *Orlando Sentinel* (13 February 2008);James Vicini, "Ex-Boeing engineer charged in China spy case," Reuters.com (11 February 2008), online: http://www.reuters.com/article/topNews/idUSWAT00887420080211?feedType=RSS&feedName=topNews&rpc=22&sp=true.

174 ,New Scientist and Reuters, "China denies attempting to get US space data," (28 November 2008), online: http://www.newscientist.com/article/dn16074-china-denies-attempting-to-get-us-space-data.html.

175 Mark K. Matthews and Robert Block, "Experts see spying case at NASA as wake-up call,"*Orlando Sentinel* (13 February 2008).

176 *Space News*, "Loral urges U.S. to block Thales Alenia Use of Chinese launcher" (3 March 2008).

177 *Space News*, "Nonprofit Group records conversation to show how firms cater to the Chinese" (21 July 2008).

178 All information from Theresa Hitchens, "OpEd: Building Transparency in Space," *Space News* (29 July 2008).

Chapter Five Endnotes

1 Euroconsult, Media Release, "Government Space Program Expenditures Worldwide Hit a Record $62 billion" (18 December 2008).

2 Union of Concerned Scientists, "UCS Satellite Database" (21 January 2009), online: http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html.

3 See Annex 4. Information collected from FAA, "Year in Review 2008"; Dr. Jonathan McDowell; and Gunter's Space Page, http://www.skyrocket.de/space/.

4 Space Foundation, The Space Report 2008 (Colorado Springs: Space Foundation 2008) at 29. Figures based on spending in 2007. Figure on US Department of Defense spending is listed as $22.5-billion, provided by the Congressional Research Service.

5 Such statistics should acknowledge that purchasing power will vary among states and affect how much can be purchased within a specific budget. Paul Shawcross, OMB, "The U.S. Government Space Budget," prepared for short course on the US Government Space Sector, George Mason University, Center for Aerospace Policy Research (17 October 2006), online: http://www.gmupolicy.net/space/shortcourse/2.%20Shawcross%20-%20U.S.%20Government%20Space%20Budget.pdf.

6 Peter L. Hays, "National Security Space Actors and Issues," in Eligar Sadeh, ed., The Politics of Space: A Survey (Routledge, 2009).

7 Peter L. Hays, "National Security Space Actors and Issues."

8 Tamar A. Mehuron, "2004 Space Almanac," Air Force Magazine (August 2004) at 43; Peter L. Hays, "National Security Space Actors and Issues."

9 Tony Capaccio, "Air Force Satellite Contract Is Delayed, Young Says," Bloomberg.com (22 September 2008), online: http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aJ8ISm.IdxvA.

10 "Special Report: The USA's Transformational Communications Satellite System (TSAT)," Defense Industry Daily (30 October 2008), online: http://www.defenseindustrydaily.com/special-report-the-usas-transformational-communications-satellite-system-tsat-0866/.

[11] Glen Elfers and Stephen B. Miller, "Future US Military Satellite Communications Systems," Crosslink (Winter 2002).

[12] "USAF Launches First of Next Generation Communications Satellites," Space War (12 October 2007), online: http://www.spacewar.com/reports/USAF_Launches_First_Of_Next_Gen_Communications_Satellites_999.html.

[13] Tamara A. Mehuron, at 43-46.

[14] Missy Frederick, "Growing Use of UAVs Strains Bandwidth," Space News (17 July 2006).

[15] Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space (Cambridge: Cambridge University Press, 2003) at 344.

[16] Tamara A. Mehuron, at 44.

[17] To date the SBIRS program has triggered four reports to Congress under the Nunn-McCurdy Act; the program breached its cost estimates by 25 percent in 2001, by 15 percent in 2004, and by 25 percent twice during 2005. Sam Black, "Fact Sheet on Space Based Infrared System," Center for Defense Information (16 October 2007), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4122; Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs (Washington, DC: Defense Science Board, May 2003) at 6; US Government Accountability Office, "Defense Acquisitions: Assessments of Major Weapon Programs," Report to Congressional Committees (March 2008) at 101-2; Tonya Racasner, "Third Generation Infrared Program Team Wins Af Space Command's Agile Acquisition Transformation Leadership Award," Los Angeles Air Force Base (14 March 2008), online: http://www.losangeles.af.mil/news/story.asp?id=123090312.

[18] All information from Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 336-338.

[19] The International Institute for Strategic Studies, Military Balance 2008 (London: Routledge, 2008) at 29.

[20] Union of Concerned Scientists, "Satellite Database" (January 2007). There are at least two NROL classified satellites operated by the National Reconnaissance Office, which are believed to be used for either radar imagery intelligence or signals intelligence.

[21] Philip Taubman, "In Death of Spy Satellite Program, Lofty Plans and Unrealistic Bids," New York Times (11 November 2007).

[22] Mark Mazzetti, "Spy Director Ends Program on Satellites," New York Times (22 June 2007).

[23] "US pursuing new satellite program," CBS News (30 November 2007), online: http://www.cbsnews.com/stories/2007/11/30/tech/main3561086.shtml; Philip Taubman, "Failure to Launch; Death of a Spy Satellite Program."

[24] Alden V. Munson, Jr., deputy director of national intelligence for acquisition, cited in Philip Taubman, "Death of Spy Satellite Program."

[25] Tamara A. Mehuron, at 44.

[26] Union of Concerned Scientists, "Satellite Database" (January 2007).

[27] "Lockheed Delivers GPS Satellites," Defense News (2 April 2007) at 50.

[28] Ben Iannotta, "$408 Million ORS Budget to Have Broad-Based Focus," Space News (17 August 2007).

[29] Robert K. Ackerman, "Small Satellite Offers Glimpse of the Future," Signal Magazine (January 2004); Gunter Dirk Krebs, "TacSat 1," Gunter's Space Page (1 January 2005), online: http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sdat/tacsat-1.htm.

[30] M. Hurley, "Tactical Microsatellite Experiment (TacSat 1)," Navy Research Laboratory Review (2004), online: http://www.nrl.navy.mil/content.php?P=04REVIEW207.

[31] US Air Force, Fact Sheet, "Evolved Expendable Launch Vehicle" (April 2003), online: http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=3643; Anthony Young, "Heavy Lifting for the New Millennium," The Space Review (26 April 2004).

[32] "Report of the Commission to Assess United States National Security Space Management and Organization" (11 January 2001) at 8-9, online: Federation of American Scientists, www.fas.org/spp/military/commission/report.htm. While established by the US Government, the Commission

does not formally set new US policy in this area. See also "Rumsfeld Asks if Pentagon is Over-Reliant on Space Systems," Space News (13 May 2002) at 4.

33 Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 70-72; Gunter Dirk Krebs, "Chronology," Gunter's Space Page, online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/home.htm (date accessed: 9 February 2007); Union of Concerned Scientists, "UCS Satellite Database;" Jonathan McDowell, "Satellite Database," (January 2008), unpublished.

34 "Weapons in Space and Global Security," Report of the NATO Parliamentary Assembly Sub-Committee on the Proliferation of Military Technology, 156 STCMT 03 E (2003) at 5.

35 Pavel Podvig, "Russia and Military Uses of Space," Working paper, The American Academy of Arts and Sciences Project, "Reconsidering the Rules of Space" (June 2004), online: Russian Strategic Nuclear Forces, http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml; Center for Defense Information, "Russian General Comments on Russian Space Forces Initiatives… Stands Firm on No Nuclear Weapons in Space," CDI Space Security Update 14 (21 July 2004), online: http://www.cdi.org/program/issue/document.cfm?DocumentID=2322&IssueID=140&StartRow=1&ListRows=10&appendURL=&Orderby=DateLastUpdated&ProgramID=68&issueID=140#3; ITAR-TASS, "Russia Does Not Plan Launching Nuclear Weapons in Space" (14 July 2004).

36 Interfax, "No More Reductions of Russian Satellite Fleet Planned" (14 July 2004).

37 "Russia's Space Defenses Stage a Revival," RIA Novosti (4 October 2006), online: http://en.rian.ru/analysis/20061004/54509604-print.html.

38 All information from Pavel Podvig, "Russia and Military Uses of Space."

39 Pavel Podvig, "Russia and Military Uses of Space"; see also Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 349.

40 BBC Monitoring Former Soviet Union, "Russian Space Conference Looks at Problems and Challenges," (25 November 2005), online: RedOrbit.com http://www.redorbit.com/news/space/302983/russian_space_conference_looks_at_problems_challenges/index.html.

41 Pavel Podvig, "History and the Current Status of the Russian Early Warning System," 10 Science and Global Security (2002) at 21-60; Pavel Podvig, "Early Warning," Russian Strategic Nuclear Forces (9 February 2009), online: http://russianforces.org/sprn/.

42 Pavel Podvig, "Reducing the risk of an accidental launch," 14 Science and Global Security (2006) at 35.

43 Pavel Podvig, "Russia is working on new early-warning satellites," Russian Strategic Nuclear Forces — Blog (22 August 2007), online: http://russianforces.org/blog/2007/08/russia_is_working_on_new_early.shtml.

44 Johnson's Russia List, "Russia to Restore Space Missile Warning System" (6 April 2006), online: Center for Defense Information, http://www.cdi.org/russia/johnson/9112-27.cfm.

45 Geoffrey Forden, Pavel Podvig, and Theodor A. Postol, "False alarm, nuclear danger," IEEE Spectrum (March 2000), online: Moscow Institute for Physics and Technology http://www.armscontrol.ru/Start/publications/spectrum-ews.htm.

46 Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 341.

47 The Lavochkin Science and Production Association agreed to build the Arkon-2 multirole radar satellite for the Federal Space Agency. It is designed to take high-resolution and medium-resolution photos for federal clients, and to use the information for national defense programs. Yuri Zatitsev, "Russia Developing New Space Radars," RIA Novosti (3 March 2005).

48 Pavel Podvig, "Russia and Military Uses of Space."

49 Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 319-323.

50 In 2007 $380-million was allocated. RIA Novosti, "Russia prepares to launch 3 GLONASS satellites on December 25th" (25 December 2007), online: http://en.rian.ru/russia/20071225/94088531.html.

51 Y. Zaitsev, "GLONASS Potential Still To Be Realised," GPS Daily (1 May 2007), online: http://www.gpsdaily.com/reports/GLONASS_Potential_Still_To_Be_Realised_999.html.

[52] Pavel Felgenhauer, "Did GLONASS Failure Sink Ivanov's Chance at the Presidency?" Eurasia Daily Monitor (6 February 2008), online: Jamestown News, www.jamestown.org/edm/article.php?article_id+2372780.

[53] CNN.com Bloomberg, "Russia to build new space port" (22 November 2007), online: http://edition.cnn.com/2007/TECH/space/11/21/russia.space.ap/index.html.

[54] Gayle S. Putrich, "U.S. Air Force's Space Budget Up 5.3%" Defense News (11 Feburary 2008).

[55] Andrea Shalal-Esa, "US military sees rising demand for satellites," Reuters (2 June 2008), online: http://www.reuters.com/article/rbssTechMediaTelecomNews/idUSN0229389520080602; "Military Satellites Tens of Billions of Dollars Over Budget," Florida Today (23 May 2008), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4323.

[56] Caitlin Harrington, "US DoD initiates acquisitions policy overhaul," Jane's Defence Weekly (10 December 2008) at 8.

[57] Colin Clark, "Pentagon, Intelligence Community To Jointly Manage System Procurement," Space News (24 March 2008); Colin Clark, "Pentagon, NRO Loses Decision Authority on BASIC Imaging Satellite Program," Space News (10 March 2008).

[58] W. David Gardener, "Congress Cuts BASIC Satellite Imaging Program," Information Week (21 October 2008), online: http://www.informationweek.com/news/government/showArticle.jhtml?articleID=211300121.

[59] Turner Briton, "NRO BASIC Procurement Approved," Space News (30 June 2008).

[60] W. David Gardner, "Congress Cuts BASIC Satellite Imaging Program."

[61] Turner Briton, "DoD Approves NRO BASIC Procurement," Defense News (14 July 2008) at 34; W. David Gardner, "Congress Cuts BASIC Satellite Imaging Program."

[62] Pamela Hess and Stephen Manning, "Congress Cancels Novel Satellite Program," Washington Times (23 October 2008) at B2.

[63] Megan Scully, "NRO cancels contracts for proposed space radar project," NextGov (04 April 2008), online: http://www.nextgov.com/nextgov/ng_20080404_4891.php; Colin Clark, "Failed Satellite Combined Optical, Radar-Like Imaging Capabilities," Space News (4 February 2008).

[64] Colin Clark, "Revamped Space Radar Approach Entail Smaller, Lower-Cost Craft," Space News (14 April 2008); Colin Clark, "'Big Mistake:' No Dough For Space Radar," DoDBuzz (5 October 2008), online: http://www.dodbuzz.com/2008/10/05/big-mistake-no-dough-for-space-radar/.

[65] "Radar Love," Aviation Week and Space Technology (29 September 2008) at 23; Barbara Opall-Rome, "DoD Looks Abroad for Space Radar," Defense News (1 September 2008), online: http://www.defensenews.com/story.php?i=3700661.

[66] "AEHF Cost Overrun Prompts Nunn-McCurdy Investigation," Aerospace Daily & Defense Report (1 August 2008); Turner Brinton, "Technical Issues Cause AEHF Cost Growth, Launch Delay," Space News (5 January 2009) at 7; Colin Clark, "Huge Cost Overrun for AEHF," DoD Buzz (8 September 2008), online: http://www.dodbuzz.com/2008/09/08/huge-cost-overrun-for-aehf/.

[67] "AEHF Fast Track," Aviation Week and Space Technology (29 September 2008) at 19.

[68] Turner Briton, "U.S. Defense Department Opts To Move Ahead on T-Sat," Space News (4 August 2008) at 13.

[69] United States House of Representatives House Armed Services Committee, "Summary of National Defense Authorizations for Fiscal Year 2009" (2009), online: http://armedservices.house.gov/pdfs/fy09ndaa/FY09conf/FY2009NDAAFundingTables.pdf. TSAT Program Staff, "Focus On — TSAT Technology is Mature," MilSat Magazine (May 2008), online: http://www.milsatmagazine.com/cgi-bin/display_article.cgi?number=1430644606; Jeremy Singer and Turner Briton, "USAF Secretary Says T-Sat Technology Is Ready," Space News (14 April 2008) at 13; Gayle S. Putrich, "Will CSAR-X, TSAT Decisions Follow Tanker to 2009?" Defence News (22 September 2008) at 6.

[70] Melanie Bender, "Bye-Bye TSAT," NextGov (23 December, 2008), online: http://techinsider.nextgov.com/2008/12/byebye_tsat.php.

[71] Turner Brinton, "Technical Issues Cause AEHF Cost Growth, Launch Delay," Space News (5 January 2009) at 7; "TSAT to be Postponed," Center for Defence Information (18 December 2008), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4427#12; Andrea Shalal-Esa,

"Pentagon OKs revamp of communications satellite," Reuters (9 December 2008), online: http://www.reuters.com/article/rbssIndustryMaterialsUtilitiesNews/idUSN0927905220081209.

72 Andrea Shalal-Esa, "U.S. satellite failure revives tracking concerns," ForexPro.com (4 December 2008), online: http://www.forexpros.com/news/general-news/analysis-u.s.-satellite-failure-revives-tracking-concerns-11190; RedOrbit, "Officials Still Investigating Security Satellite Failure" (6 January 2009), online: http://www.redorbit.com/news/space/1618645/officials_still_investigating_security_satellite_failure/

73 "Second SBIRS payload completes early on-orbit checkout," Air Force Print News Today (20 June 2008), online: GlobalSecurity.org, http://www.globalsecurity.org/space/library/news/2008/space-080620-afpn01.htm; LockHeed Martin, News Release, "Lockheed Martin SBIRS Team Completes On-Orbit Handover Of First HEO Payload To U.S. Air Force" (5 August, 2008), online: http://www.lockheedmartin.com/news/press_releases/2008/85_ss_sbirs.html.

74 Staff Writers, "New Missile Warning Satellite Built by LockMart Progressing in Critical Test Phase," Space War (28 March 2008), online: http://www.spacewar.com/reports/New_Missile_Warning_Satellite_Built_By_LockMart_Progressing_In_Critical_Test_Phase_999.html; Amy Butler, "Newest DSP Satellite Likely Failing in Orbit," Aviation Week (1 December 2008), online: http://www.aviationweek.com/aw/generic/story.jsp?id=news/DSP120108.xml&headline=Newest%20DSP%20Likely%20Failing%20in%20Orbit&channel=space.

75 Turner Brinton, "U.S. Air Force to Buy 4th SBIRS Satellite," Space News (10 September 2008); US Government Accountability Office, "Space Based Infrared System High Program and its Alternative," Report to Congress, GAO-07-1088R (12 September 2007); Turner Brinton, "DSP Constellation Health Concerns Prompt Plan for Gap-Filler Satellite," Space News (24 November 2008).

76 United States House of Representatives House Armed Services Committee, "Summary of National Defence Authorizations for Fiscal Year 2009"; "House Report 110-652 — Duncan Hunter National Defense Authorization Act for Fiscal Year 2009," (16 May 2008), online: http://www.congress.gov/cgi-bin/cpquery/?&sid=cp110MHseG&refer=&r_n=hr652.110&db_id=110&item=&sel=TOC_320133&.

77 Amy Butler, "Quick Sat," Aviation Week and Space Technology (13 October 2008) at 32.

78 Jeremy Singer, "U.S. Army Sees Growing Need for Commercial Imagery," Space News (18 February 2008) at A3.

79 William Matthews, "Smaller, Quicker, Cheaper: Military Searches for Faster, Less Expensive Techniques to Lift Payloads," Defense News (7 April 2008).

80 Colin Clark, "Army to Launch SATS After 50 Years Lull," DefenceTech.org (28 April 2008), online: http://www.defensetech.org/archives/004147.html.

81 "TacSat-3 Delayed Until Ides of March," SpacePorts — Blog (20 December 2008), online: http://spaceports.blogspot.com/2008/12/tacsat-3-light-this-candle-jan-31.html; "Technical issues, more tests delay TacSat-3's liftoff," SpaceFlight Now (6 November 2008), online: http://spaceflightnow.com/news/n0811/06tacsat3/.

82 Turner Briton, "AFRL Anticipates TacSat-5 Contract Award in Mid-2009," Space News (11 August 2008) at 15.

83 Simon Saradzhyan and Nabi Abdullaev, "Georgian War Highlights Gaps in Russian Space Capabilities," Space News (1 December 2008) at 16.

84 Simon Saradzhyan, "Russians Say Georgian Conflict Highlighted Need for Upgraded Surveillance Satellites," Space News (22 September 2008) at 4.

85 "Putin orders additional $2.6 bln on GLONASS development," Ria Novosti (12 September 2008), online: http://en.rian.ru/russia/20080912/116749330.html.

86 Andrei Kislyakov, "Outside View: GLONASS plans — part 2," GPS Daily (12 June 2008), online: http://www.gpsdaily.com/reports/Outside_View_GLONASS_plans_Part_2_999.html.

87 Ot redakcii, "Zamah na 67 milliardov" [in Russian, From the editor, "Goal for 67 billion"], Independent Newspaper (19 September 2008), online: http://nvo.ng.ru/forces/2008-09-19/1_red.html.

[88] Russian Federal Space Agency, "Roskosmos launches database" [in Russian], online: http://www.federalspace.ru/StartsMain.asp?ShowYear=2008.

[89] Ria Novosti, "Russia launches rocket with three new GLONASS satellites" (25 December 2008), online: http://en.rian.ru/russia/20081225/119169033.html.

[90] Andrei Kislyakov, "Outside View: Problems with GLONASS," GPS News (9 April 2008), online: http://www.spacedaily.com/reports/Outside_View_Problems_with_GLONASS_999.html.

[91] "GLONASS 'near GPS accuracy' by 2010," Royal Institute of Navigation (6 September 2008), online: https://www.rin.org.uk/sigs-branches/space/space-special-interest-group/news/GLONASS-near-gps-accuracy-2010.

[92] Russian Strategic Nuclear Forces — Blog, "Launch of Cosmos-2441 — first Persona optical reconnaissance satellite" (26 July 2008), online: http://russianforces.org/blog/2008/07/launch_of_cosmos-2441_-_first.shtml; Simon Saradzhyan, "Georgian War Highlights Gaps in Russian Space Capabilities," Space News (1 December 2008) at 16.

[93] Economist.com, "Russia's secret satellite snoopers" (3 April 2008).

[94] Pavel Podvig, "Launch of three Gonets-M spacecraft," Russian Strategic Nuclear Forces — Blog (23 May 2008), online: http://russianforces.org/blog/2008/05/launch_of_three_gonetsm_spacec.shtml.

[95] Pavel Podvig, "Cosmos-2437, -2438, and -2439 are not Gonets-M," Russian Strategic Nuclear Forces — Blog (19 June 2008), online: http://russianforces.org/blog/2008/06/cosmos-2437_-2438_and_-2439_ar.shtml.

[96] Pavel Podvig, "Launch of an Early Warning Satellite," Russian Strategic Nuclear Forces — Blog (25 January 2008), online: http://russianforces.org/blog/2008/01/russia_pulls_out_of_an_earlywa.shtml; Stephen Clark, "Russian Proton Rocket Launches Military Satellite," Space.com (30 June 2008), online: http://www.space.com/missionlaunches/sfn-080630-proton-launch.html.

[97] Pavel Podvig, "Launch of Cosmos-2446, a new first-generation early-warning satellite," Russian Strategic Nuclear Forces — Blog (2 December 2008), online: http://russianforces.org/blog/2008/12/launch_of_cosmos-2446_a_new_fi.shtml.

[98] Pavel Podvig, "Russia pulls out of an early-warning arrangement with Ukraine," Russian Strategic Nuclear Forces — Blog (25 January 2008), online: http://russianforces.org/blog/2008/01/russia_pulls_out_of_an_earlywa.shtml; RIA Novosti, "Russia to put new radar station on combat duty by yearend" (11 April 2008), online: http://en.rian.ru/russia/20080411/104874373.html

[99] Pavel Podvig, "Angara launcher to be ready in 2011," Russian Strategic Nuclear Forces — Blog (27 January 2008), online: http://russianforces.org/blog/2008/01/angara_launcher_to_be_ready_in.shtml.

[100] Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 70-72.

[101] Euroconsult, Media Release, "Government Space Program Expenditures Worldwide Hit a Record $62 billion."

[102] Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 72.

[103] Yahya A. Dehqanzada and Ann M. Florini, Secrets for Sale: How Commercial Satellite Imagery will Change the World (Washington, DC: Carnegie Endowment for International Peace, 2000), cited in Jeffrey T. Richelson, "The Whole World is Watching," Bulletin of Atomic Scientists (January/February 2006) at 33.

[104] Theresa Hitchens and Tomas Valasek, "National Programs," European Military Space Capabilities, A Primer (Center for Defense Information, 2006) at 24.

[105] Defense News, "Europe begins debate on next-generation spy satellites" (6 February 2006).

[106] French Imagery Intelligence, "The First European Military Observation Satellite," Federation of American Scientists, 1999, online: http://www.fas.org/spp/guide/france/military/imint/helios1a.htm.

[107] Spaceflight Now, "German Radar Spy Satellite Launches into Space" (19 December 2006), online: http://www.spaceflightnow.com/news/n0612/19sarlupe/; Tom Kington, "Crunch Time for Europe," Defense News (6 February 2006) at 11; Alenia Spazio, "COSMO-SkyMed," online: http://www.aleniaspazio.it/earth_observation_page.aspx?IdProg=23 (date accessed: 9 February 2007); Staff

Writers, "Thales Alenia Space To Deliver Very-High-Resolution Optical Imaging Instrument To Astrium," SpaceMart (11 July 2008), online: http://www.spacemart.com/reports/Thales_Alenia_Space_To_Deliver_Very_High_Resolution_Optical_Imaging_Instrument_To_Astrium_999.html.

108 Rodoula Zissi, "Multinational Space-based Imaging System (MUSIS): European space cooperation for security and defence," European Security and Defence Assembly: Fifty-Fifth Session (6 November 2008), online: http://www.assembly- weu.org/en/Reports%20Dec%202008/2025.pdf?PHPSESSID=46e63a1504db501f256c1a193010123d.

109 Pierre Tran, "France Readies Satellite Launches," Defence News (6 November 2008), online: http://www.defensenews.com/story.php?i=3807629.

110 Space News, "European Rocket Sends French Military Satellite Aloft" (28 November 2005).

111 For a discussion see online: Federation of American Scientists, http://www.fas.org/spp/guide/france/military/imint/ (date accessed: 9 February 2007).

112 The International Institute for Strategic Studies, Military Balance 2003-2004 (London: Routledge 2004) at 230.

113 "German Forces Will Receive Secure Network with Two Satellites," Space War (9 July 2006), online: http://www.spacewar.com/reports/German_Armed_Forces_Will_Receive_Secure_Network_With_Two_Satellites_999.html.

114 The International Institute for Strategic Studies, Military Balance 2003-2004, at 230.

115 Pierre Tran, "France Readies Satellite Launches," Defence News (6 November 2008), online: http://www.defensenews.com/story.php?i=3807629.

116 Peter B. de Selding, "Rest of Europe Cool to French Missile Warning Ambitions," Space News (27 October 2008) at 13; Peter B. de Selding, "France Determined to Demonstrate Missile Warning Technology, Improve U.S. Ties," Space News (1 October 2008) at 13.

117 European Commission, Communication from the Commission to the Council and the European Parliament: European Space Policy, COM (2007) 212 final (26 April 2007) at para. 3.4, online: http://ec.europa.eu/enterprise/space/doc_pdf/esp_comm7_0212_en.pdf.

118 Jonathan Amos, "Europe's 10bn euro space vision," BBC World (26 November 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7747539.stm.

119 David Long et al., "The Evolution and Shape of European Space Policy: Preliminary Report for DFAIT" (Government of Canada, Department of Foreign Affairs and International Trade, International Security Research and Outreach Programme, 2004) at 25.

120 Andrew B. Godefroy, "Europe in a Changing Global Context: Space Policy, Security, and Non-Weaponization" (Government of Canada, Department of Foreign Affairs and International Trade, International Security Research and Outreach Programme, 2004) at 14.

121 Luca del Monte, cited in Peter B. de Selding, "ESA Positioning itself on Europe's Security and Defense Issues," Space News (27 March 2006).

122 GlobalSecurity.org, "China Military Space Projects," online: http://www.globalsecurity.org/space/world/china/military.htm (date accessed: 10 July 2008).

123 Mark Stokes, China's Strategic Modernization: Implications for the United States (Strategic Studies Institute, September 1999), at 6, 173, online: http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=74.

124 State Council Information Office, White Paper, China's National Defense in 2008 (20 January 2009), online: China Daily http://www.chinadaily.com.cn/china/2009-01/20/content_7413294.htm; Trefor Moss, "Space Race," Jane's Defence Weekly (29 October 2008), at 28.

125 GlobalSecurity.org, "China and Imagery Intelligence," online: http://www.globalsecurity.org/space/world/china/imint.htm (date accessed: 10 July 2008).

126 Jane's Space Directory, "Government and Non Government Space Programs: China" (14 October 2004).

127 The International Institute for Strategic Studies, Military Balance 2003-2004 at 230, 304; Union of Concerned Scientists, "UCS Satellite Database."

128 Surrey Satellite Technologies Ltd., SSTL Space Missions, "Disaster Monitoring and High-Resolution Imaging," (2005), online: http://www.sstl.co.uk/index.php?loc=121. It has been reported that

"Government departments will also use the satellite during emergencies to aid decision-making of the central government." From People's Daily Online, "Beijing-1 Satellite Starts Remote Sensing Service" (8 June 2006), online: http://english.people.com.cn/200606/08/eng20060608_272262.html.

129 Xinhua, "Remote Sensing Satellite Successfully Launched" (27 April 2006), online: http://news.xinhuanet.com/english/2006-04/27/content_4480989.htm.

130 Jonathan Weng, "China satellite launch indicates rapid progress," Jane's Defence Review (13 June 2007) at. 25; Jonathan McDowell, "NROL," Jonathan's Space Report No. 581, online: http://www.planet4589.org/space/jsr/back/news.581. The last two satellites were launched in 2008 after the publication of these articles. They are most likely optical imaging satellites.

131 John Pike, "The Military Uses of Outer Space," in SIPRI Yearbook 2002 (Oxford: Oxford University Press: 2002) at 635-6; Center for Nonproliferation Studies, "China: Military Programs," online: http://cns.miis.edu/research/space/china/mil.htm (date accessed: 10 July 2008).

132 "Fenghuo-1 Military Communications Satellite," Chinese Defence Today (14 September 2006), online: SinoDefence.com http://www.sinodefence.com/strategic/spacecraft/fenghuo1.asp.

133 John Pike, "The Military Uses of Outer Space," at 635-6.

134 Geoffrey Forden, "Strategic Uses for China's Bei Dou Satellite System," Jane's Intelligence Review (16 September 2003); Geoffrey Forden, "The Military Capabilities and Implications of China's Indigenous Satellite-Based Navigation System," 12 Science and Global Security (2004) at 232.

135 Dr. Jing Guifei, National Remote Sensing Center of China and the Ministry of Science and Technology, quoted in GPS World, "China Discusses Beidou with the GNSS Community" (21 February 2008), online: http://sidt.gpsworld.com/gpssidt/content/printContentPopup.jsp?id=493496; Glen Gibbons, "China's Compass/Beidou: Back-Track or Dual Track?" Inside GNSS (March/April 2008). According to the following article, the military signal could provide accuracy up to 10 meters: GPS Daily, "China Starts to Build Own Satellite Navigation System" (3 November 2006), online: http://www.gpsdaily.com/reports/China_Starts_To_Build_Own_Satellite_Navigation_System_999.html.

136 Xinhua, "China puts new navigation satellite into orbit" (3 February 2007), online: http://news.xinhuanet.com/english/2007-02/03/content_5689019.htm; Xinhua, "China launches 'Compass' navigation satellites" (14 April 2007), online: http://news.xinhuanet.com/english/2007-04/14/content_5974414.htm.

137 Glen Gibbons, "China's Compass/Beidou: Back-Track or Dual Track?" Inside GNSS News (1 March 2008), online: http://www.insidegnss.com/node/573#Baseband_Technologies_Inc; John Walko, "China set to launch rival to GPS, Galileo," EE Times (5 February 2007), online: www.eetimes.com/showArticle.jhtml?articleID=197003167.

138 Astronautix, "CZ 4B Chronology" (2007), online: http://www.astronautix.com/lvs/cz4b.htm; James Lewis, "China as a Military Space Competitor" (January 2004) at 12, online: Space Policy Institute, http://www.gwu.edu/~spi/spaceforum/China.pdf.

139 Indian Space Research Organisation, Indian Space Research Organisation Annual Report 2005-2006 (2007), online: http://www.isro.org/rep2007/Earth%20Observation.htm; India Defence, "Army's satellite based surveillance and intelligence program near completion" (18 September 2006), online: http://www.india-defence.com/reports/2519.

140 G. Madhavan Nair, Secretary in the Department of Space and Chairman of Indian Space Research Organisation, quoted in Fresh News, "India ready for launch of satellite with military applications" (21 September 2007), online: http://www.freshnews.in/india-ready-for-launch-of-satellite-with-military-applications-15639.

141 Space News, "India to Set Up Military SBS System by 2007" (9 August 2005).

142 Staff Writers, "ISRO's New Satellite Could See Through Even Cloudy Sky," SpaceMart (7 November 2008), online: http://www.spacemart.com/reports/ISRO_New_Satellite_Could_See_Through_Even_Cloudy_Sky_999.html; Richard Cochrane, "New Indian Satellite Can See Through Clouds," Hypocrisy.com (Blog) (7 November 2008), online: http://richardcochrane.hypocrisy.com/2008/11/07/new-indians-satellite-can-see-through-clouds/.

143 "Army's satellite based surveillance and intelligence program near completion."

[144] ISRO, Indian Space Research Organisation Annual Report 2005-2006; "Army's satellite based surveillance and intelligence program near completion."

[145] ISRO, Indian Space Research Organisation Annual Report 2005-2006.

[146] RIA Novosti, "GLONASS Navigation System Available to India — Russia" (21 January 2007), online: http://en.rian.ru/russia/20070122/59520011.html.

[147] Dr. Kasturirangan, National Institute of Advanced Studies, Keynote Address at the International Space Security Conference: Scope and Prospects for Global Cooperation, Institute for Defence Studies and Analyses and Centre for Defence and International Security Studies, New Delhi (13-14 November 2007).

[148] Terra Daily, "Process For Establishing Aerospace Command," (November 20 2007), online: http://www.terradaily.com/reports/Process_On_For_Establishing_Aerospace_Command_999.html.

[149] Rear Admiral Raja Menon, "Space and National Strategies," Presentation at the International Space Security Conference: Scope and Prospects for Global Cooperation, Institute for Defence Studies and Analyses and Centre for Defence and International Security Studies, New Delhi (13-14 November 2007); Esther Pan, Backgrounder, "The U.S.-India Nuclear Deal," Council on Foreign Relations (2 October 2008), online: http://www.cfr.org/publication/9663/.

[150] The International Institute for Strategic Studies, Military Balance 2003-2004, at 292.

[151] Dawn, "Pakistan to Launch Remote Sensing Satellite System" (22 August 2005).

[152] Gunter Dirk Krebs, "IGS-Optical 1, 2," Gunter's Space Page (4 January 2005), online: http://www.skyrocket.de/space/doc_sdat/igs-optical-1.htm.

[153] Mark Wade, "IGS," Astronautix, online: http://www.astronautix.com/craft/igs.htm (date accessed: 20 January 2009).

[154] "Japanese Spy Satellite Rockets into Orbit," Space Flight (11 September 2006), online: http://www.spaceflightnow.com/news/n0609/11h2aigs/.

[155] Kim Yong-ho, "Air Force Begins Establishment of the Space Command Center in Full-Scale," Seoul Kukpang Journal (1 December 2003).

[156] John Pike, "The Military Uses of Outer Space," at 641.

[157] The order was placed in 1996. The International Institute for Strategic Studies, Military Balance 2003-2004, at 306.

[158] Asia Satellite News, "Koreasat 5 Launched" (29 August 2006), online: TelecomsEurope, http://www.telecomseurope.net/article.php?id_article=2979.

[159] RIA Novosti, "Russian Rocket Launches South Korea's Kompsat 2" (28 July 2006), online: GIS Development, http://www.gisdevelopment.net/news/print.asp?id=GIS:N_sawjfmqrvz&cat=New+Products&subc=Satellite+Imagery.

[160] Spot Image, "Kompsat 2: The Alternative Metric Solution," online: http://www.spotimage.fr/html/_167_171_1155_.php (date accessed: 9 February 2007).

[161] "Thailand Signs Deal with French Company for Spy Satellite," Agence-France Presse (19 July 2004).

[162] "Taiwan Planning Spy Satellite: Report," Agence France-Presse (10 October 2005); "Taiwan Plans Launch of Spy Satellite," Mail and Guardian (10 October 2005). In 2006 Taiwan's military released reconnaissance photos that it claimed depicted China's military buildup. "Taiwanese Military Shows Satellite Images of China's Military Build-up," Yahoo! Asia News (20 January 2006), online: http://asia.news.yahoo.com/060119/kyodo/d8f7mj280.html.

[163] Defense Update, "Israel Launches New Satellite," (updated 9 July 2002), online: http://www.defense-update.com/news/ofeq5.htm; The International Institute for Strategic Studies, Military Balance 2003-2004, at 230. The launch of Ofek-4 in 1999 failed. The International Institute for Strategic Studies, Military Balance 2003-2004, at 281.

[164] SatNews Daily, "Ofeq-7, Other Spy Satellites Give Israel Persistent Eyes on the Middle East" (13 June 2007), online: http://www.satnews.com/stories2007/4599/. Some reports indicate that the Ofeq-7 has an imaging capability of up to 70 centimeters, while others indicate 50 centimeters.

[165] Space News, "Israel's Eros B imaging satellite reaches orbit" (1 May 2006).

[166] Barbara Opall-Rome, "Israel Eyes UAVs, Comsat for Future Military Communications," Space News (7 December 2006).

167 Arieh O'Sullivan, "Successful Test of New Rocket Launcher," Jerusalem Post (14 July 2005).

168 Craig Covault, "Israeli space based radar set for Indian launch," Aviation Week and Space Technology (16 September 2007), online: http://aviationnow.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw091707p2.xml&headline=Israeli%20Space-Based%20Radar%20Set%20for%20Indian%20Launch.

169 Jeffrey T. Richelson, "The Whole World Is Watching," at 35.

170 Yitaf S. Shapir, "The Spirit is Willing: Iran's Effort to Conquer Space," 152 Tel Aviv Notes (6 November 2005); Ali Akbar, "Iran Now Says Satellite Can Spy on Israel," Associated Press (16 November 2005).

171 Robin Hughes, "Long Range Ambitions" Jane's Defence Weekly (13 September 2006) at 26.

172 "Egyptsat-1 placed into orbit," GIS Development (18 April 2007), online: http://www.gisdevelopment.net/news/viewn.asp?id=GIS:N_hkzlwgbfpr.

173 Jerusalem Post, "Egypt to launch first spy satellite" (15 January 2007), online: http://www.jpost.com/servlet/Satellite?cid=1167467733037&pagename=JPost%2FJPArticle%2FShowFull.

174 Burak Ege Bekdil, "Turkey Plans First Recon Satellite, Worldwide Aerospace Forecast," Defense News (18 June 2007).

175 GlobalSecurity.org, "Australia and Satellite Communication Systems," online: http://www.globalsecurity.org/space/world/australia/comm.htm (date accessed: 9 February 2007).

176 Stephen Butler, "DSTO Plans Unique Test Phase to Model New Era Defence C1 Communications Satellite," Australian Defence Science and Technology Organization (23 June 2003), online: http://www.dsto.defence.gov.au/news/3775/.

177 Space War, "Australia To Join With United States In Defense Global Satellite Communications Capability" (9 October 2007), online: http://www.spacewar.com/reports/Australia_To_Join_With_United_States_In_Defence_Global_Satellite_Communications_Capability_999.html.

178 David Pugliese, "Canada Nears Access to Dedicated Milsats," Defense News (25 September 2006) at 16.

179 DND/CF News Release, "Project Polar Epsilon Will Enhance Canada's Surveillance and Security Capability" (2 June 2005), online: http://www.forces.gc.ca/site/newsroom/view_news_e.asp?id=1674.

180 Stephen Thorne, "Feds Look to Satellite to Assert Arctic Sovereignty," Canadian Press (28 August 2005); National Defence and the Canadian Forces, Backgrounder, "Polar Epsilon" (10 January 2008), online: http://www.forces.gc.ca/site/news-nouvelles/view-news-afficher-nouvelles-eng.asp?id=2546.

181 MacDonald, Dettwiler and Associates Ltd., "Features and Benefits," RADARSAT-2 Information (13 May 2009), online: http://www.radarsat2.info/about/features_benefits.asp .

182 David Pugliese, "Canada to Launch Design Work on Radarsat," Defence News (29 September 2008) at 10.

183 David Pugliese, "Canada to Use Commercial Sats for Mission Imagery," Defense News (6 February 2006) at 19.

184 David Pugliese, "Canada Nears Access to Dedicated Milsats."

185 Donald Bedard, "Microsatellites for Northern Surveillance — Abstract," Defence Research and Development Canada (1 October 2007), online: http://www.ottawa.drdc-dc.gc.ca/html/abstract_microsatellites_norther_e.html.

186 Fernand Verger, Isabelle Sourbès-Verger, and Raymond Ghirardi, The Cambridge Encyclopedia of Space, at 72; Gunter Dirk Krebs, "Spacecraft: Military," Gunter's Space Page, online: http://www.skyrocket.de/space/space.html (date accessed: 9 February 2007); Small Satellites Home Page, "Modern Military Small Satellites," online: Surrey Satellite Company, http://centaur.sstl.co.uk/SSHP/list/list_mil.html; Union of Concerned Scientists, "Satellite Database" (January 2008).

187 Greece and Belgium also use the Helios satellites through their participation in the Besoin Opérationnel Commun framework agreement, but they do not have independent dedicated military satellites.

188 Staff Writers, "German military satellite launched by Russia: report," SpaceTravel (27 March 2008), online: http://www.space-travel.com/reports/German_military_satellite_launched_by_

Russia_report_999.html; NASA, National Space Science Data Center, "SAR Lupe 5" (5 August 2008), online: http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=2008-036A; Stephen Clark, "German Earth-observing radar satellite launched," SpaceFlight Now (27 March 2008), online: http://spaceflightnow.com/news/n0803/27sarlupe4/; Denise Hammick, "German SAR-Lupe system declared fully operational," Jane's Defence Weekly (8 October 2008) at 12.

189 Telespazio, "Third Cosmo-SkyMed Satellite Launched from California" (24 October 2008), online: http://www.telespazio.it/docs/PR_post_eng.pdf.

190 Andy Nativi, "The Italian Job," Aviation Weeks & Space Technology (3 November 2008) at 52.

191 Peter B. de Selding, "Sarkozy Faces Uphill Battle to Boost Military Space Spending," Space News (23 June 2008) at 1. Tim Hepher, "Space to get boost in French defence review," Reuters (5 June 2008), online: http://www.reuters.com/article/marketsNews/idUSL0514874720080605.

192 Peter B. de Selding "Remote Sensing/GIS: Spain to Buy Imaging Satellite from EADS-CASA, Astrium," Space News (12 May 2008) at 9.

193 Michael A. Taverna, "Imaging Ingenuity: Go-ahead for Spanish Satellites reinforces European surveillance capability," Space News (24 November 2008) at 22.

194 Douglas Barrie, "Eye Spy," Aviation Week (9 September 2008) at 30.

195 Norwegian Space Centre, News Archives, "Norway Builds AIS Satellite" (10 September 2008), online: http://www.spacecentre.no/?module=Articles;action=Article.publicShow;ID=51125.

196 Jonathan Amos, "Final Skynet satellite launched," BBC World (12 June 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7451867.stm.

197 Europcritics Magazine, "Skynet Military Satellite Launches" (30 May 2008), online: http://www.eurocriticsmagazine.com/scitech/skynet-military-satellite-launches.

198 Peter B. de Selding, "Italy, France to Procure Dual-Use Telecom Craft," Space News (1 December 2008) at 16.

199 Peter B. de Selding, "European Leaders Endorse Military Role for Galileo," Defence News (6 October 2008) at 58; Peter B. de Selding, "European Defence Agency Has Growing Interest in Military Space," Space News (6 October 2008) at 12.

200 BBC News, "Contest to Build Galileo Begins" (1 July 2008), online: http://news.bbc.co.uk/1/hi/sci/tech/7483582.stm; J. Amos, "Firms Chosen for Galileo Run-Off," BBC News (19 September 2008), online: http://news.bbc.co.uk/2/hi/science/nature/7625357.stm.

201 SPX, "SSTL Completes Galileo In-Orbit Test Campaign" (10 September 2008), online: GPS Daily, http://www.gpsdaily.com/reports/SSTL_Completes_Galileo_In_Orbit_Test_Campaign_999.html; Agence-France Press, "Europe's Galileo Network Continues to Evolve" (29 April 2008), online: Space Daily, http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4298#10.

202 Peter B. de Selding, "Second Satellite in Galileo Constellation Reaches Orbit," Space News (5 May 2008) at 7.

203 Peter B. de Selding, "Half of Galileo PRS Users Expected to be Military," Space News (30 June 2008) at 6; Peter B. de Selding, "Half of Galileo Users Expected to be Military," Defence News (14 July 2008) at 46.

204 Peter B. de Selding, "ESA Gives Initial Approval to Program with Military Applications," Space News (1 December 2008), at 6.

205 BBC News, "North Korea space launch 'fails'" (5 April 2009), online: http://news.bbc.co.uk/2/hi/asia-pacific/7984254.stm.

206 Peter B. de Selding, "European Officials Urge Early Acceptance of Military Use of GMES," Space News (22 September 2008), at 6.

207 Peter B. de Selding, "European Parliament Calls for Civil-Military Space Collaboration," Space News (24 November 2008) at 14.

208 Peter B. de Selding, "EU Satellite Center Gains Access to European Recon Data," Space News (8 December 2008) at 10.

[209] Rui C. Barbosa, "China launch remote sensing satellite Yaogan-4 —with potential military use," NASA SpaceFlight (1 December 2008), online: http://www.nasaspaceflight.com/2008/12/china-yaogan-4-with- potential-military-use/; Craig Covault, "Size Doesn't Matter," Aviation Week and Space Technology (22/29 December 2008) at 22.

[210] SinoDefense.com, "ShiJian 6 Scientific Research Satellite," online: http://www.sinodefence.com/space/spacecraft/shijian6.asp (date accessed: 15 June 2009).

[211] Rui C. Barbosa, "China launch meteorological satellite Fengyun-2-06," NASA Spaceflight (23 December 2008), online: http://www.nasaspaceflight.com/2008/12/china-launch-meteorological-satellite-fengyun-2-06/.

[212] BBC World, "India launches Israeli satellite" (21 January 2008), online: http://news.bbc.co.uk/2/hi/south_asia/7199736.stm; Ninan Koshy, "India and Israel Eye Iran," Foreign Policy in Focus (13 February 2008), online: http://www.fpif.org/fpiftxt/4959.

[213] William Atkins, "India launches Israeli spy satellite: With Iran in its sights," iWire (22 January 2008), online: http://www.itwire.com/content/view/16201/1066/; Yaakov Katz and JPost.com Staff, "Spy satellite launched from India," The Jerusalem Post (21 January 2008), online: http://www.jpost.com/servlet/Satellite?cid=1200572504264&pagename=JPost%2FJPArticle%2FShowFull; Alon Ben-David, "Satellite launch raises Israeli imagery cover," Jane's Defence Weekly (30 January 2008) at 16; Barbara Opall-Rome, "Israel Tests 1st Radar-Imagery Satellite," Defence News (4 February 2008) at 8.

[214] Rahul Bedi, "Getting in step," Jane's Defence Weekly (6 February 2008) at 29.

[215] Barbara Opall-Rome, "Software, Ground Systems to Push Israeli Satellite Performance," Defence News (10 November 2008) at A4.

[216] Harsh V Pant and Bharath Gopalaswamy, "India's Emerging Profile in Space," 153: 5 Royal United Services Institute Journal (October 2008).

[217] United Press International, "India to set up integrated space cell" (11 June 2008), online: http://www.upi.com/Emerging_Threats/2008/06/11/India_to_set_up_integrated_space_cell/UPI-64431213218084/.

[218] "Cartosat-2A Launched," Asian Surveying and Mapping (30 April 2008), online: http://www.asmmag.com/news/cartosat-2a-launched; Staff Writers, "India to launch remote sensing satellite this month," Space Mart (4 April 2008), online: http://www.spacemart.com/reportsIndia_to_launch_remote_sensing_satellite_this_month_999.html; Bharath Gopalaswamy, "Indian Space Policy: Aiming Higher," Space News (22 July 2008), online: http://www.space.com/spacenews/archive08/gopalswamyopted_0721.html.

[219] Leo Lewis, "Change in law launches Japanese military into space," Times Online (10 May 2008), online: http://www.timesonline.co.uk/tol/news/world/asia/article3905247.ece.

[220] Article 25 of the Basic Space Law cited in Setsuko Aoki, "Basic Space Law," Space Law, Instalment 14 (27 August 2008) at 6.

[221] Paul Kallender-Uzemu, "Japan Gears Up for Expansion of Military Space Activities," Space News (10 November 2008) at A4.

[222] Kazuto Suzuki, interview with the author (March 2009).

[223] Setsuko Aoki, "Challenges for Japan's Space Strategy," AJISS-Commentary, No. 34 (26 June 2008) at 3.

[224] For an overview, see Brad Wallce, "Space: A New Approach," 5:6 Frontline (2008), at 18-22.

[225] Canadian Space Agency, "RADARSAT Constellation" (2 March 2009), online: http://www.asc-csa.gc.ca/eng/satellites/radarsat/default.asp.

[226] "Polar Epsilon project," National Defence and Canadian Forces (10 January 2008), online: http://www.forces.gc.ca/site/Newsroom/view_news_e.asp?id=2546.

[227] Canadian Space Agency, "Report on Plans and Priorities 2009-2010" (18 March 2009), online: http://www.asc-csa.gc.ca/eng/publications/rpp_2009.asp.

[228] CBC News, "Com Dev wins micro-satellite contract" (23 June 2008), online: http://www.cbc.ca/technology/story/2008/06/23/comdev-m3msat.html.

Chapter Six Endnotes

1 For a comprehensive overview of non-offensive defenses in space, see Phillip J. Baines, “Prospects for ‘Non-Offensive’ Defenses in Space,” in Clay Moltz, ed., *New Challenges in Missile Defense, Missile Proliferation, and Space Security,* Center for Nonproliferation Studies Occasional Paper No. 12 (August 2003) at 31-48.

2 Bruce deBlois, Richard Garwin, Scott Kemp, and Jeremy Marwell, “Space Weapons Crossing the US Rubicon,” 29 *International Security* (Fall 2004) at 50-84.

3 Bruce deBlois et al., “Space Weapons Crossing the US Rubicon.”

4 Gunter Dirk Krebs, “SPIRALE 1, 2,” Gunter’s Space Page, online: http://www.skyrocket.de/space/doc_sdat/spirale-1.htm (date accessed: 10 June 2008).

5 Pavel Podvig, “History and the Current Status of the Russian Early Warning System,” 10 *Science and Global Security* (2002) at 21-60; Pavel Podvig, “Early Warning,” *Russian Strategic Nuclear Forces — Current Status* (9 February 2009), online: http://russianforces.org/sprn/.

6 Pavel Podvig, “Reducing the risk of an accidental launch,” 14 *Science and Global Security* (2006) at 35.

7 Pavel Podvig, “Russia is working on new early-warning satellites*,” Russian Strategic Nuclear Forces — Blog* (22 August 2007), online: http://russianforces.org/blog/2007/08/russia_is_working_on_new_early.shtml.

8 Johnson’s Russia List, “Russia to Restore Space Missile Warning System” (6 April 2006), online: Center for Defense Information, http://www.cdi.org/russia/johnson/9112-27.cfm.

9 *RIA Novosti,* “Russia Puts New Early Warning Radar Station on Combat Duty” (22 December 2006), online: http://en.rian.ru/russia/20061222/57586624.html.

10 Nikolai Sokov, “Russian Military is Working to Enhance Precision Targeting and Early Warning Capabilities,” *WMD Insights* (December 2007—January 2008); Pavel Podvig, “Russia pulls out of an early-warning arrangement with Ukraine,” *Russian Strategic Nuclear Forces — Blog* (25 January 2008), online: http://russianforces.org/blog/2008/01/russia_pulls_out_of_an_earlywa.shtml; *RIA Novosti,* “Russia terminates early-warning radar agreement with Ukraine” (25 January 2008), online: http://en.rian.ru/russia/20080125/97746840.html.

11 Air Force Space Command, *Strategic Master Plan FY06 and Beyond* (1 October 2003), online: Center for Defense Information, http://www.cdi.org/news/space-security/afspc-strategic-master-plan-06-beyond.pdf.

12 Pavel Podvig, “Reducing the risk of an accidental launch,” at 30.

13 US Government Accountability Office, “Space Based Infrared System High Program and its Alternative,” Report to Congress, GAO-07-1088R (12 September 2007).

14 Timothy Barnes, “Factsheet on Space Based Infrared System,” Center for Defense Information (18 October 2007), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4123.

15 Michael C. Sirak, “The View From Above,” *Airforce-Magazine* (8 February 2008), online: http://www.airforce-magazine.com/Features/modernization/Pages/box020808infrared.aspx.

16 US Government Accountability Office, “Space Based Infrared System High Program and its Alternative”; Jeremy Singer, “Air Force Plans August Awards for AIRSS Flight Demo,” *Space News* (7 March 2007).

17 Marcia S. Smith, “Military Space Programs: Issues Concerning DOD’s SBIRS and STSS Program,” Congressional Research Service (30 January 2006). Marcia Smith’s cost estimates are based on 2005 dollars. “Cost estimates are problematic because there is no final system architecture and the schedule is in flux.” In 2001 it was reported that the program lifecycle had grown from $10-billion to $23-billion.

18 Globalsecurity.org, “Yuan Wang Tracking Ships” (last updated: 23 July 2005), online: http://www.globalsecurity.org/military/world/china/yuan-wang.htm; Globalsecurity.org, “Large Phased-Array Radar (LPAR)” (last updated: 28 April 2005), online: http://www.globalsecurity.org/wmd/world/china/lpar.htm.

[19] Heiner Klinkrad, "Monitoring Space — Efforts Made by European Countries," paper presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France (27-28 November 2002), online: Federation of American Scientists, http://www.fas.org/spp/military/program/track/klinkrad.pdf.

[20] Globalsecurity.org, "RAF Fylingdales" (last updated: 27 April 2005), online: http://www.globalsecurity.org/space/facility/fylingdales.htm.

[21] Stephen Kosiak, "Arming the Heavens: A Preliminary Assessment of the Potential Cost and Cost-Effectiveness of Space-Based Weapons," Center for Strategic and Budgetary Assessments (31 October 2007) at 66, online: http://www.csbaonline.org/4Publications/PubLibrary/R.20071031.Arming_the_Heavens/R.20071031.Arming_the_Heavens.pdf.

[22] MacDonald Dettwiler and Associates, News, "MDA Awarded Contract To Build Canadian Information Solution For Surveillance of Space Objects" (4 October 2007), online: http://www.newswire.ca/en/releases/archive/October2007/04/c8747.html.

[23] Amy Butler, "Bush Memo Orders Space Situation Awareness," *Aviation Week and Space Technology* (12 October 2007), online: http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/MEMO10127.xml.

[24] "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108-136 (24 November 2003).

[25] "A — Rapid Attack Identification, Detection, and Reporting System Spiral 2 Studies," *FBO Daily*, Issue #1033 (24 September 2004), online: http://www.fbodaily.com/archive/2004/09-September/24-Sep-2004/FBO-00679518.htm.

[26] Corey Dahl, "New squadron activates at Peterson," *Air Force Print News* (21 May 2007).

[27] Jeremy Singer, "Air Force ANGELS: Satellite Escorts to Take Flight," *Space News* (30 November 2005). Aeroastro put out a fact sheet indicating that their Escort microsatellite does basically what ANGELS does. There is no reference to Escort on their website so one may assume that they did this work for the ANGELS contract but lost out to Lockheed Martin. A similar situation can be seen with Spacedev; *Space Daily* reported that they received a $1.24-million contract to develop ANGELS, but there the story ended.

[28] Quotation found in Theresa Hitchens, Victoria Sampson, and Sam Black, "CDI Space Weapons Spending in FY 2008 Defense Budget," Center for Defense Information (21 February 2007).

[29] Gunter Dirk Krebs, "Vela," Gunter's Space Page, online: http://space.skyrocket.de/ (date accessed: 10 June 2009).

[30] Andrea Shalal-Esa, "U.S. still probing security satellite failure," Reuters (6 January 2009), online: http://www.reuters.com/article/scienceNews/idUSTRE5055DW20090106.

[31] SPX, "New Missile Warning Satellite Built by Lockheed Martin Progressing in Critical Test Phase," Space War (28 March 2008), online: http://www.spacewar.com/reports/New_Missile_Warning_Satellite_Built_By_LockMart_Progressing_In_Critical_Test_Phase_999.html; Amy Butler, "Newest DSP Satellite Likely Failing in Orbit," *Aviation Week and Space Technology* (1 December 2008), online: http://www.aviationweek.com/aw/generic/story.jsp?id=news/DSP120108.xml&headline=Newest%20DSP%20Likely%20Failing%20in%20Orbit&channel=space.

[32] Turner Brinton, "U.S. Air Force to Buy 4th SBIRS Satellite," *Space* News (10 September 2008); US Government Accountability Office, "Space Based Infrared System High Program and its Alternative," Report to Congress, GAO-07-1088R (12 September 2007); Turner Brinton, "DSP Constellation Health Concerns Prompt Plan for Gap-Filler Satellite," Space News (24 November 2008).

[33] 1st Lt. Nickolas Barton, AFNS, "SBIRS Payload Operationally Accepted," Space Mart (29 January 2009), online: http://www.spacemart.com/reports/SBIRS_Payload_Operationally_Accepted_999.html.

[34] United States House of Representatives House Armed Services Committee, "Summary of National Defense Authorizations for Fiscal Year 2009," (2009), online: http://armedservices.house.gov/pdfs/fy09ndaa/FY09conf/FY2009NDAAFundingTables.pdf; US Congress, "House Report 110-652 — Duncan Hunter National Defene Authorization Act for Fiscal Year 2009," (16 May 2008), online: http://www.congress.gov/cgi-in/cpquery/?&sid=cp110MHseG&refer=&r_n=hr652.110&db_id=110&item=&sel=TOC_320133&.

35 Craig Covault, "Secret inspection satellites boost space intelligence ops," *Spaceflight Now* (14 January 2009), online: http://www.spaceflightnow.com/news/n0901/14dsp23/.

36 Stephen Clark, "Russian Proton Rocket Launches Military Satellite," Space.com (30 June 2008), online: http://www.space.com/missionlaunches/sfn-080630-proton-launch.html.

37 Pavel Podvig, "Launch of an Early Warning Satellite," *Russian Strategic Nuclear Forces — Blog* (27 June 2008), online: http://russianforces.org/blog/2008/06/launch_of_an_early-warning_sat.shtml.

38 Pavel Podvig, "Angara launcher to be ready in 2011," *Russian Strategic Nuclear Forces — Blog* (27 January 2008), online: http://russianforces.org/cgi-bin/mt/mt-search.cgi?search=angara+launcher&IncludeBlogs=1.

39 Pavel Podvig, "Russia pulls out of an early-warning arrangement with Ukraine," *Russian Strategic Nuclear Forces — Blog* (25 January 2008), online: http://russianforces.org/blog/2008/01/russia_pulls_out_of_an_earlywa.shtml.

40 *RIA Novosti,* "Russia to put new radar station on combat duty by yearend" (11 April 2008), online: http://en.rian.ru/russia/20080411/104874373.html.

41 Paul Kallender-Uzemu, "Japan Gears Up for Expansion of Military Space Activities," *Space News* (10 November 2008) at A4; Kyodo News, "Defense Ministry may develop early warning satellite," *The Japan Times* (18 January 2009), online: http://search.japantimes.co.jp/cgi-bin/nn20090118a7.html.

42 Lockheed Martin, "Lockheed Martin Receives $30-million Contract for US Air Force SASSA Program" (4 November 2008), online: PCB007, http://www.pcb007.com/pages/zone.cgi?a=46237.

43 William Matthews, "USAF Seeks Threat Detectors for Satellites," *Defense News* (9 June 2008) at 40; online: http://www.defensenews.com/story.php?i=3576560.

44 Paul Marks, "Pentagon wants laser attack warnings for satellites," *New Scientist* (28 May 2008), online: http://www.newscientist.com/article/dn14002-pentagon-wants-laser-attack-warnings-for-satellites.html.

45 Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest," Center for Defense Information, online: http://www.cdi.org/pdfs/FY2009ChartFinal.pdf (date accessed: 10 June 2009).

46 Theresa Hitchens and Victoria Sampson, "Space Weapons Spending in the FY 2009 Defense Budget," Center for Defense Information (March 2008), online: http://www.cdi.org/pdfs/SpaceWeaponsFY09.pdf.

47 *Jane's Defence Weekly,* "Nano satellites to improve space situational awareness" (28 November 2007); Alan Collinson, "Cutting the clutter," *Jane's Defence Weekly* (16 January 2008) at 30.

48 Amy Butler, "USAF Ey4es Counter-ASAT System in 2011," *Aviation Week and Space Technology* (16 March 2008).

49 President's National Security Telecommunications Advisory Committee (NSTAC), "Satellite Taskforce Report, Fact Sheet" (February 2004), online: National Communications Systems, http://www.ncs.gov/nstac/reports/2004/Satellite%20Task%20Force%20Fact%20Sheet%20(March%202004).pdf; Theresa Hitchens, e-mail communication with author, 17 March 2005.

50 EADS-Astrium UK, e-mail communication with author, December 2004.

51 US General Accounting Office, "Critical Infrastructure Protection: Commercial Satellite Security Should Be More Fully Addressed," Report to the Ranking Minority Member, Permanent Subcommittee on Investigations, Committee on Governmental Affairs, US Senate, GAO-02-781 (August 2002), online: http://www.gao.gov/new.items/d02781.pdf.

52 M.R. Frater and M. Ryan, *Electronic Warfare for the Digitized Battlefield* (Boston: Artech House, 2001). The discussion of electronic warfare in this chapter was largely drawn from the approach provided in this book. US Army Corps of Engineers, "Electromagnetic Pulse (EMP) and TEMPEST Protection for Facilities, Engineering and Design," Pamphlet EP 1110-3-2 (December 1990); W.E. Burrows, *Deep Black Space Espionage and National Security* (Random House: New York, 1986) at 182; Roohi Banu, Tanya Vladimirova, and Martin Sweeting, "On-Board Encryption in Satellites," Paper presented at 2005 Military and Aerospace Programmable Logic Devices (MAPLD) International Conference, Washington, DC, 7-9 September 2005, abstract online: NASA Office of Logic Design, http://klabs.org/mapld05/abstracts/184_banu_a.html; Eric Swankoski and Vijaykrishnan Narayanan, "Dynamic High-Performance Multi-Mode Architectures for AES Encryption," paper presented at 2005 MAPLD International Conference, Washington, DC,

7-9 September 2005, abstract online: NASA Office of Logic Design, http://klabs.org/mapld05/abstracts/103_swankoski_a.html.

53 M.R. Frater and M. Ryan, *Electronic Warfare for the Digitized Battlefield.*

54 Don J. Hinshilwood and Robert B. Dybdal, "Adaptive Nulling Antennas for Military Communications," 3 *Crosslink*, The Aerospace Corporation (Winter 2001/2002) at 30-37. Adaptive antenna systems contain five major components: a means of detecting interference, a means of distinguishing desired signals from interference, a control processor for determining how to combine the antenna elements, antenna elements and circuitry to respond to commands from the control processor, and a performance monitor to identify changes in the interference environment and respond accordingly.

55 Don J. Hinshilwood and Robert B. Dybdal, "Adaptive Nulling Antennas for Military Communications"; Mark Wade, "Milstar," *Encyclopedia Astronautica*, online: http://www.astronautix.com/craft/milstar.htm.

56 US Department of Defense, "Fiscal Year 2006/2007 Budget Estimates. Research, Development, Test and Evaluation (RDT&E) Descriptive Summaries, Volume I: Defense Advanced Research Projects Agency" (February 2005) at 423, online: Defense Technical Information Center, http://www.dtic.mil/descriptivesum/Y2006/DARPA/0603768E.pdf; Maj. Earl Odom, "Future Missions for Unmanned Aerial Vehicles: Exploring Outside the Box," *Aerospace Power Journal* (Summer 2002); Lt. Col. Gregory Vansuch, "Navigation & Guidance," DARPA Special Projects Office, Presentation at DARPATECH 2002; David C. Hardesty, "Space-based Weapons: Long-Term Strategic Implications and Alternatives," *Naval War College Review* (Spring 2005) at 8.

57 The US is developing the TSAT program described in the section on Space Support for Terrestrial Military Operations. See Michael Fabey, "Air Force Approach Raises Questions about TSAT Capability and Cost," *Aerospace Daily and Defense Report* (18 December 2006), online: http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=aerospacedaily&id=news/TSAT12186.xml. The Germany company Tesat Spacecom has a laser communications terminal that is being tested on the US Missile Defense Agency's NFIRE satellite. See "NFIRE testing laser comms," *Aviation Week and Space Technology* (5 November 2007); France's Astrium Satellites and its subsidiary Tesat Spacecom in Germany launched a civil-military laser communications program in 2007. See Peter B. de Selding, "European Firms Launched Dual-Use Sat Laser Project," *Defense News* (8 October 2007).

58 John T. Bennett, "Air Force to Establish New Cyberspace Operations Command," *Inside the Air Force* (4 October 2006), online: World Politics Watch, http://www.worldpoliticswatch.com/article.aspx?id=233.

59 *China Daily,* "China to Launch its First Anti-Jamming Satellite Next Year" (4 March 2004).

60 *Xinhua,* "China Enhances Spacecraft Monitoring Network" (12 December 2006), online: http://news3.xinhuanet.com/english/2006-12/12/content_5473204.htm; Zhour Honghsun and Liu Wubing, "Status Quo and Assumption of China's Space Satellite Monitoring," *China Communications* (June 2006) at 123.

61 Bob Brewin, "Air Force Suspends Cyber Command Program," Nextgov (12 August 2008), online: http://www.nextgov.com/nextgov/ng_20080812_7995.php; Erik Holmes, "AFSPC Commander Foresees Smooth Mission Transition," *Defense News* (10 November 2008).

62 Bob Brewin, "Air Force pursues Cyber Command again," Nextgov (7 October 2008), online: http://www.nextgov.com/nextgov/ng_20081007_1366.php.

63 Noah Shachtman, "Air Force Aims to 'Rewrite Laws of Cyberspace,'" *Wired — Blog* (3 November 2008), online: http://blog.wired.com/defense/2008/11/air-force-aims.html.

64 Phillip Coyle referenced in Bob Brewin, "Air Force Suspends Cyber Command Program"; Erik Holmes, "AFSPC Commander Foresees Smooth Mission Transition," *Defense News* (10 November 2008).

65 Denise Hammick, "NATO cyber defence centre established." *Jane's Defence Weekly* (21 May 2008) at 11.

66 "NATO agrees common approach to cyber defense," EurActiv.com (4 April 2008), online: http://www.euractiv.com/en/infosociety/nato-agrees-common-approach-cyber-defence/article-171377.

67 Jeremy Singer, "U.S. Army System Tracking Interference with Communication Satellites," *Space News* (18 February 2008) at A2.

68 Amy Butler, "USAF Eyes Counter-ASAT System in 2011," *Aviation Week and Space Technology* (16 March 2008).

69 *San Antonio Business Journal,* "Air Force Awards General Dynamics a $9 million satellite encryption contract" (9 July 2008).

70 SPX, "TerraSar-X and NFIRE Fire Up the Pipe With Laser Data Transfer," Space Mart (14 May 2008), online: http://www.spacemart.com/reports/TerraSAR_X_And_NFIRE_Fire_Up_The_Pipe_With_Laser_Data_Transfer_999.html.

71 Peter B. de Selding, "U.S.-German Laser Intersatellite Link Performs Well on 2 Spacecraft," *Space News* (17 March 2008) at 1, 4.

72 SPX, "TerraSar-X and NFIRE Fire Up the Pipe With Laser Data Transfer."

73 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts & Sciences, 2005).

74 Dana Priest, "New Spy Satellite Debated On Hill," *Washington Post* (11 December 2004); Dana Priest, "Lawmakers Balk at Cost of Satellite Few Admit Exists," *Washington Post* (12 December 2004).

75 Lt. Col. Richard E. Fitts, ed., *The Strategy of Electromagnetic Conflict* (Los Altos: Peninsula Publishing, 1980).

76 "'Misty' Stealth Spy Satellite Program Cancelled?" SatNews (26 June 2007), online: http://www.satnews.com/stories2007/4677/.

77 Stephen Kosiak, "Arming the Heavens," at 95.

78 Will Marshall, "Reducing the Vulnerability of Space Assets: A Multitiered Microsatellite Constellation Architecture," 6:2 *Astropolitics* (2008) at 154-199.

79 Noah Shachtman, "'Autonomous' Mini-Spacecraft Team up to Replace Big Sats," *Wired — Blog* (31 July 2007), online: http://blog.wired.com/defense/2007/07/the-objective-o.html.

80 European Commission, Press Release, "Loyola de Palacio Welcomes the Outcome of EU/US Discussions on GALILEO" (26 February 2004), online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/264&format=HTML&aged=0&language=EN&guiLanguage=en; European Commission, Press Release, "GALILEO and GPS will Navigate Side by Side: EU and US Sign Final Agreement" (26 June 2004), online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/805&format=HTML&aged=0&language=en&guiLanguage=en.

81 Brian Berger, "Pentagon Pulls Plug on Satellite Refueling Prototypes," Space.com (25 July 2007), online: http://www.space.com/missionlaunches/070725_darpa_orbitalexpress_end.html.

82 Michael Sirak, "DARPA Eyes Mini Satellites for Rapid Launch to Protect Other Spacecraft," *Defense Daily* (10 August 2007); Sam Black and Timothy Barnes, "Fiscal Year 2008 Budget: Programs of Interest," Center for Defense Information (19 December 2008), online: http://www.cdi.org/program/issue/document.cfm?DocumentID=4131&IssueID=80&StartRow=1&ListRows=10&appendURL=&Orderby=DateLastUpdated&ProgramID=68&issueID=80.

83 Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

84 Defense Advanced Research Projects Agency, "Orbital Express Space Operations Architecture" (8 August 2006), online: http://www.darpa.mil/tto/programs/oe.htm.

85 Stephen Kosiak, "Arming the Heavens," at 91.

86 Clay Wilson, Congressional Research Service, "High Altitude Electromagnetic Pulse (HEMP) and High Power Microwave Devices (HMP): Threat Assessments," CRS Report for Congress (Order Code RL32544) (updated 26 March 2008), online: FAS http://fas.org/sgp/crs/natsec/RL32544.pdf.

87 Dennis Papadopoulos, "Satellite Threat Due to High Altitude Nuclear Detonations," online: Lightwatcher, http://www.lightwatcher.com/chemtrails/Papadopoulos-chemtrails.pdf (date accessed: 10 June 2009).

88 Sharon Weinberger, "Atmospheric physics: Heating up the heavens," *Nature* (23 April 2008) at 452, 930-932.

89 Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space*.

[90] John Foster et al., "Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack," US Arms Services Committee (22 July 2004), online: Globalsecurity.org, http://www.globalsecurity.org/wmd/library/congress/2004_r/04-07-22emp.pdf.

[91] Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," 10 *International Security* (Spring 1986) at 46-98; Federation of American Scientists, "Laser ASAT Test Verification"; David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual*.

[92] Noah Shachtman, "Air Force Looks to Laser Proof Its Weapons," *Wired — Blog* (30 July 2008), online: http://blog.wired.com/defense/2008/07/spray-on-laser.html.

[93] Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," at 79.

[94] DARPA, Press Release, "DARPA Awards Contracts for Fractionated Spacecraft Program" (26 February 2008), online: http://www.darpa.mil/news/2008/F6.pdf; William Matthews, "Cluster Solution," *Defense News* (10 March 2008) at 16.

[95] University of Toronto Institute for Aerospace Studies, Space Flight Laboratory, "CANX 4 AND 5," online: http://www.utias-sfl.net/nanosatellites/CanX45/ (date accessed: 29 January 2009).

[96] Swedish Institute of Space Physics, "PRISMA and IRF's instrument PRIMA" (2 December 2008), online: http://www.irf.se/Topical/?dbfile=Prisma%20and%20PRIMA&dbsec=Administration.

[97] Alliance Spacesystems, Press Release, "Alliance Spacesystems Delivers Robotic Arm for DARPA's 'FREND' Technology Demonstration" (12 September 2008).

[98] Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[99] DARPA, Tactical Technology Office, Broad Agency Announcement, "Fast Access Spacecraft Testbed" (20 November 2007) at 5, online: http://www.darpa.mil/tto/solicit/FAST_BAA_07-65.pdf.

[100] SPX, "Boeing Team to Design New Spacecraft Power Generation System," Space Travel (4 August 2008), online: http://www.space-travel.com/reports/Boeing_Team_To_Design_New_Spacecraft_Power_Generation_System_999.html; Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[101] Tamar A. Mehuron, "2004 Space Almanac," *Air Force Magazine* (August 2003), online: http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf.

[102] *Moscow Times,* "Military Planning Nuclear Exercises" (2 February 2004).

[103] Pavel Podvig, "Russia and Military Uses of Space," Working Paper, The American Academy of Arts and Sciences Project "Reconsidering the Rules of Space" (June 2004), online: http://russianforces.org/podvig/2004/07/russia_and_military_uses_of_sp.shtml.

[104] Ben Iannotta, "$408 Million ORS Budget To Have Broad-Based Focus," *Space News* (17 August 2007).

[105] Air Force Space Command, *Strategic Master Plan FY06 and Beyond,* at 5.

[106] Formerly called US Force Application from the Continental US (FALCON) but the acronym was dropped when the strike component of the program ended.

[107] DARPA, "FALCON Broad Agency Announcement, Phase I Proposer Information Pamphlet" (29 July 2003); Frank Colucci, "FALCON Aims at Global Striking Power," 6 (1) *Military Aerospace Technology* (February 2007).

[108] Brian Berger and Jeremy Singer, "Field Narrows for DARPA's Falcon Program; Decision Expected Soon," *Space News* (29 August 2005); Jefferson Morris, "Falcon SLV Program Nearing Next Phase," *Aerospace Daily and Defense Report* (8 December 2006), online: Aviation Week, http://www.aviationnow.com/avnow/news/channel_space_story.jsp?id=news/FALC12086.xml.

[109] Robert K. Ackerman, "Small Satellite Offers Glimpse of the Future," *Signal Magazine* (January 2004); Gunter Dirk Krebs, "TacSat 1," Gunter's Space Page (1 January 2005), online: http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sdat/tacsat-1.htm.

[110] James Canan, "Renaissance for Military Space," *Aerospace America* (June 2003), online: http://www.aiaa.org/aerospace/Article.cfm?issuetocid=364&ArchiveIssueID=39.

[111] Air Force Research Laboratories, Fact Sheet, "Space Maneuver Vehicle" (September 2002).

[112] Andreas Parsch, "X-37/X-40" (2006), online: Directory of U.S. Military Rockets and Missiles, http://www.designation-systems.net/dusrm/app4/x-37.html.

113 V. Brinda et al., "Mission Analysis of a Reusable Launch Vehicle Technology Demonstrator," American Institute of Aeronautics and Astronautics, 13th International Space Planes and Hypersonics Systems and Technologies (2005).

114 *Jane's Defence Weekly,* "Clearing Skies" (29 April 1998).

115 Alexander Zhelezniakov, "New Space Carrier Rocket 'Mikron,'" *Russian Pereplet* (15 February 2002), online: http://www.pereplet.ru/cgi/science.cgi?id=61.

116 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual*, at 83.

117 Robert Hewson, "China Plans New Space Launchers," *Jane's Defence Weekly* (22 November 2006).

118 Officials from the Operationally Responsive Space office quoted in Caitlin Harrington, "ORS prepares to demo rapid space launch capability," *Jane's Defence Weekly* (4 June 2008) at 5.

119 Jeremy Singer, "First TacSat Launch Will Be No Earlier Than December," *Space News* (30 May 2006); Michael Kleiman, "Technical Issues, More Tests Delay Tactical Satellite-3 Liftoff," Space War (3 November 2008), online: http://www.spacewar.com/reports/Technical_Issues_More_Tests_Delay_Tactical_Satellite_3_Liftoff_999.html.

120 Jeremy Singer and Colin Clark, "Budget Puts ORS, Counterspace on Different Funding Trajectories," *Space News* (11 February 2008) at 11.

121 DARPA, "Falcon Technology Demonstration Program — HTV-3X Blackswift Testbed" (October 2008), online: http://www.darpa.mil/Docs/Falcon-Blackswift%20FS%20Oct08.pdf.

122 William Matthews, "Military Searchers for Faster, Less Expensive Techniques to Lift Payloads," *Defense News* (7 April 2008).

123 Craig Covault, "Size Doesn't Matter," *Aviation Week and Space Technology* (22 December 2008) at 22.

124 CDI, "French Fighter Jet Suggested as Small Satellite Launcher," CDI Space Security Update #8 (18 December 2008), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4427#5; Robert Wall, "Rafale as Satellite Launcher," *Aviation Week* (28 October 2008), online: http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post:90058091-e52e-436b-b631-d423032078a9.

Chapter Seven Endnotes

1 Negation of space systems is called "offensive counterspace" in current US Air Force terminology, and includes the "Five Ds" mission. US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1 (2 August 2004) at 3. *Counterspace Operations* represents the views of the USAF and not necessarily those of the US Government.

2 The Van Allen belts are two rings of highly energetic protons trapped by the Earth's magnetic field. The lower belt is situated between 1,000 and 5,000 kilometers about the equator. The second belt is situated between 15,000 and 25,000 kilometers above the equator. David Stern, "Radiation Belts" (25 November 2001), online: NASA, http://www-istp.gsfc.nasa.gov/Education/Iradbelt.html. See also "Van Allen Belts" in Alan Isaacs, ed., *A Dictionary of Physics* (Oxford: Oxford University Press, 2000).

3 Robert Butterworth, "Assuring Space Support Despite ASATs," *George C. Marshall Institute Policy Outlook* (January 2008) at 1.

4 Bruce DeBlois et al., "Space Weapons: Crossing the US Rubicon," 20 *International Security* (Fall 2004), at 66.

5 Defense Technical Information Center, "Counterspace Systems," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Project Element 0604421F (February 2003) at 1, online: http://www.dtic.mil/descriptivesum/Y2004/AirForce/0604421F.pdf.

6 Capt. Angie Blair, Air Force Spokesperson quoted in Jim Wolf, "US Deploys Satellite Jamming System," Reuters (29 October 2004), online: SignOnSanDiego.com, http://www.signonsandiego.com/news/military/20041029-1531-arms-satellite-usa.html.

7 Jeremy Singer, "U.S. Air Force To Upgrade Satcom Jamming System," *Space News* (22 February 2007).

8 Center for Defense Information, "Air Force Deploying Two Satellite Jamming Squadrons," Space Security Updates (2 April 2007), online: http://www.cdi.org/program/issue/document.cfm?DocumentID=3909&IssueID=140&StartRow=11&ListRows=10&appendURL=&Orderby=DateLastUpdated&ProgramID=68&issueID=140#2, originally sourced from *Defense Daily* (9 March 2007); Jeremy Singer, "U.S. Air Force To Upgrade Satcom Jamming System."

9 Defense Technical Information Center, "Space Control Technology," Unclassified RDT&E Budget Item Justification, Exhibit R-2, Project Element 0603438F (February 2004) at 3, online: http://www.dtic.mil/descriptivesum/Y2005/AirForce/0603438F.pdf.

10 Defense Technical Information Center, "Space Control Technology," at 1.

11 Office of Science and Technology Policy, Fact Sheet, "US Space-Based Positioning, Navigation, and Timing Policy" (15 December 2004), online: http://www.ostp.gov/html/FactSheetSPACE-BASEDPOSITIONINGNAVIGATIONTIMING.pdf.

12 Peter de Selding, "Libya Pinpointed as Source of Months-Long Satellite Jamming in 2006" Space News (9 April 2007), online: http://www.space.com/spacenews/businessmonday_070409.html.

13 Alan Cameron, "Perspectives — June 2008," *GPS World* (24 June 2008), online: http://sidt.gpsworld.com/gpssidt/Latest+News/National-Space-Symposium-Day-3-OCX-and-GPS-III/ArticleStandard/Article/detail/525875.

14 Frank Vizard, "Safeguarding GPS," *Scientific American* (14 April 2003).

15 Steven Kosiak, "Arming the Heavens: A Preliminary Assessment of the Potential Cost and Cost-Effectiveness of Space-Based Weapons," Center for Strategic and Budgetary Assessments (31 October 2007) at 83, online: http://www.csbaonline.org/4Publications/PubLibrary/R.20071031.Arming_the_Heavens/R.20071031.Arming_the_Heavens.pdf.

16 In July 2003, broadcasts of Persian-language Voice of America and other Iranian broadcasts emerging from the US were blocked by a signal believed to originate in Cuba. *BBC News,* "US Broadcasts 'Jammed by Cuba'" (18 July 2003), online: http://news.bbc.co.uk/1/hi/world/americas/3077303.stm.

17 Broadcasting from the UK and Belgium, Med-TV was a satellite network operated by Kurdish exiles. Beginning in 1995 it experienced several interruptions in service, blamed on a jamming signal originating in Turkey, before its closure in 1999. *BBC News,* "World: Middle East Kurds Retaliate in Turkish Jam War" (16 October 1998), online: http://news.bbc.co.uk/1/hi/world/middle_east/193529.stm.

18 The Falun Gong has been accused of jamming SINOSAT signals to block broadcasts and overriding transmission with pirate broadcasts in several incidents in 2002 and 2003. *China Daily,* "Jamming Harms World Trade" (30 September 2002).

19 Michael Evans, "China 'tops list' of cyber-hackers seeking UK government secrets," *Times* (London) (6 September 2007), online: http://www.timesonline.co.uk/tol/news/world/asia/article2393979.ece; France24.com, "France government falls prey to cyber-attacks 'involving China'" (9 September 2007), online: http://www.france24.com/france24Public/en/news/france/20070909-Internet-piracy-france-secuirty-china-hacker.html; Demetri Sevastopulo, "Chinese hacked into Pentagon," *Financial Times* (3 September 2007), online: http://www.ft.com/cms/s/0/9dba9ba2-5a3b-11dc-9bcd-0000779fd2ac.html?nclick_check=1; Reuters (UK), "China says suffers 'massive' Internet spy damage" (12 September 2007), online: http://uk.reuters.com/article/internetNews/idUKPEK7050420070912.

20 Jeremy Wagstaff, "Satellite Interference: Indonesian Hackers Show How Easy It Is to Get Information from the Sky," *The Wall Street Journal* (15 September 2006).

21 "Cyberspace Operations -- Air Force Doctrine Document 2-11" (draft document), cited in Noah Shachtman, "Air Force Wants 'Freedom to Attack Online,'" *Wired — Danger Room Blog* (24 October 2008), online: http://blog.wired.com/defense/2008/10/in-new-doctrine.html.

22 Ellen Nakashima, "Bush Order Expands Network Monitoring," *Washington Post* (26 January 2008) at A3, online: http://www.washingtonpost.com/wp-dyn/content/article/2008/01/25/AR2008012503261.html; Ryan Singel, "U.S. Has Launched a Cyber Security 'Manhattan Project,' Homeland Security Chief Claims," *Wired — Blog* (8 April 2008), online: http://blog.wired.com/27bstroke6/2008/04/feds-cyber-cent.html#previouspost.

23 Sharon Weinberger, "Cyber Warfare: Darpa's New 'Space Race,'" *Wired — Danger Room Blog* (1 May 2008), online: http://blog.wired.com/defense/2008/05/the-pentagon-wa.html.

24 Bob Brewin, "Air Force Suspends Cyber Command Program," Nextgov (12 August 2008), online: http://www.nextgov.com/nextgov/ng_20080812_7995.php; Erik Holmes, "AFSPC Commander Foresees Smooth Mission Transition," *Defense News* (10 November 2008).

25 Noah Shachtman, "Air Force Will Fight Online, Without Cyber Command," *Wired — Danger Room Blog* (8 October 2008), online: http://blog.wired.com/defense/2008/10/air-force-will.html.

26 Michael Hoffman, "U.S. Air Force's Cyber Command Takes Shape," *Defense News* (14 July 2008) at 43.

27 Julian E. Barnes, "Pentagon Debates Development of Offensive Cyberspace Capabilities," *Los Angeles Times* (8 September 2008) at 1.

28 State Council Information Office, *China's National Defense in 2008*, White Paper (2008), online: http://www.china.org.cn/government/central_government/2009-01/20/content_17155577.htm.

29 "China's Proliferation Practices, and the Development of its Cyber and Space Warfare Capabilities," Hearing Before the U.S.-China Economic and Security Review Commission (20 May 2008), online: http://www.uscc.gov/hearings/2008hearings/transcripts/08_05_20_trans/08_05_20_trans.pdf.

30 Wendell Minnick, "Is Beijing Behind Cyberattacks on the Pentagon?" *Defense News* (2 June 2008) at 15.

31 Tony Skinner, "War and PC — Cyberwarfare Briefing," *Jane's Defence Weekly* (24 September 2008) at 38-45.

32 US Department of Defense, "Quadrennial Defense Review Report" (30 September 2001) at 45, online: http://www.defenselink.mil/pubs/qdr2001.pdf.

33 USAF, *Counterspace Operations,* at vii.

34 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108-136-24 (November 2003).

35 "Improving Our Vision: Approaches for Shared Space Situational Awareness," Report of the 15-16 September 2006 Conference, The Antlers Hotel, Colorado Springs, CO, The World Security Institute's Center for Defense Information and The U.S. Air Force Academy's Center for Space and Defense Studies (2007).

36 US Air Force, Fact Sheet, "Space Situational Awareness Integration Office" (April 2004), online: Peterson Air Force Base, http://www.peterson.af.mil/hqafspc/Library/FactSheets/FactsSheets.asp?FactChoice=23.

37 Launched in 1996, the MSX satellite has reached its intended lifespan. For system details see Grant H. Stokes et al., "The Space-Based Visible Program," 11 *Lincoln Laboratory Journal* (1998), online: http://www.ll.mit.edu/ST/sbv/sbv.pdf.

38 US Air Force, *US Air Force Transformation Flight Plan*, "Appendix D: Brief Descriptions of Programs, ACTDs and Future System Concepts" (November 2003), at D-10, online: http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf.

39 Amy Butler, "USAF Expects SBSS Launch by Early 2009," *Aviation Week and Space Technology* (9 April 2008), online: http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/SBSS040908.xml.

40 Boeing, News Release, "Boeing Completes Key Risk Reduction Milestone for Space Surveillance System" (29 September 2006), online: http://www.boeing.com/news/releases/2006/q3/060929b_nr.html; John A. Tirpak, "Space and Counterspace," 89(6) *Air Force Magazine* (June 2006).

41 P. Maskell and L. Oram, "Sapphire: Canada's Answer to Space-Based Surveillance of Orbital Objects," in S. Ryan, ed., *Proceedings of the Advanced Maui Optical and Space Surveillance Technologies Conference, held in Wailea, Maui, Hawaii, September 17-19, 2008*, at E5.

42 US Air Force, *US Air Force Transformation Flight Plan*, "Appendix D: Brief Descriptions of Programs, ACTDs and Future System Concepts," at D-9; *Space News*, "Briefs — Pentagon Cancels Funds For Deep Space Imager" (20 February 2006), online: http://www.space.com/spacenews/archive06/Briefs_022006.html.

43 *Xinhua,* "China Launches New Space Tracking Ship to Serve Shenzhou VII" (22 September 2008), online: http://english.cri.cn/3126/2008/09/22/902s407814.htm.

44 *Xinhua,* "China Enhances Spacecraft Monitoring Network" (12 December 2006), online: http://news3.xinhuanet.com/english/2006-12/12/content_5473204.htm; Zhour Honghsun and Liu Wubing, "Status Quo and Assumption of China's Space Satellite Monitoring," *China Communications* (June 2006) at 123.

45 Craig Covault, "China's ASAT Test Will Intensify U.S.-Chinese Faceoff in Space," *Aviation Week and Space Technology* (21 January 2007), online: http://www.aviationnow.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw012207p2.xml.

46 Peter B. de Selding, "French Say 'Non' to U.S. Disclosure of Secret Satellites," *Space News* (8 June 2007).

47 Allen Thomson, "A GRAVES Sourcebook, Version 2007-12-01."

48 Peter B. de Selding, "French Say "Non" to U.S. Disclosure of Secret Satellites."

49 US Air Force, Publication 3-14, *Space Operations* (January 6, 2009).

50 William Matthews, "USAF Seeks Threat Detectors for Satellites," *Defense News* (9 June 2008) at 40.

51 Jim Hodges, "Space Fence Reinvented," *C4ISR Journal* (1 October 2008), online: http://www.c4isrjournal.com/story.php?F=3677126.

52 Peter B. de Selding, "ESA Space Surveillance Effort of Little Interest to French Military," *Space News* (8 December 2008) at 11.

53 China View, "Ships ready to track Shenzhou VII space mission" (22 September 2008), online; http://news.xinhuanet.com/english/2008-09/22/content_10093728.htm; *Xinhua*, "China Launches New Space Tracking Ship to Serve Shenzhou VII" (22 September 2008), online: People's Daily Online, http://english.people.com.cn/90002/95532/6504730.html.

54 System details taken from Clayton K.S. Chun, "Shooting down a 'Star' Program 437, the US Nuclear ASAT System and Present Day Copycat Killers," Cadre Paper No. 6 (Maxwell Air Force Base, Alabama: Air Force University Press, April 2000) at 4; Laura Grego, "A History of US and Soviet ASAT Programs," Union of Concerned Scientists (9 April 2003), online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1151; David Baker, "Soviet ASAT Series," *Jane's Space Directory* (17 September 2003); David Baker, "United States ASAT Series," *Jane's Space Directory* (3 March 2004).

55 DeBlois et al. estimate that the North Korean Nodong missile or a GPS-guided bomb could achieve the altitude and accuracy for this kind of attack. Bruce DeBlois et al., "Space Weapons: Crossing the US Rubicon," at 61.

56 Steven Kosiak, "Arming the Heavens."

57 *Counterspace Operations*, at 3.

58 Funding appropriated by Congress for the system included $30-million in FY1996, $50-million in FY1997, $37.5-million in FY1998, $7.5-million in FY2000, $3-million in FY2001, and $7.5-million in FY2004. Marcia Smith, "US Space Programs: Civilian, Military, and Commercial," CRS Issue Brief for Congress (21 October 2004), online: Federation of American Scientists, http://www.fas.org/spp/civil/crs/IB92011.pdf. Funding in FY2005 was $14.0-million. Theresa Hitchens, Michael Katz-Hymen, and Jeffrey Lewis, "US Space Weapons: Big Intentions, Little Focus," 13(1) *Nonproliferation Review* (March 2006) at 43, Table 4.

59 Theresa Hitchens, Michael Katz-Hymen, and Jeffrey Lewis, "US Space Weapons: Big Intentions, Little Focus," at 43, Table 4.

60 David C. Isby, "US Army continues with KE-ASAT," *Jane's Missiles and Rockets* (March 2005); Keith J. Costa, "ASAT Technology Test Bed in the Works at Redstone Arsenal," *Inside Missile* Defense (22 December 2004); Sandra I. Erwin, "US Space Command Chief Warns About Technological Complacency," *National Defense* (May 2001), online: http://www.nationaldefensemagazine.org/issues/2001/May/US_Space.htm; United States Department of Defense, Press Release No. 503-04, "Contracts: Army" (25 May 2004), online: http://www.defenselink.mil/contracts/2004/ct20040525.html.

61 Space Daily, "Raytheon Delivers Exoatmospheric Kill Vehicle Payloads for Fort Greely" (18 August 2004), online: http://www.spacedaily.com/news/bmdo-04y.html; Raytheon, "EKV/GMD: Exoatmospheric Kill Vehicle / Ground-Based Midcourse Defense," online: http://www.raytheon.

com/capabilities/rtnwcm/groups/rms/documents/content/rtn_rms_ps_ekv_datasheet.pdf; Missile Defense Agency, Press Release, "Missile Defense Agency Accomplishments in 2007" (14 January 2008), online: http://www.mda.mil/mdalink/pdf/08news0002.pdf.

62 Raytheon, "EKV/GMD: Exoatmospheric Kill Vehicle / Ground-Based Midcourse Defense."

63 David Wright and Laura Grego, "ASAT Capabilities of Planned US Missile Defense System," 68 *Disarmament Diplomacy* (December 2002-January 2003) at 7-10.

64 Missile Defense Agency, News Release, "Japan/U.S. Missile Defense Flight Test Successful," 07-NEWS-0053 (17December 2007), online: http://www.mda.mil/mdaLink/pdf/07news0053.pdf.

65 Laura Grego, "A History of Anti-Satellite Programs."

66 Pavel Podvig, "Russian Military Space Capabilities," in Phillip E. Coyle, ed., *Ensuring America's Space Security* (Washington, DC: Federation of American Scientists, September 2004) at 127.

67 "Gorgon (SH-11/ABM-4)," Missile Threat, online: http://www.missilethreat.com/systems/gorgon.html (date accessed: 10 July 2008).

68 GlobalSecurity.org, "Chinese Anti-Satellite [ASAT] Capabilities" (last updated 18 January 2007), online: http://www.globalsecurity.org/space/world/china/asat.htm; Michael R. Gordon and David S. Cloud, "US Knew of China's Missile Test, But Kept Silent," *New York Times* (23 April 2007) at 1.

69 SPX, "China Says Anti-Satellite Test Did Not Break Rules," Space War (12 February 2007), online; http://www.spacewar.com/reports/China_Says_Anti_Satellite_Test_Did_Not_Break_Rules_999.html.

70 Shirley Kan, "China's Anti-satellite Weapon Test," Congressional Research Center (23 April 2007) at 3.

71 Barbara Opall-Rome, "Israel, U.S., Test Compatibility of Arrow-Patriot Interceptors," *Space News* (14 March 2005); Vivek Raghuvanshi, "India Plans 2nd ABM Test in June," *Defense News* (29 January 2007).

72 Approximately 80 percent of all the energy from a nuclear weapon detonated in outer space appears in the form of X-rays. In addition there are small amounts of gamma radiation and neutrons, small fractions in residual radio activity, and in the kinetic energy of bomb debris. An electromagnetic pulse (EMP) is also generated by a HAND when X-rays and gamma rays create an electron flux in the upper atmosphere of the Earth that re-radiates its energy in the radio frequency portion of the electromagnetic spectrum. When this radio frequency hits space systems it induces currents and voltages that may damage or destroy electronic systems not hardened against these effects. Satellites in GEO would experience an EMP of smaller magnitude than would either LEO satellites or ground facilities located within line of sight of the HAND. Long after the initial detonation of a nuclear device, electrons liberated by the device would join the naturally occurring radiation in the Van Allen belts. Satellites not specifically designed for operations after detonation of a nuclear weapon may fail quickly in this enhanced radiation environment due to a rapid accumulation of total ionizing doses on the critical electronic parts of a satellite. Wiley J. Larson and James R. Wertz, eds., *Space Mission Design and Analysis*, 2nd ed. (Dordrecht: Kluwer Academic Publishers, 1992), at 215-228.

73 Union of Concerned Scientists, "History of Russia's ABM System" (27 October 2002), online: http://www.ucsusa.org/global_security/missile_defense/page.cfm?pageID=609.

74 The International Atomic Energy Agency has never been able to fully verify the status of the North Korea nuclear safeguards agreement and reports that North Korea is non-compliant with its obligations. Although claims have been made that North Korea reprocessed nuclear fuel for weapons, they remain unsubstantiated as inspectors have been denied access to nuclear facilities since 2002. International Atomic Energy Agency General Conference, "Implementation of the Safeguards Agreement between the Agency and the Democratic People's Republic of Korea Pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons," GC(48)/17 (16 August 2004), online: http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48-17.pdf; *BBC News,* "Outcry at N Korea 'Nuclear Test'" (9 October 2006), online: http://news.bbc.co.uk/2/hi/asia-pacific/6033457.stm.

75 Mark Mazzetti, "U.S. Says Iran Ended Atomic Arms Work," *New York Times* (3 December 2007), online: http://www.nytimes.com/2007/12/03/world/middleeast/03cnd-iran.html; James Blitz and Roula Khalaf, "ElBaradei warns on 'work plan,'" *Financial Times* (2 October 2007), online: http://www.ft.com/cms/s/0/1ed44230-711e-11dc-98fc-0000779fd2ac.html?nclick_check=1.

76 S. Karamow, "Army Scores a Hit on Satellite in Test of Laser," *USA Today* (21 October 1997) at A6.

77 Laura Grego, "A History of US and Soviet ASAT Programs."

78 "That a commercially available laser and a 1.5 m mirror could be an effective ASAT highlighted a US vulnerability that had not been fully appreciated." The 30-watt laser used in the test was capable of temporarily blinding the target satellite. Laura Grego, "A History of US and Soviet ASAT Programs."

79 Adaptiveoptics.org, "Adaptive Optics Establishments," online: http://www.adaptiveoptics.org/Establishments.html (date accessed: 10 July 2008).

80 Theresa Hitchens, "US Air Force Plans a Laser Test Against a Satellite in FY 07," Center for Defense Information (3 May 2006), online: http://www.cdi.org/program/document.cfm?DocumentID=3411&StartRow=11&ListRows=10&&Orderby=D.DateLastUpdated&ProgramID=68&typeID=(8)&from_page=relateditems.cfm.

81 Missile Defense Agency, Fact Sheet, "The Airborne Laser" (last updated May 2006), online: http://www.mda.mil/mdalink/pdf/laser.pdf.

82 Missile Threat, "Airborne Laser fact sheet," online: http://www.missilethreat.com/missiledefensesystems/id.8/system_detail.asp; Jeremy Singer, "MDA Officials Lay Out Milestones for Airborne Laser," *Space News* (13 March 2006).

83 William Matthews, "Weapon of the Future," *Defense News* (15 September 2008) at 11, 22, 26.

84 Boeing, News, "Boeing's ABL Team Begins Laser Activation Tests" (28 May 2008), online: http://www.asd-network.com/press_detail/16396/Boeing%27s_ABL_Team_Begins_Laser_Activation_Tests.htm.

85 Northrop Grumman, Press Release, "Northrop Grumman Chosen to Proceed with Developing Solid-State Laser Technology for Military Applications" (5 January 2006), online: http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=91947; Textron Systems, Press Release, "Textron Systems Receives Award to Develop Joint High Powered Solid State Laser (JHPSSL) for the US Army" (16 February 2006), online: http://www.textrondefense.com/news/2006/02_16_06.htm.

86 China has developed significant capacity in gas, chemical, dye, excimer, solid-state, semi-conductor, and free electron lasers, both for pulse and continuous wave functions. Subtypes developed by China include krypton-fluoride, helium-argon-xenon, neodymium-doped yttrium aluminum garnet (Nd:YAG), oxygen-iodine, carbon-dioxide, neodymium glass (Nd:Glass), titanium-sapphire, quantum cascade, xenon-fluoride, and both infrared and X-ray free electron lasers. See the Chinese journals *Chinese Journal of Lasers*, *Infrared and Laser Engineering*, *High Powered Laser and Particle Beams, Chinese Optics Letters,* and *Laser and Infrared.* Sun Chengwei, Zhang Ning and Du Xiangwan, "Recent developments of Chinese activities in lasers and laser beam interactions with materials," AIAA-1995-1920, 26th Plasmadynamics and Lasers Conference, San Diego, CA (19-22 June 1995), online: http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=82509; Huang He, "A Dust-Laden Secret: Review and Prospects for China's Optical Instruments and Laser Weapons," *Defense International* (1 April 1998), at 100-115; *Chinese Journal of Lasers,* "LD-Pumped Nd: YAG Microchip Laser with 62.5MW CW Output Power" (3 May 1994); *Chinese Journal of Lasers,* "Ti-Sapphire Laser Attains CW Output Power of 650MW" (December 1994); Hui Zhongxi, "Sg-1 FEL Amplifier Output Reaches 140MW," *High Power Laser and Particle Beams* (December 1994); *Chinese Journal of Lasers,* "A GW Power Level High Power CO_2 Laser System" (June 1990); IAEA, "World Survey of Activities in Controlled Fusion Research, Special Supplement" (2001), online: http://epub.iaea.org/fusion/public/ws01/ws_toc.html; Howard DeVore, "Directed Energy Weapons and Sensors," *China's Aerospace and Defence Industry* (Jane's Information Group, 2000); Mark A. Stokes, "China's Strategic Modernization: Implications for the United States," Strategic Studies Institute, US Army War College (September 1999), online: http://www.strategicstudiesinstitute.army.mil/pdffiles/PUB74.pdf.

87 Zhu Jianqiang, "Solid-State Laser Development Activities in China," Conference on Lasers and Electro-Optics (2007), online: http://ultralaser.iphy.ac.cn/cleo/data/papers/CThE6.pdf.

88 Yang Wen-shi, Wang Wei-li, Sun Wei-na, Bi Guo-jiang, Zhu Chen, and Wang Xiao-han, "Beam Quality of the High Power DPL," 5 *Infrared and Laser Engineering* (2005) at 511-516. Shi Xiang-chun, Chen Wei-biao, and Hou Xia, "Application of All Solid State Laser in Space," 2 *Infrared and Laser Engineering* (2005) at 127-131.

[89] *USA Today,* "China Jamming Test Sparks US Satellite Concerns" (5 October 2006), online: http://www.usatoday.com/tech/news/2006-10-05-satellite-laser_x.htm?POE=TECISVA.

[90] During a test in 1997 a 30-W ground-based tracking laser reportedly dazzled an imaging satellite at 500-km altitude, although few details are available. John Donnelly, "Laser of 30 Watts Blinded Satellite 300 Miles High," *Defense Week* (8 December 1997) at 1, cited in David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge: American Academy of Arts and Sciences, 2005) at 128. Gen. James Cartwright, Commander of US Strategic Command, denied that there is clear evidence of Chinese intentions to interfere with US space assets and no official Chinese statements have been released. See Elaine M. Grossman, "Is China Disrupting US Satellites?" InsideDefense.com (13 October 2006), online: http://www.military.com/features/0,15240,116694,00.html.

[91] AFP, "SKorea develops laser weapons: report," Space War (10 November 2007), online: http://www.spacewar.com/reports/SKorea_develops_laser_weapons_report_999.html.

[92] AFP, "Japan Develop Laser Weapons Amid North Korea Threat," Space War (13 May 2007), online: http://www.spacewar.com/reports/Japan_Develop_Laser_Weapons_Amid_North_Korea_Threat_999.html.

[93] Rajat Pandit, "Space Command must to check China," *Times of India* (17 June 2008), online: http://timesofindia.indiatimes.com/India/Space_command_must_to_check_China/articleshow/3135817.cms.

[94] Gayle S. Putrich, "U.S.: Shooting Down Satellite Will Reduce Risk," *Defense News* (18 February 2008) at 32. The risk to populations on Earth is not clear. The US government determined that it was significant, but there was some dissent in scientific and civil society communities. See *Physics Today,* "More doubts surface over Pentagon's explanation for shooting down satellite" (18 February 2008), online: http://blogs.physicstoday.org/newspicks/2008/02/experts-query-pentagons-explan.html; *Washington Post,* "Satellite Fuel's Risks Are Disputed" (21 February 2008) at 3.

[95] Jon Rosamond, "USN admiral says satellite kill was 'one-time event,'" *Jane's Defence Weekly* (26 March 2008) at. 8.

[96] Turner Brinton, "U.S. Satellite Smashed to Pieces by SM-3 Interceptor," *Space News* (25 February 2008) at 4.

[97] *Physics Today,* "More doubts surface over Pentagon's explanation for shooting down satellite" (18 February 2008).

[98] Christina Rocca, Permanent Representative of the United States to the Conference on Disarmament, Statement (15 February 2008), online: United Nations Office at Geneva, http://www.unog.ch/80256EDD006B8954/(httpAssets)/DE7EEEEB629D982FC12573F0004A1E07/$file/Statement+by+Ambassador+Rocca.pdf; American Forces Press Service, "Officials Declare Satellite Mission Successful," US Department of Defense (25 February 2008), online: http://www.defenselink.mil/news/newsarticle.aspx?id=49066.

[99] Turner Brinton, "Plans for European Interceptors Highlight MDA Request," *Space News* (11 February 2008) at 10.

[100] Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[101] Amy Butler, "KEI First Stage Motor in Full Burn Test," *Aviation Week and Space Technology* (14 November 2008), online: http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/BURN11148.xml.

[102] Warren Ferster, "Focus of KEI Shifts to Shooting Down Missiles in Mid-Flight," *Space News* (14 March 2007), online: http://www.space.com/spacenews/archive07/keinew_0312.html.

[103] AFP, "Iran gives details on controversial space launch," Space Travel (19 February 2008), online: http://www.space-travel.com/reports/Iran_gives_details_on_controversial_space_launch_999.html.

[104] Ariel Cohen, "Sword and Shields: Iran's ICBM Threat," Space War (29 September 2008), online: http://www.spacewar.com/reports/Sword_and_Shields_Irans_ICBM_threat_999.html.

[105] Peter Crail, "Iran Space Launch Raises Missile Concerns," *Arms Control Today* (September 2008), online: http://www.armscontrol.org/act/2008_09/IranSpace.

[106] *BBC News,* "Iran launches satellite carrier" (17 August 2008), online: http://news.bbc.co.uk/2/hi/in_depth/7566804.stm; James Oberg, "Iran tried, but failed, to launch satellite," MSNBC (19 August 2008), online: http://www.msnbc.msn.com/id/26294174/.

[107] *BBC News,* "Iran 'fires second rocket'" (26 November 2008), online: http://news.bbc.co.uk/2/hi/middle_east/7750052.stm.

[108] Geoffrey Forden, "Smoke and mirrors: Analysing the Iranian missile test," *Jane's Intelligence Review* (April 2008) at 47-51.

[109] Joseph S. Bermudez Jr., and Tim Brown, "North Korea's New Missile Facility," Briefing, *Jane's Defence Weekly* (17 September 2008) at 30-31.

[110] *BBC News,* "North Korea space launch 'fails'" (5 April 2009), online: http://news.bbc.co.uk/2/hi/asia-pacific/7984254.stm.

[111] Missile Defense Agency, News Release 07-NEWS-0053, "Japan/U.S. Missile Defense Flight Test Successful," (17 December 2007), online: http://www.mda.mil/mdaLink/pdf/07news0053.pdf.

[112] AFP, "Japan Says Missile Defense Test Failed," *Defense News* (20 November 2008), online: http://www.defensenews.com/story.php?i=3829681.

[113] Joshua Williams, "World Missile Chart," Carnegie Endowment for International Peace (November 2005), online: http://www.carnegieendowment.org/npp/ballisticmissilechart.cfm. The chart includes only missiles in operation as of 2007. The range used in Figure 7.4 is for the missile carrying its nominal payload. The cutoff point of 1,000 km+ is used because, as a rule of thumb, a rocket can deliver its nominal payload mass to an altitude roughly half of its maximum range and smaller payloads to a greater altitude (see David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security*). The missiles on the chart can potentially lift a payload with a mass equal to that of their nominal warhead to an altitude of at least 500 km. This is high enough to reach most Earth observation and imaging satellites in LEO, such as the US Lacrosse radar satellites, but not to reach communications satellites in GEO. Direct ascent ASAT systems based on ballistic missiles are possible; the Chinese ASAT interceptor used in the 11 January 2007 test was boosted into space by a modified DF-21 missile. Actors without a hit-to-kill capability could choose to intentionally scatter debris and pollute an orbit or conduct a HAND attack. All commercial launch vehicles also inherently have ASAT capabilities. See also Federation of American Scientists, "North Korea's Taepodong and Unha Missiles," online: http://www.fas.org/programs/ssp/nukes/nuclearweapons/Taepodong.html (date accessed: 10 June 2009).

[114] National Air and Space Intelligence Center, NASIC-1031-0985-06, "Ballistic and Cruise Missile Threat" (March 2006).

[115] Stephen A. Hildreth, Specialist in Missile Defense and Non-Proliferation, Foreign Affairs, Defense, and Trade Division, "North Korean Ballistic Missile Threat to the United States" (updated 24 February 2008).

[116] Globalsecurity.org, "M-5/M-51," online: http://www.globalsecurity.org/wmd/world/france/m-5.htm (last updated: 28 April 2005).

[117] Sinodefense.com, "DongFeng 3 (CSS-2) Intermediate Range Ballistic Missile" (last updated: 27 February 2009), online: http://www.sinodefence.com/strategic/missile/df3.asp.

[118] William Matthews, "Weapon of the Future," *Defense News* (15 September 2008) at 11, 22, 26.

[119] Gareth Jennings, "MDA test-fires complete ABL," *Jane's Defence Weekly* (10 December 2008); Paul Marks, "Airborne Laser lets rip on first target," *New Scientist* (15 December 2008), online: http://www.newscientist.com/article/mg20026866.200-airborne-laser-lets-rip-on-first-target.html.

[120] *Space News,* "MDA Extends ABL Laser Work for Three Firms," News Briefs (18 February 2008) at 3; Northrop Grumman, News Release, "Northrop Grumman Wins Phase 2 of Solid State Advanced Track Illuminator Laser Program" (5 February 2008), online: http://www.deagel.com/news/Northrop-Grumman-Wins-Phase-2-of-Solid-State-Advanced-Track-Illuminator-Laser-Program_n000003558.aspx.

[121] Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[122] Graham Warwick, "Solid-State Laser Programs Advance," *Aviation Week and Space Technology* (11 January 2009), online: http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/aw011209p1.xml.

[123] Turner Brinton, "Northrop to Demo 100-Kilowatt Class Laser by End of the Year," *Space News* (17 March 2008), at 17.

124 Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest"; Theresa Hitchens, Michael Katz-Hyman, and Jeffrey Lewis, "Space Weapons Spending in the Fiscal Year 2006 Presidential Request: A Preliminary Assessment," Center for Defense Information (10 February 2005), online: http://www.cdi.org/PDFs/FY06SpaceSpending.pdf.

125 William J. Broad, "Administration Researches Laser Weapon," *New York Times* (3 May 2006).

126 Report of the APS Study Group on Boost Phase Missile Defense Systems for National Missile Defense: Scientific and Technical Issues (July 2003).

127 The Surrey Space Centre's partnership with China to develop microsatellite technology has caused much speculation about Chinese ASAT intentions, although there is no evidence of an official Chinese ASAT program. Surrey Satellites' CEO posted a statement on its website that "there have been a number of reports in the press that have portrayed SSTL's commercial satellite business with PR China in a very misleading light.… SSTL has carried out two micro-satellite projects for PR China. Both projects are entirely civil in nature and both have been executed strictly within export controls specifically approved for each project by the UK government.… No propulsion technologies or know-how has been provided by SSTL to China and therefore the satellites supplied by SSTL are not able to be used either as 'ASAT' anti-satellite devices nor as a basis to develop such devices as claimed by some press reports." Surrey Satellite Technology, "News" (23 March 2005), online: http://www.sstl.co.uk/index.php?loc=6. For an analysis of China's interest in ASAT weapons, including the Chinese academic debate about this subject, see Phillip Saunders, Jing-dong Yuan, Stephanie Lieggi, and Angela Deters, "China's Space Capabilities and the Strategic Logic of Anti-Satellite Weapons," Center for Nonproliferation Studies (22 July 2003), online: http://cns.miis.edu/pubs/week/020722.htm. A full description of the Tsinghua-1/SNAP mission is online: Surrey Space Centre, http://www.ee.surrey.ac.uk/SSC/ (date accessed: 10 July 2008).

128 Theresa Hitchens, Victoria Sampson, and Sam Black, "Space Weapons Spending in the FY 2008 Defense Budget," Center for Defense Information (21 February 2008), online: http://www.cdi.org/PDFs/Space%20Weapons%20Spending%20in%20the%20FY%202008%20Defense%20Budget.pdf.

129 Jeffrey Lewis, "NFIRE Kill Vehicle Finally Dead. Really," *Armscontrolwonk — Blog* (23 August 2005), online: http://www.armscontrolwonk.com/741/nfire-kill-vehicle-finally-dead-really.

130 Justin Ray, "Delta 2 Rocket Puts Military Experiment into Space," Spaceflight Now (21 June 2006), online: http://spaceflightnow.com/delta/d316/.

131 Defense Technical Information Center, "Ballistic Missile Defense System Interceptors," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Program Element 0603886C (February 2004), online: http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf.

132 Mark Wade, "Rockets," *Encyclopedia Astronautica* (May 2005), online: http://www.astronautix.com.

133 See for example the mobile land- and sea-based ballistic missiles identified in Hajime Ozu, *Missile 2000 Reference Guide to World Missile Systems* (Tokyo: Shinkigensha, 2000).

134 Space Flight Now, "Overview of the Taurus Rocket" (19 September 2001), online: http://www.spaceflightnow.com/taurus/t6/010919taurus.html.

135 See Hajime Ozu, *Missile 2000 Reference Guide to World Missile Systems.*

136 Sea Launch, online: http://www.sea-launch.com/ (date accessed: 10 June 2009).

137 See for example the Shtil SLBM launch identified in Brian Harvey, *Russia in Space the Failed Frontier?* (Chichester, UK: Springer-Praxis Books, 2001) at 236.

138 Sea Launch.

139 Sea Launch.

140 Muhammad Shamsui Kamal Adnan and Md. Azlin Md. Said, "Aircraft-Based Satellite Launching (ABSL) System — Future Space Transportation System," German Aerospace Center, online: http://www.dlr.de/iaa.symp/Portaldata/49/Resources/dokumente/archiv5/0810P_Kama_Adnan.pdf (date accessed: 10 July 2008).

141 Orbital Sciences Corporation, "Space Launch Systems" (May 2005), online: http://www.orbital.com/.

142 "China Tracks Space Debris," Space.com (18 March 2005), online: http://www.space.com/astronotes/astronotes_mar1_mar31_2005.html .

143 The TAROT and ROSACE space debris monitoring programs are surveyed in Fernand Alby et al, "Status of CNES Optical Observations of Space Debris in Geostationary Orbit," 34(5) *Advances in Space Research* (2002) at 1143-1149.

144 Fernand Alby et al, "Status of CNES Optical Observations of Space Debris in Geostationary Orbit," at 1143-1149.

145 National Space Development Agency of Japan, "Space Debris Optical Observation and Orbit Determination Experiment Initiated" (September 2000), online: http://www.nasda.go.jp/lib/nasda-news/2000/09/head_e.html.

146 Brian Harvey, *Russia in Space: The Failed Frontier?*

147 US Air Force, "Space Surveillance," Air University (May 2005), online: http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm.

148 Wei Long, "Chinese Space Workers Celebrate Their Labour to Launch Shenzhou," Space Daily (9 January 2002).

149 Heiner Klinkrad, "Monitoring Space — Efforts Made by European Countries," paper presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France (27-28 November 2002), online: Federation of American Scientists, http://www.fas.org/spp/military/program/track/klinkrad.pdf.

150 Klinkrad, "Monitoring Space."

151 Radio Atmospheric Science Center, Kyoto University, "Introduction to MU Radar," online: http://www-lab26.kuee.kyoto-u.ac.jp/study/mu/mu_e.html (date accessed: 10 July 2008).

152 Brian Harvey, *Russia in Space: The Failed Frontier?* at 209.

153 US Air Force, "Space Surveillance."

154 Department of Earth Observation and Space Systems, Delft University, "Satellite Laser Ranging for ERS-1" (8 August 1998), online: http://www.deos.tudelft.nl/ers/tracking1/global.html.

155 European Space Agency, "ConeXpress Orbital Life Extension Vehicle (CX-OLEV)" (May 2005), online: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=17870.

156 "Soyuz Launches Progress Cargo Flight to ISS/Automated Rendezvous Tests," *Space and Tech* (26 June 2002), online: http://www.spaceandtech.com/digest/flash2002/flash2002-060.shtml.

157 NASA, "DART Mission" (May 2005), online: http://www.nasa.gov/mission_pages/dart/main/.

158 European Space Agency, "ConeXpress Orbital Life Extension Vehicle."

159 Mark Wade, "Polyot 11A59," *Encyclopedia Astronautica* (May 2005), online: http://www.astronautix.com/lvs/pol11a59.htm.

160 European Space Agency, "ConeXpress Orbital Life Extension Vehicle."

161 *Air Force Research Laboratory Technology Horizons,* "Autonomous Proximity Microsatellites" (December 2003).

162 European Space Agency, "ConeXpress Orbital Life Extension Vehicle."

163 *Air Force Research Laboratory Technology Horizons,* "Autonomous Proximity Microsatellites."

164 The Advanced Video Guidance Sensor was first demonstrated in the 1990s with the space shuttle in NASA's Automated Rendezvous and Capture project. NASA, Fact Sheet, "DART Demonstrator to Test Future Autonomous Rendezvous Technologies in Orbit" (September 2004).

165 Michael Braukus and Kim Newton, "On Orbit Anomaly Ends DART Mission Early," NASA, (16 April 2005), online: http://www.nasa.gov/mission_pages/dart/media/05-051.html.

166 Lt. Col. James Shoemaker, "Orbital Express Space Operations Architecture," DARPA (19 October 2004).

167 US Tactical Technology Office, "Front-End Robotic Enabling Near-Term Demonstrations" (18 February 2008), online: http://www.darpa.mil/tto/programs/frend.htm.

168 NRL, Press Release, "NRL Developing Space 'Tow Truck' Technology For Satellite Operations" (27 August 2007), online: http://www.nrl.navy.mil/pressRelease.php?Y=2007&R=47-07r.

[169] Michael Sirak, "DARPA Eyes Mini Satellites for Rapid Launch to Protect Other Spacecraft," *Defense Daily* (10 August 2007); Sam Black and Timothy Barnes, "Fiscal Year 2008 Budget: Programs of Interest."

[170] German Aerospace Center, Institute of Robotics and Mechanics, "Ongoing Space Robotics Missions," online: http://www.dlr.de/rm/en/desktopdefault.aspx/tabid-3825/5963_read-8759/ (date accessed: 28 July 2009). See also German Aerospace Center, News, "German Federal Minister of Economics Michael Glos and Bavarian Prime Minister Günther Beckstein visit DLR in Oberpfaffenhofen," (17 July 2008), online: German Federal Minister of Economics Michael Glos and Bavarian Prime Minister Günther Beckstein visit DLR in Oberpfaffenhofen.

[171] Gerd Hirzinger et al., "DLR's Robotics Technologies for On-Orbit Servicing," 2 *Advanced Robotics* (2003) at 139-174.

[172] "PRISMA Satellites, " PRISMA, online: http://www.prismasatellites.se/?sid=9028 (date accessed: 10 July 2008). See also

[173] Staffan Persson, Björn Jakobsson, Eberhard Gill, "PRISMA—Demonstration Mission for Advanced Rendezvous and Formation Flying Technologies and Sensors," Paper IAC-05-B5.6.B072005 at the International Astronautical Congress (2005), online: Nordicspace, http://www.nordicspace.net/PDF/NSA142.pdf.

[174] Wang Chaoqun, "Semi Physical Simulation Technique about the RF/IR Dual-mode Integrated Homing Guidance System," 1 *Aerospace Control* (2005) at 76-78.

[175] Richard D. Fischer Jr., "China's Close Call," *Asian Wall Street Journal* (31 October 2008) at 15.

[176] David Wright and Gregory Kulacki, "Chinese Shenzhou-7 'Companion Satellite' BX-1," Union of Concerned Scientists (21 October 2008), online: http://www.ucsusa.org/assets/documents/nwgs/UCS-Shenzhou7-CompanionSat-10-21-08.pdf; Brian Weeden, "China's BX-1 microsatellite: a litmus test for space weaponization," The Space Review (20 October 2008), online: http://www.thespacereview.com/article/1235/1.

[177] *Aviation Week and Space Technology* (13 October 2008) at 18.

[178] Brian Weeden, "China's BX-1 microsatellite."

[179] Noah Shachtman, "'Autonomous' Mini-Spacecraft Team up to Replace Big Sats," *Wired — Blog* (31 July 2007), online: http://blog.wired.com/defense/2007/07/the-objective-o.html.

[180] Michael Sirak, "DARPA Eyes Mini Satellites for Rapid Launch to Protect Other Spacecraft," *Defense Daily* (10 August 2007); Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest"; Jeremy Singer, "DARPA Seeks Increase for Space Programs in 2009," *Space News* (25 February 2008) at 22, 30.

[181] Michael Sirak, "DARPA Eyes Mini Satellites for Rapid Launch to Protect Other Spacecraft."

[182] Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest"; Jeremy Singer, "DARPA Seeks Increase for Space Programs in 2009."

[183] DARPA, Tactical Technology Office, Broad Agency Announcement, "Fast Access Spacecraft Testbed" (20 November 2007) at 5, online: http://www.darpa.mil/tto/solicit/FAST_BAA_07-65.pdf.

[184] SPX, "Boeing Team to Design New Spacecraft Power Generation System," Space Travel (4 August 2008), online: http://www.space-travel.com/reports/Boeing_Team_To_Design_New_Spacecraft_Power_Generation_System_999.html; Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[185] University of Toronto Institute for Aerospace Studies, Space Flight Laboratory, "CANX 4 AND 5," online: http://www.utias-sfl.net/nanosatellites/CanX45/ (date accessed: 29 January 2009).

[186] Swedish Institute of Space Physics, "PRISMA and IRF's instrument PRIMA" (2 December 2008), online: http://www.irf.se/Topical/?dbfile=Prisma%20and%20PRIMA&dbsec=Administration.

[187] Alliance Spacesystems, Press Release, "Alliance Spacesystems Delivers Robotic Arm for DARPA's 'FREND' Technology Demonstration" (12 September 2008).

[188] Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

[189] Tariq Malik and Peter B. de Selding, "European Space Freighter Makes Docking Debut," Space.com (3 April 2008), online: http://www.space.com/missionlaunches/080403-atv-iss-docking-wrap.html.

190 William Matthews, "Military Searchers for Faster, Less Expensive Techniques to Lift Payloads," *Defense News* (7 April 2008).

191 Craig Covault, "Size Doesn't Matter," *Aviation Week and Space Technology* (22 December 2008) at 22.

192 *Aerospace Daily and Defense Report* (3 November 2008).

193 Globalsecurity.org, "MiG-31 FOXHOUND," online: http://www.globalsecurity.org/military/world/russia/mig-31.htm (last updated: 11 September 2008).

194 Theresa Hitchens and Victoria Sampson, "Space Weapons Spending in the FY 2009 Defense Budget," Center for Defense Information (March 2008), online: http://www.cdi.org/pdfs/SpaceWeaponsFY09.pdf; Beau Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest."

195 Theresa Hitchens and Victoria Sampson, "Space Weapons Spending in the FY 2009 Defense Budget."

196 Justin Ray, "Delta 2 Rocket Puts Military Experiment into Space"; Defense Technical Information Center, "DARPA FY 2007 Exhibit R-2 RDT&E Project Justification" (February 2006), online: www.dtic.mil/descriptivesum/Y2007/AirForce/0604855F.pdf.

197 Satnews Daily, "Top Secret in Space — Covert Inspection of Crippled Defense Military Satellite" (19 January 2008), online: http://www.satnews.com/cgi-bin/story.cgi?number=252590162. For information on the program see Justin Ray, "Delta 2 Rocket Puts Military Experiment into Space"; Defense Technical Information Center, "DARPA FY 2007 Exhibit R-2 RDT&E Project Justification"; Ryan Caron, "CDI Factsheet: MiTEx (Micro-satellite Technology Experiment)," Center for Defense Information (14 July 2006), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=3591.

198 Satnews Daily, "Top Secret in Space."

199 Brian Weeden, "China's BX-1 microsatellite."

Chapter Eight Endnotes

1 Jeffrey Lewis, "Space-Based Laser in the Black Budget?" *Armscontrolwong.com — Blog* (1 June 2004), online: http://www.armscontrolwonk.com/161/space-based-laser-in-the-black-budget.

2 Stephen Kosiak, "Arming the Heavens: A Preliminary Assessment of the Potential Cost and Cost-Effectiveness of Space-Based Weapons," Center for Strategic and Budgetary Assessments (31 October 2007), online: http://www.csbaonline.org/4Publications/PubLibrary/R.20071031.Arming_the_Heavens/R.20071031.Arming_the_Heavens.pdf.

3 Elizabeth Waldrop, "Weaponization of Outer Space: US Policy," 29 *Annals of Air and Space Law* (2004) at 1-28.

4 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security* (Cambridge: American Academy of Arts and Science, 2005) at 97.

5 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1 (2 August 2004).at 2; Marc J. Berkowitz, "National Space Policy and National Defense," in Peter Hayes, ed., *Spacepower for a New Millennium: Space and U.S. National Security* (New York: McGraw-Hill, 2000); Everett Dolman, *Classical Geopolitics in the Space Age* (London: Frank Cass, 2002); Tom Wilson, "Threats to United States Space Capabilities," Prepared for the Commission to Assess United States National Security Space Management and Organization (2003), online: Federation of American Scientists, http://www.fas.org/spp/eprint/article05.html#33.

6 Bob Preston, Dana J. Johnson, Sean J. A. Edwards, Michael D. Miller, and Calvin Shipbaugh, *Space Weapons, Earth Wars* (Santa Monica: RAND Corporation, 2002).

7 Jonathan McDowell, personal communication with author (3 April 2005).

8 Jonathan McDowell, "The Soviet Fractional Orbital Bombardment System, A Short History," publication in preparation; personal communication with author (3 April 2005).

9 Robert Scheer, "Pssst. Want to Know a Secret? Just Ask Teller," *Los Angeles Times* (25 May 1999); Joseph Nilsen, "Legacy of the X-ray Laser Program" (November 1994), online: Lawrence Livermore

National Laboratory, http://www.llnl.gov/etr/pdfs/11_94.2.pdf; Ball Aerospace, "Relay Mirror Experiment," online: http://www.ball.com/aerospace/rme.html; Bob Preston et al., *Space Weapons, Earth Wars*; Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington, DC: The Henry L. Stimson Center, 2003); Ball Aerospace, "Brilliant Pebbles: Fact Sheet," online: http://www.ball.com/aerospace/bpebbles.html.

10 Mark Wade, "Chronology 2004," Encyclopedia Astronautica, online: http://www.astronautix.com/; Jonathan McDowell, "Satellite Catalogue and Launch Catalogue," Jonathan's Space Report, online: http://planet4589.org/space/log/satcat.txt.

11 *Arms Control Today,* "Space Based Laser Put on Hold" (December 2002).

12 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security,* at 89.

13 "National Defense Authorization Act for FY 2007," Report of the Committee on Armed Services House of Representatives on H.R. 5122 (109-452) (5 May 2006), online: http://www.gpoaccess.gov/serialset/creports/pdf/hr109-452/preliminary.pdf.

14 David Pugliese, "US Wants to Build Space Laser in Total Secrecy: Weapon Could Be in Use Before it's Made Public, Canadian Military Fears," *Ottawa Citizen* (1 July 2004).

15 US Naval Research Laboratory, "Clementine — DSPSC" (2002), online: http://www.cmf.nrl.navy.mil/clementine/; NASA-GSFC, "Clementine Project Information," online: http://nssdc.gsfc.nasa.gov/planetary/clementine.html.

16 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification" (February 2004), online: Defense Technical Informational Center, http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf.

17 David Ruppe, "House Committee Cuts Space Interceptor Test Program," Global Security Newswire (15 June 2004), online: Nuclear Threat Initiative http://www.nti.org/d_newswire/issues/2004/6/15/ed3ecef6-efb6-4740-a39c-b49388ec20a9.html; Jeremy Singer, "MDA to remove 'kill vehicle' sensor from NFIRE," *Space News* (23 August 2004).

18 Air Force Material Command, "Microsatellite Propulsion Experiment Industry Day" (30 August 2004), online: SpaceRef.com, http://www.spaceref.com/news/viewsr.html?pid=13807.

19 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification."

20 Rick Lehner, "Missile Defense Research Satellite Launched," Missile Defense Agency Press Release (24 April 2007).

21 Sam Black, "Evolution of the Space Test Bed," Center for Defense Information (21 March 2007), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=3884.

22 *Inside Missile Defense,* "House, Senate Authorizers Block Space-Based Interceptor Funding" (25 October 2006).

23 David Barton, Roger W. Falcone, Daniel Kleppner, Frederick K. Lamb, Ming K. Lau, Harvey L. Lynch, David E. Moncton, L. David Montague, David E. Mosher, William C. Priedhorsky, Maury Tigner, and David R. Vaughan, "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," 76:3 *Reviews of Modern Physics*, at S1-S424 , online: Physical Review Online Archive, http://prola.aps.org/pdf/RMP/v76/i3/pS1_1.

24 David Barton et al., "Report of the American Physical Society Study Group on Boost-phase Intercept Systems for National Missile Defense: Scientific and Technical Issues."

25 Congressional Budget Office, "Alternatives for Boost-Phase Missile Defense" (July 2004), online: http://www.cbo.gov/ftpdoc.cfm?index=5679&type=1.

26 Missile Defense Agency, "Fiscal Year 2009 Budget Estimates — Overview," 08-MDA-3199 (21 January 2008), at 22, online: http://www.mda.mil/mdalink/pdf/budgetfy09.pdf.

27 House Armed Services Committee, "H.R.5658: FY 2009 National Defense Authorization Act Summary" at 25, online: http://armedservices.house.gov/pdfs/fy09ndaa/FINAL051508.pdf (date accessed: 9 Feb 2009)

28 B. Rizzo, "Fiscal Year 2009 (FY 09) Defense Budget: Programs of Interest," Center for Defense Information, online: http://www.cdi.org/pdfs/FY2009ChartFinal.pdf (date accessed: 15 Feb 2009)

29 Missile Defense Agency, News Release, "Missile Defense Data Collection Experiment Successfully Completed" (23 September 2008), online: http://www.mda.mil/mdalink/pdf/08news0079.pdf.

30 General Dynamics, Fact Sheet, "Near Field Infrared Experiment Fact Sheet" (1 December 2005), online: NASA Wallops Flight Facility, http://www.nasa.gov/centers/wallops/pdf/175158main_NFIREdatasheet.pdf.

31 R. Geoffroy, "Vandenberg supports missile defense tracking test," Air Force Space Command Public Affairs (24 September 2008), online: Air Force Space Command, http://www.afspc.af.mil/news/story.asp?id=123116591.

32 R. Geoffroy, "Vandenberg supports missile defense tracking test."

33 M. Hoffman, "USAF Unveils Global Strike Command," *Defense News* (24 October 2008), online: http://www.defensenews.com/story.php?i=3787270.

34 Sam Black and Timothy Barnes, "Fiscal Year 2008 Defense Budget: Programs of Interest," Center for Defense Information (19 December 2007), online: http://www.cdi.org/program/document.cfm?documentid=4131&programID=68&from_page=../friendlyversion/printversion.cfm.

35 Center for Defense Information, "Raytheon Awarded $441.9 million MKV Contract," Missile Defense Update #8 (10 November 2008), online: http://www.cdi.org/friendlyversion/printversion.cfm?documentID=4400#5.

36 Jeremy Singer, "Tests Ease Overheating Concerns with MKV Technology," *Space News* (18 October 2005); Jeffrey Lewis, "Multiple Kill Vehicles," *Arms Control Wonk — Blog* (12 September 2005), online: http://www.armscontrolwonk.com/781/multiple-kill-vehicles-mkv.

37 Bob Preston et al., *Space Weapons, Earth Wars*; Krepon and Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space*; Bruce deBlois, Richard Garwin, Scott Kemp, and Jeremy Marwell, "Space Weapons Crossing the US Rubicon," 29 *International Security* (Fall 2004) at 50-84.

38 Marcia S. Smith, "Chinese Space Program: An Overview," CRS Report for Congress RS21641 (18 October 2005), online: Federation of American Scientists, http://www.fas.org/sgp/crs/space/RS21641.pdf.

39 John Pike and Peter Voth, "Current Plans for Missile Defence," 1 *Disarmament Forum* (2001) at 7.

40 Victoria Samson, "A Contender for SBIRS High," *Space News Business Report* (13 March 2006), online: Space.com, http://www.space.com/spacenews/archive06/SamsonOpEd_031306.html.

41 Gunter Dirk Krebs, "Spirale 1, 2," Gunter's Space Page, online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/spirale-1.htm.

42 Formerly called Force Application and Launch from Continental US program (FALCON) but the acronym was dropped when the program ended its strike component.

43 Space Exploration Technologies, "Company Description," online: http://www.spacex.com/ (date accessed: 10 June 2009).

44 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security,* at 104.

45 China has developed significant capacity in gas, chemical, dye, excimer, solid-state, semi-conductor, and free electron lasers, both for pulse and continuous wave functions. Subtypes developed by China include krypton-fluoride, helium-argon-xenon, neodymium-doped yttrium aluminum garnet (Nd:YAG), oxygen-iodine, carbon-dioxide, neodymium glass (Nd:Glass), titanium-sapphire, quantum cascade, xenon-fluoride, both infrared and X-ray free electron lasers, and others. See the Chinese journals *Chinese Journal of Lasers*, *Infrared and Laser Engineering*, *High Powered Laser and Particle Beams, Chinese Optics Letters,* and *Laser and Infrared.* Sun Chengwei, Zhang Ning, and Du Xiangwan, "Recent developments of Chinese activities in lasers and laser beam interactions with materials," AIAA-1995-1920, 26th Plasmadynamics and Lasers Conference, San Diego, CA (19-22 June 1995), online: http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=82509; Huang He, "A Dust-Laden Secret: Review and Prospects for China's Optical Instruments and Laser Weapons," *Defense International* (1 April 1998) at 100-115; "LD-Pumped Nd: YAG Microchip Laser with 62.5MW CW Output Power," *Chinese Journal of Lasers* (3 May 1994); "Ti-Sapphire Laser Attains CW Output Power of 650MW," *Chinese Journal of Lasers* (December 1994); Hui Zhongxi, "Sg-1 FEL Amplifier Output Reaches 140MW," *High Power Laser and Particle Beams* (December 1994); "A GW Power Level High Power CO_2 Laser System," *Chinese Journal of Lasers* (June 1990); IAEA, "World Survey of Activities in Controlled Fusion Research, Special

Supplement" (2001), online: http://epub.iaea.org/fusion/public/ws01/ws_toc.html; Howard O. DeVore, "Directed Energy Weapons and Sensors," *China's Aerospace and Defense Industry,* Jane's Special Report (Jane's Information Group, December 2000); Mark A. Stokes, "China's Strategic Modernization: Implications for the United States," Strategic Studies Institute, US Army War College (September 1999), online: http://www.strategicstudiesinstitute.army.mil/pdffiles/PUB74.pdf.

46 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security,* at 134.

47 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security,* at 74.

48 Uranium Information Centre, Briefing Paper 8, "Nuclear Reactors in Space" (January 2004).

49 Gunter Dirk Krebs, "Military Satellites," Gunter's Space Page, online: http://www.skyrocket.de/space/sat.htm.

50 Press Trust of India, "China to launch first space solar telescope in 2008" (24 October 2004).

51 European Space Agency, "Crew Return Vehicle for the International Space Station," online: http://www.esa.int/esaHS/ESARZS0VMOC_iss_0.html (date accessed: 10 July 2008).

52 CNES, "CNES and Aquitaine Regional Council join forces for atmospheric re-entry programmes" (8 November 2004), online: http://www.cnes.fr/html/_455_463_1545_2863_.php.

53 Japanese Aerospace Exploration Agency, "Research on Flight Demonstrations," online: http://www.ista.jaxa.jp/res/b01/0b02.html (date accessed: 10 July 2008).

54 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security,* at 59.

55 "House and Senate Conference Report on H.R. 3222," US House of Representatives (6 November 2007) at 210, online: US House of Representatives, http://www.rules.house.gov/110/text/110_hr3222crtxt.pdf (date accessed: 1 February 2008).

56 US General Accounting Office, "Military Transformation: DOD Needs to Strengthen Implementation of Its Global Strike Concept and Provide a Comprehensive Investment Approach for Acquiring Needed Capabilities," GAO Report to Congressional Requesters (April 2008) at 4 and 8, online: Federation of American Scientists, http://www.fas.org/programs/ssp/nukes/doctrine/GAOApril2008.pdf (date accessed: 7 February 2009).

57 Elaine Grossman, "Senior US Official Doubts Conventional Global Strike Value," Global Security Newswire (26 November 2008), online: http://www.globalsecuritynewswire.org/gsn/nw_20081126_9258.php.

58 Elaine Grossman, "Senior US Official Doubts Conventional Global Strike Value."

59 Elaine Grossman, "Senior US Official Doubts Conventional Global Strike Value."

60 Bill Sweetman, "No Place to Hide," *Defense Technology International* (May 2008) at 25-28, online: http://www.nxtbook.com/nxtbooks/aw/dti0508/.

61 Bill Sweetman, "No Place to Hide."

62 Elaine Grossman, "Science panel backs conventional trident missile," *Global Security Newswire* (15 August 2008), online: Government Executive.com, http://www.govexec.com/dailyfed/0808/081508gsn1.htm.

63 Elaine Grossman, "Navy to Launch Controversial Weapon Next Year," *Global Security Newswire*, (3 April 2008), online: http://www.globalsecuritynewswire.org/gsn/GSN_20080403_A0E13E91.php.

64 Elaine Crossman, "Navy to Launch Controversial Weapon Next Year."

65 US House of Representatives, "House and Senate Conference Report on H.R. 3222," at 820.

66 See technologies described in Stephen Kosiak, "Arming the Heavens."

67 Bob Preston et al., *Space Weapons, Earth Wars*; Krepon and Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space*; Bruce deBlois et al., "Space Weapons Crossing the US Rubicon."

68 The SBSW section of the table implies neither the existence of a program for integrating these into an actual SBSW system nor the capability to deploy that SBSW, but only the existence of some capability for each of the necessary prerequisite technologies for that particular SBSW system. This clarification is important since integration of these technologies into a working system, including testing, can take many years. Nevertheless, with the prerequisite technologies in hand, the SBSW

systems are considerably closer to the reach of that actor. It is clear that only the US and Russia currently have all the prerequisite technologies for SBSW systems.

[69] The Galileo navigation system is an initiative of the European Commission of the EU in partnership with the European Space Agency, which is responsible for the technical aspects of the project. All EU members will have access to it, as well as Norway and Switzerland, who are ESA member states. Additional international partners include Israel, Ukraine, India, Morocco, Saudi Arabia, South Korea, the US, and Russia. China will not have access to the encrypted service. See Civil Space and Global Utilities Trend 3.4.

[70] The capabilities in each prerequisite technology can vary greatly. The filled square only indicates some capability.

2009

"The annual Space Security Index is a major reference document on the current status of space security and threats to the safe and secure use of outer space by the present and future generations."

Gérard Brachet
Former Chair of the UN Committee on the Peaceful Uses of Outer Space; President, Académie de l'Air et de l'Espace/Air and Space Academy; Vice President, International Astronautical Federation

"As more nations and private actors turn to space for essential services, the long-term sustainability of the space environment becomes a critical concern. By providing a comprehensive, annual assessment of civil, military and commercial space activities, the Space Security Index provides an essential tool for policy makers, commercial actors, and researchers, allowing them to track and analyze major trends in space utilization"

Richard DalBello
Vice-President Government Relations, Intelsat General Corporation

"The Space Security Index is unique as an independent reviewof space activities with input from experts from many disciplines and from diverse points of view. As an accessible, comprehensive summary of policy and technical developments it is the best non-partisan resource available."

Dr. Jonathan McDowell
Harvard Smithsonian Center for Astrophysics

"The annual Space Security Index presents a comprehensive overview of all current space issues and provides a truly indispensible foundation for advancing sustainable space security. It helps promote global community among its enthusiastic supporters and is the first reference anyone concerned with these issues should use."

Dr. Peter L. Hays
Associate Director, Eisenhower Center for Space and Defense Studies, USAF Academy

"The Space Security Index continues to provide an objective 'one stop shopping' resource for information related to international space activities and their potential consequences. It's a must for every space research bookshelf."

Theresa Hitchens
Director, Center for Defense Information

"The Space Security Index continues to be the indispensable volume for those interested in space policy security, based on comprehensive research and sound analysis."

Ambassador Thomas Graham, Jr.
Former Special Assistant to the President for Arms Control, Nonproliferation and Disarmament

"Over the past few years, the issue of how best to secure sustainable access to and use of space has risen to the top of the global space policy agenda. The Space Security Index has been a significant contributor to the growing political and public awareness of this issue, and thus deserves great credit for helping shape that agenda."

Dr. John Logsdon
Professor Emeritus of Political Science and International Affairs, The George Washington University