BOEING

ASTRO / NEXTSat Self-Portrait

Fostering Sustainable Satellite Servicing
Orbital Express Program Summary

June 26, 2012

Manny Leinz
Director, Autonomous Space Capabilities
Boeing Phantom Works
(714) 896-1648
manny.r.leinz@boeing.com

ASTRO Image of NEXTSat Over Crete

Orbital Express Demonstration System Overview

- ***Orbital Express (OE) was a DARPA program demonstrated the technical feasibility, operational utility, and cost effectiveness of autonomous techniques for on-orbit satellite servicing***
  - Phase 1 Concept study (2000-2001)
  - Phase 2 Advanced Technology Flight Demonstration (1/2002 – 7/2007)
- ***Specific objectives were to develop and demonstrate on orbit:***
  - A nonproprietary satellite servicing interface specification
  - Orbit propellant transfer between a depot/serviceable satellite and a servicing satellite
  - Component transfer and verified operation of the component
  - Autonomous rendezvous, proximity operations, and capture
- ***On-Orbit demonstration of technologies was required to reduce risk of autonomous on-orbit satellite servicing***
  - Perform autonomous fuel transfer in a zero-g environment
  - Perform autonomous Orbital Replacement Unit (ORU) transfer
    - Component replacement (Battery and Computer)
  - Perform autonomous rendezvous and capture of a client satellite
    - Direct Capture, Free-Flyer Capture / Berth

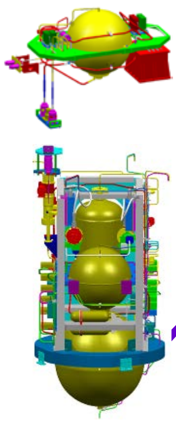
APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED

Orbital Express

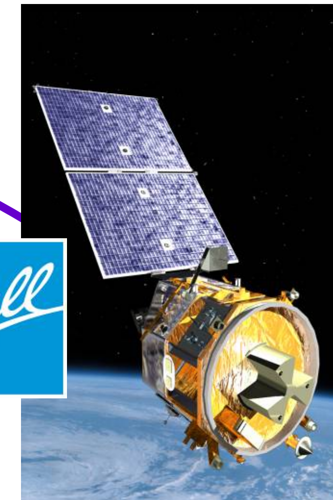
The Orbital Express Team

DARPA

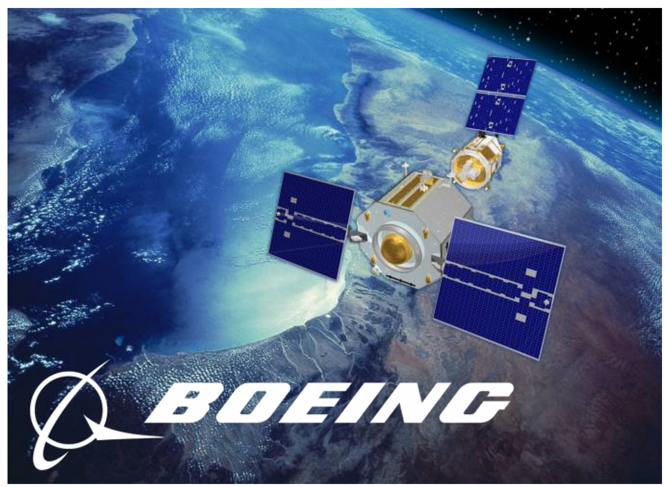
NASA



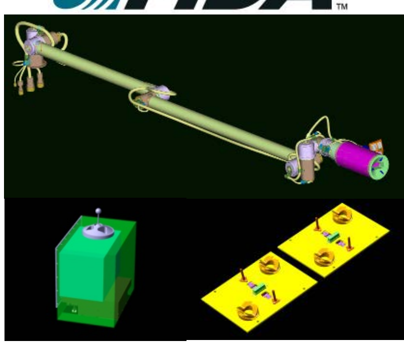
NORTHROP GRUMMAN



Ball



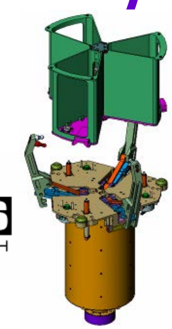
MDA



SPACE TEST PROGRAM
PATHFINDER FOR DoD SPACE SYSTEMS

DRAPER LABORATORY

STARSYS RESEARCH



BOEING

Orbital Express Vehicles

ASTRO (Autonomous Space Transfer and Robotic Orbiter)

BOEING PhantomWorks

Dimensions:
1.75 x1.77 m
Span:
5.59 m
Power:
1,560 Watts
Fueled Mass:
~1,100 kg

- **Hydrazine monopropellant reaction control system for 6 DoF Control**
- **Integrated GPS and INS**
- **Active servicing functions:**
  - Rendezvous and Proximity Operations Sensors
  - Relative Navigation Software
  - Robotic Arm
  - Active Capture Mechanism
  - Active Fluid Coupler and Fluid Transfer Components
  - Battery and Computer ORU bays (MDA)
  - 1553 Data Interface
  - Crosslink

NEXTSat/CSC (Next Generation Satellite/Commodity Spacecraft

Ball Aerospace & Technologies Corp.

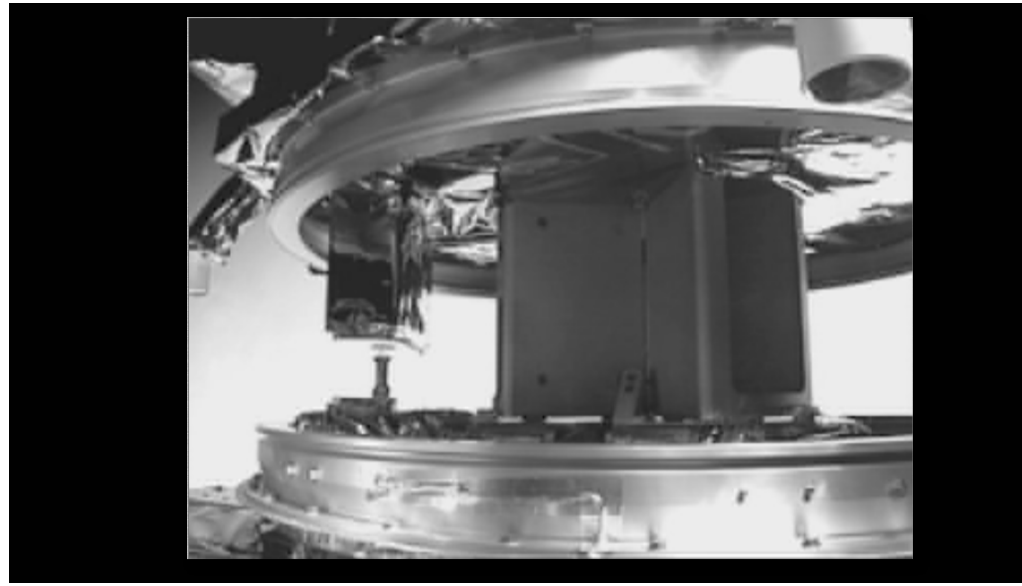
Dimensions:
~ I m x 2 m
Power:
500 Watts
Mass:
224 kg

- **Attitude Determination and Control, no maneuver capability**
- **Fixed Solar Array**
- **Standard servicing interfaces**
  - Passive capture mechanism
  - Passive Fluid Coupler and Transfer Tank
  - Battery ORU bay
  - 1553 Data Interface
  - Crosslink

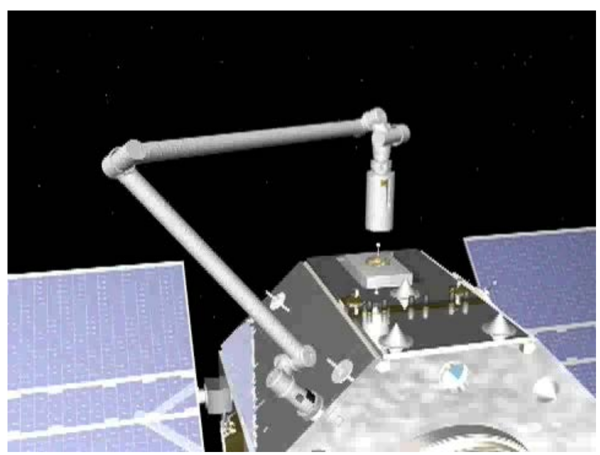
Orbital Express On-Orbit Demonstration Summary

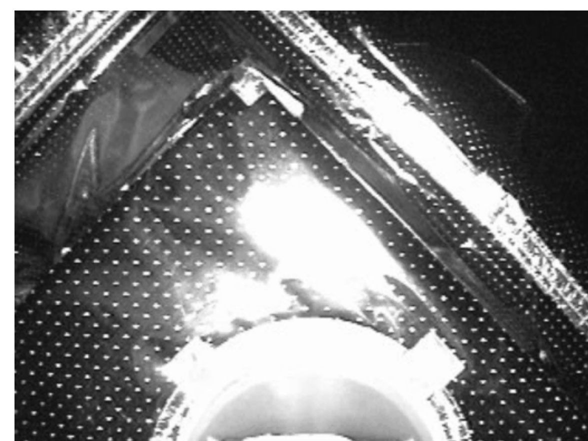
- ***Launched March 8, 2007***

- ***Fifteen propellant transfers performed***
  - Varying levels of autonomy
  - Pressure-fed and pump-fed
  - Multiple means of mass transfer control



- ***Eight ORU Transfers performed***
  - Battery and Computer
  - Varying levels of autonomy
  - Transfers to and from client/commodity depot
  - Functionality of both components proven after transfer

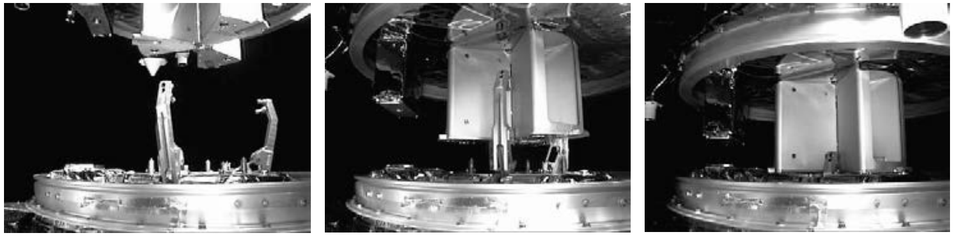




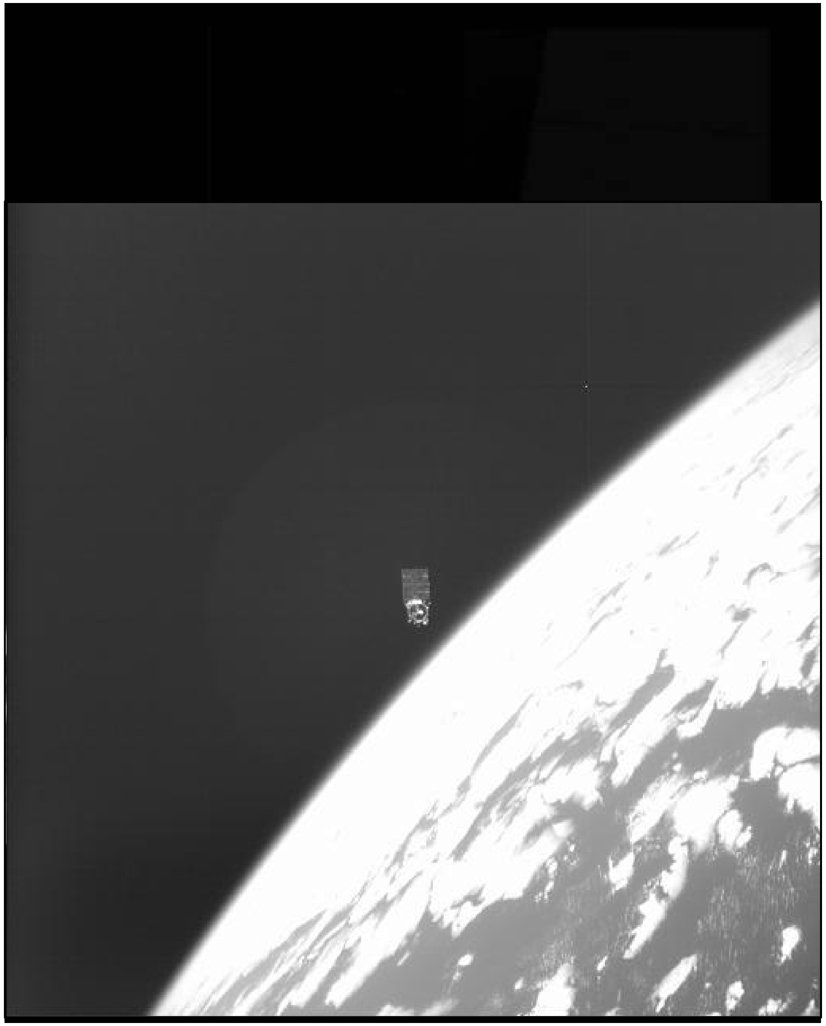
APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED

Orbital Express On-Orbit Demonstration Summary

- ***Six rendezvous exercises performed***
  - Relative ranges of 12m to 400+ km
  - Rendezvous from in front of, and behind target
  - Stand-off at 4 km, 1 km, 500 m
  - Station-keeping at 120 m, & 10 m
  - Elliptical and circular fly-around inspections at 1x and 3x orbit rates
  - Corridor approaches to fixed and rotating client spacecraft/depot
  - Day and night, direct and robotic-arm captures
  - Autonomous and ground-commanded aborts
- ***Mission Completed July 22, 2007***



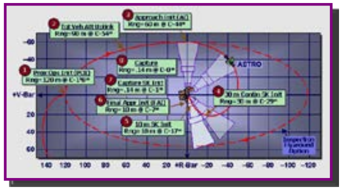
On-Orbit Capture Sequence

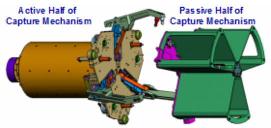


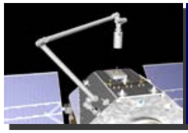
Scenario 7-1: Rendezvous to 4 km, Free-flyer Capture

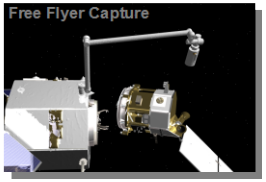
APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED

Orbital Express Program Accomplishments









Six Major World and US Firsts:

- ✓ First U.S. fully autonomous on-orbit transfer of propellant (Hydrazine) from one spacecraft to another
- ✓ First fully autonomous battery transfers
- ✓ First fully autonomous computer transfer
- ✓ First fully autonomous rendezvous and direct capture without client spacecraft navigation assistance
- ✓ First fully autonomous capture and berthing of a free-flying satellite with a robotic arm
- ✓ First fully autonomous Long Range (> 400 km) rendezvous

100% Mission Success

- ✓ 100% of Mission Requirements Met (23/23)
- ✓ 96% of Mission Goals Met (25/26)

“The folks who did this clearly have more experience in how to bring two spacecraft together than probably anyone in the world--past and present. Thanks again to everyone.”

- Dr. Tony Tether, DARPA Director

APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED

Low Risk Servicing Capability Demonstrations Improves Customer Confidence and Encourages A New Paradigm

Orbital Express

Demonstrate

Technical Feasibility

Demonstrate

- Rendezvous, proximity operations & capture
- Propellant and hardware transfer

Satellite Servicing of Existing Assets

Demonstrate “real-world” life, reliability

& cost benefits for operational satellites

Provide

- Customer value at less cost than replacement satellite
- Service at virtually no risk to customer by use of insurance and by initially focusing on satellites at near-end-of-life

Next Generation

Operators demand minimum impact

OE-enabled features in next gen satellites

Encourage

- Standardized servicing interfaces
- Scheduled maintenance and servicing op’s
- Greater flexibility and performance

Cooperative Servicing Infra-structure

Enable

- Revolutionary new space missions and capabilities

APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED