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Development of means for space debris de-orbiting on the basis of separating parts of upper stages of the space launcher vehicle with liquid propulsion engine

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Main methods to solve the problem of mitigation of near-Earth space contamination

Fundamental documents for contamination mitigation

- **GOST R52925 2008.** Space technology items. General requirements on space systems for the mitigation of human produced near earth space pollution/Russia
- **A/62/20** UN Space Debris Mitigation Guidelines. Resolution of 62nd Session of UN General Assembly, 2007
- **A/AC.105/C.1/L.260** IADC Guidelines for space debris mitigation, 2007

1. Passivation of spacecraft **(SC)** after operation → Presence on working orbit

2. SC Removal from operational orbits to disposal orbits after mission completion → **Lifetime** of SC on the orbit shall not exceed **25** years

- **3. Passivation** Separating Orbital Stages (SOS) of Space Launch Vehicle **(SLV)** presence on working orbit

4. Removal SOS of SLV from operational orbits to utilization or disposal orbits

Technological approaches and technical solutions for separating orbital stages of the space launch vehicle

Technological approaches and technical solutions on development means for deorbitting

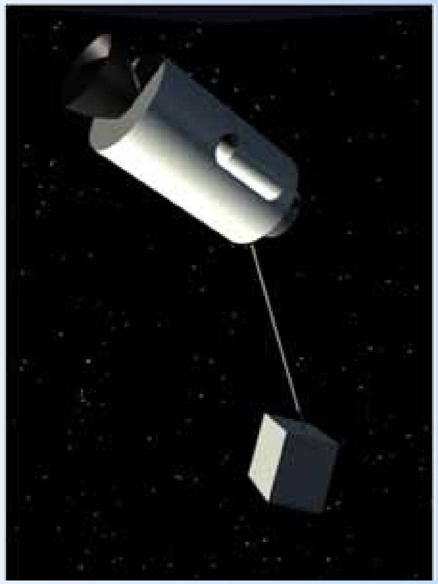
- ***Restarting of the propulsion engine***
- ***autonomous active propulsion engine***
- ***passive solutions***
- ***tether systems***
- ***Special spacecraft-tugs***

Traditional methods of removal from operational orbits

Passive system

- High probability of the sphere accidently opening;
- Insufficient practical experience;
- Difficult to maintain functionality of the sphere for 25 years;
- Applicable only up to 750 km

Tether system



- Insufficient practical experience;
- Difficult to deploy and release tether;
- Difficult to control tether attitude;
- Large mass

Active local system

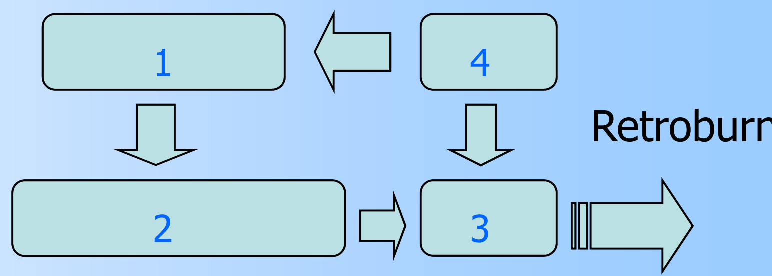
- Sufficient practical experience;
- High power parameters;
- High reliability;
- Low mass

Proposed concept of approach:

Using power resources of separated orbital stages including:

- Resources of unspent remaining liquid components of propellant (3-5% of initial amount);
- Resources of unspent remaining electricity (up to 30-40% of initial amount) and pressurized gas (up to 40% of initial amount);
- Kinetic and potential energy of orbital stages in orbit close to orbit of the space debris

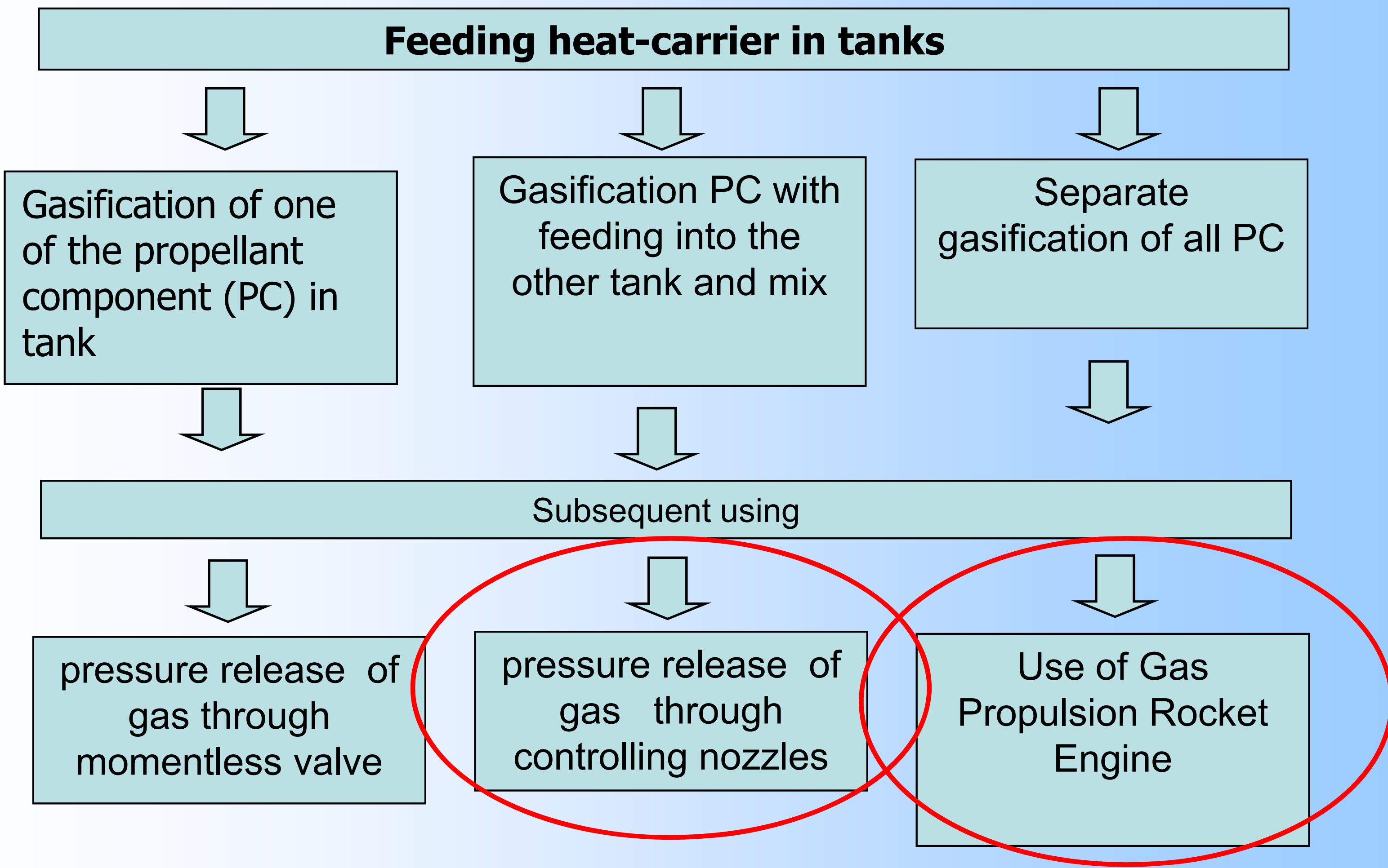
Basic diagram of gasification of remaining (unspent) propellant



Composition of active on-board de-orbiting system (ADS):

1. Gasification device for propellant residues
2. Propellant tanks of separated orbital stages of SLV
3. Propulsion system for retroburn;
4. ADS control system

Functional flow diagram of residual gasification



Scientific and technical problems of ADS development

1. Obtaining heat carrier with specified parameters.

2. Identifying power sources on board separated orbital stages of SLV for gasification of unusing liquid for high-boiling and low-boiling propellant components.

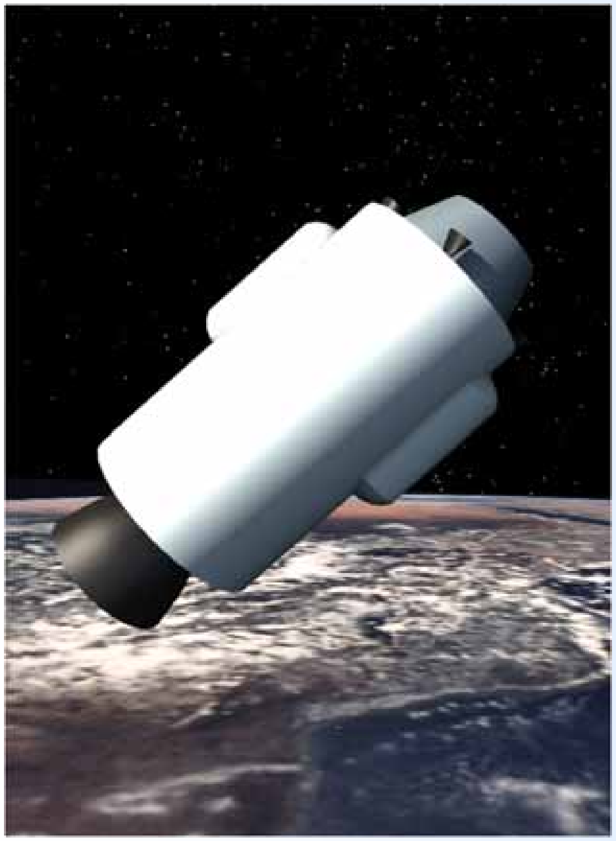
3. Implementing optimal modes of gasification of unspent liquid propellant components in the following conditions:

- **Low gravity;**
- **Undetermined position of remaining propellant;**
- **Undetermined actual amount and condition of remaining propellant.**

4. Determining energetically optimal disposal orbit for separated stages of SLV

5. Controlling ADS operation.

Realization scheme for proposed concept



Phase 1. Development of autonomous on-board de-orbiting sistem (ADS) for separate orbital stages of SLV based on gasification of unspent propellant components and usage of this power resource for de-orbiting maneuver.

Power resources contained in unspent electricity and pressurized gas are used for ADS operation.

The following can be used:

- Computing resources of on board computer system;
- Telemetry system etc.

Realization scheme for proposed concept and technical tasks

Phase 2. By means of accumulated kinetic energy of SP, removal of space debris from near orbits is carried out during the same launch.

It is proposed to use a space micro-tug **(SMT)**, connected with SP by tether system.

New on-board service systems are introduced: navigation and control system, telemetry, SMT, tether system, and joint-actuation system (JAS)/ grappler system.

Gasification system upgrades:

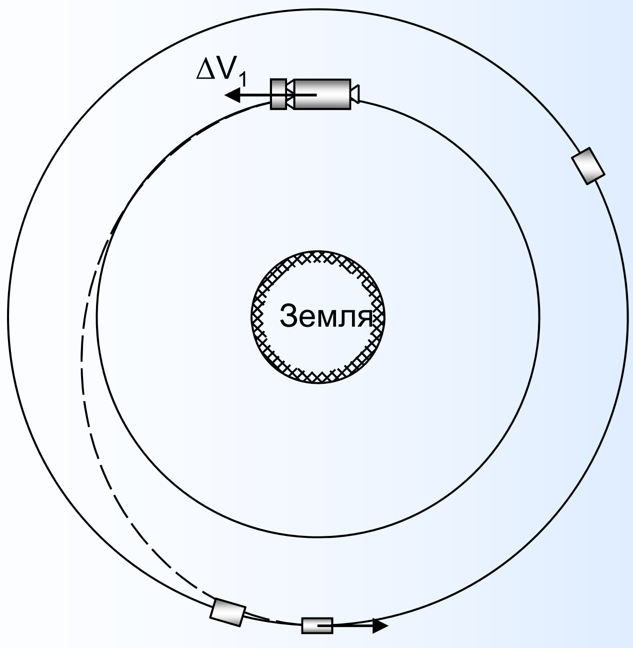
- Recurrence activation heat carrier supply system (till 4);
- Maintenance of specified amount and ratio of remaining propellants components;
- Improvement of efficiency of gasification system and specific impulse of gas rocket engine **(GRE)** (fuel additives and ultra sound treatment of supplied heat carrier).

Control and navigation system should be enhanced by the following additional equipment :

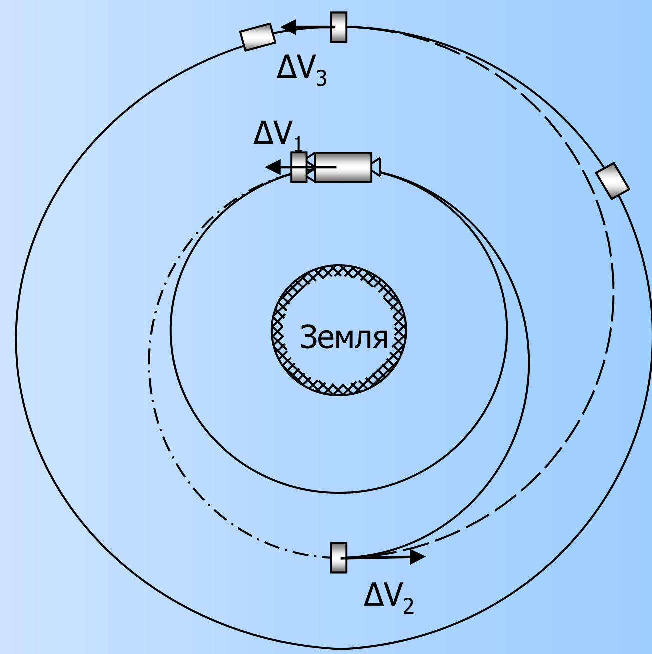
- navigation equipment, control system etc.;

Functional scheme of proposed system

Far approach phase with space debris



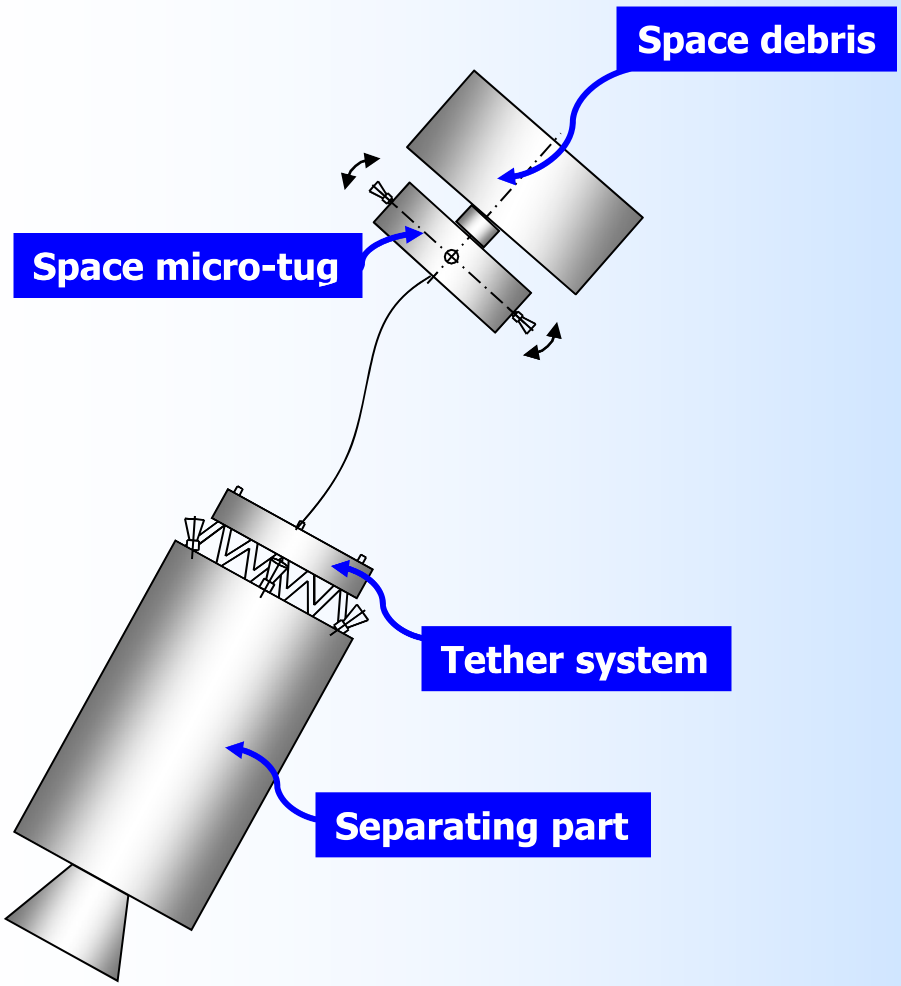
Far approach phase with phasing orbit with SD



After separation of payload from upper stages of SLV, upper stage equipped with ADS, tether system, space tug, and **joint-actuation system implement**:

- **Far approach** phase by means of detachable SMT connected with SP of SLR by unwinding tether;
- **far guidance phase** for SP of LR upper stage by means of ADS by application of far guidance impulses (1 to 3).

Functional scheme of proposed system



SMT composition includes :

- Cartesian propulsion system providing guidance impulses;
- guidance and docking (**grappler**) system.

System operation

After docking SMT to SD, a de-orbiting maneuver is carried out by the SP-tether-SMT-SD assembly transferring it to disposal orbit with the use of ADS.

Practical realization of assigned task

- ✓ ADS capable of multiple starting of propulsion system (up to 4 times)
- ✓ solution of navigation and movement control problems;
- ✓ space micro-tug system enabling close guidance phase;
- ✓ tether from separated orbital stages of SLV to space debris;
- ✓ joint-actuation system / grappler system.

Technical tasks for tether system development

Tether system rigidly connected with SOS is used by ADS to transport space debris to disposal orbit. One tether end is attached to the tether system, the other end is delivered by SMT to space debris and during soft docking is mechanically attached to space debris through docking/ grappler system.

SOS–deployed tether–SMT–docking unit-SD assembly in deployed state is transported to disposal orbit by ADS.

Main tasks for tether system development:

- controlled drum drive keeping linear speed of tether release at 2-4% above the relative velocity of SOS-SMT;
- determination of tether slack before transportation of SOS-deployed tether SMT docking unit-SD assembly;
- large tether length determined by exact application of far guidance impulses by ADS (up to 30 km)

Technical tasks for tether system development

SMT includes the following systems :

- control system based on radio location self guidance head;
- 4-chamber Cartesian propulsion system with membrane propellant supply, each chamber n 2-degree suspension enabling to apply control forces and torques in all directions;
- radio-communication channel to SOS.

Example of realization ADS for 2 stage SLV “Kosmos-3M”

Classification of active systems of removal SOS

Active de-orbiting system

- *Autonomous with additional propellant budget*
- *Autonomous with gasification the rest of propellant*

Parameters of orbit of deducing

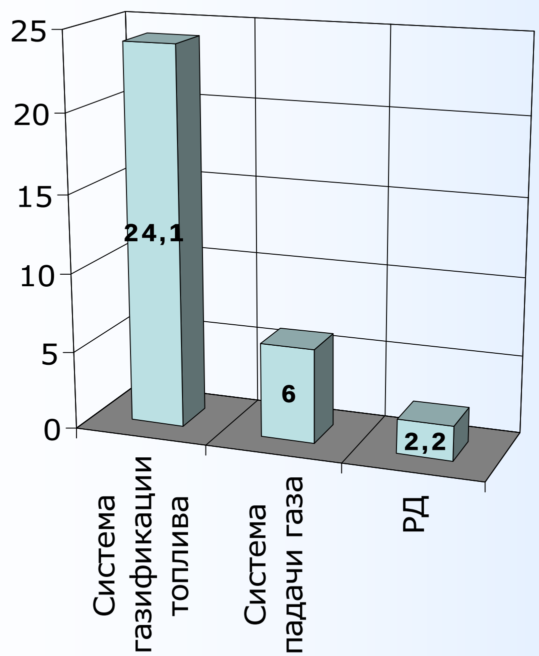
altitude [км]	800
Size ΔV [м/с]	74
Time of existence of stage	25

Parameters of system of gasification

Burn-time GPE [с]	50
Quantity of combustion chambers of GPRE	4
exhaust velocity [м/с]	~ 2800
Thrust GPRE [кН]	2.24
Mass AORS [кг]	~ 32

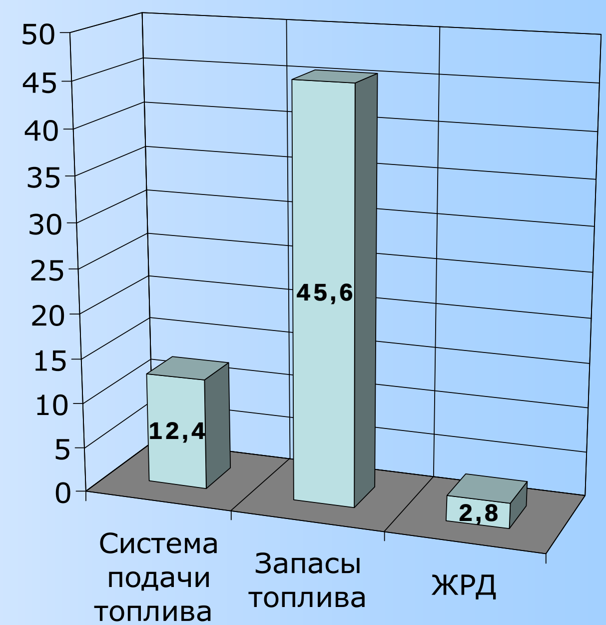
Characteristics of systems of removal on basis of ADS and autonomous additional propulsion system with propellant budget

System of removal on basis of gasification of remaining fuels



Total mass ~ 32 kg

System of removal with additional propellant budget



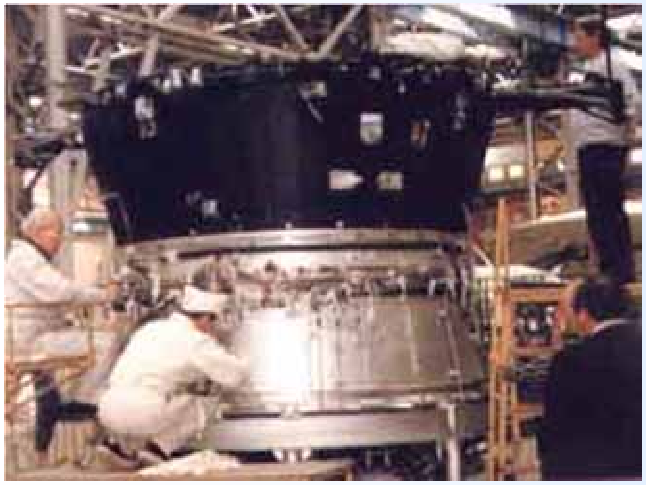
Total mass ~ 61 kg

Calculations are resulted for improvement of characteristic speed of braking
V = 74 m/s and time of existence of stage in orbit 25 years

Technical characteristics of space tug "Breeze-m"

Central part ST "Breez-M"»

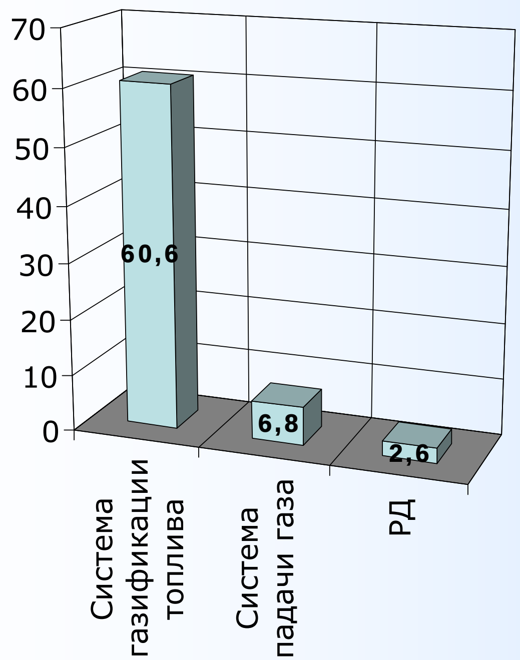
Separated part ST "Breez-M"



Mass in filled condition [kg]	**22170**	**6620**	**15550**
Dry mass [kg]	**2370**	**1420**	**950**
Mass of propellant [kg]	**19800**	**5200**	**14600**
Total remaining propellant [kg]	**~ 600**	**~ 300**	**~ 300**
Components of propellant	**АТ+НДМГ**	**АТ+НДМГ**	**АТ+НДМГ**
Specific thrust LPRE [s]	**325.5**	**Central part**	**Separated part**
Relation of area of stage to mass **[m²/kg]**	**0.01**		

Characteristics of systems of removal on basis ADS

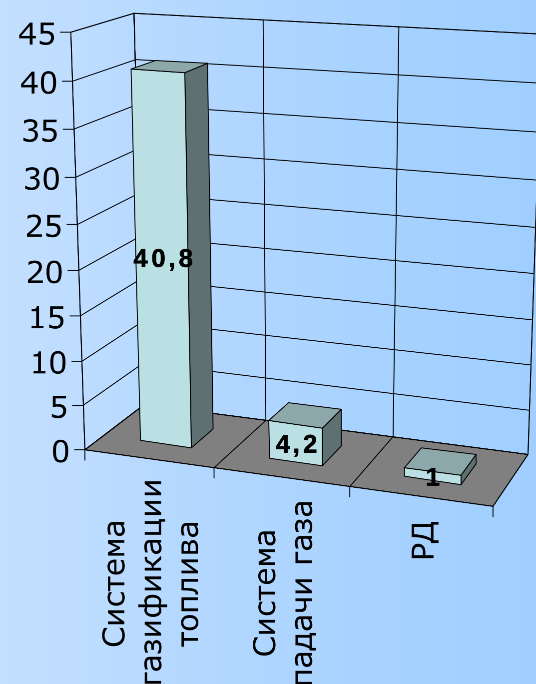
Mass of system of removal SP



Total mass ~ 70 kg

Thrust GPRE [кН]	**2.813**
Value ΔV [м/с]	**637**

Mass of system of removal of central part

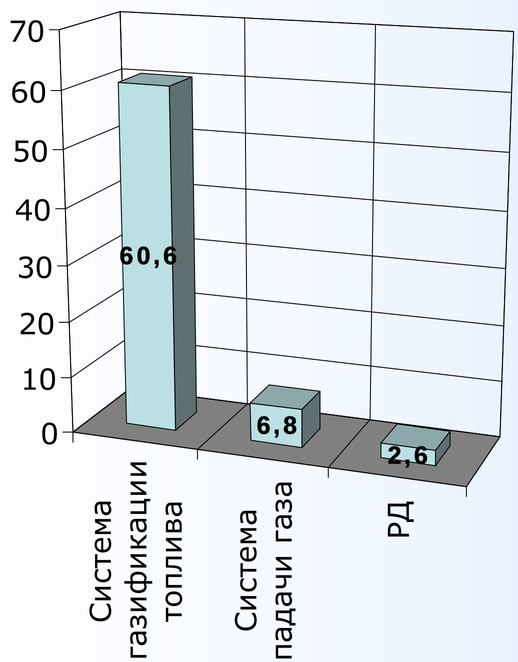


Total mass ~ 46 kg

Thrust GPRE [кН]	**0.612**
Value ΔV [м/с]	**259**

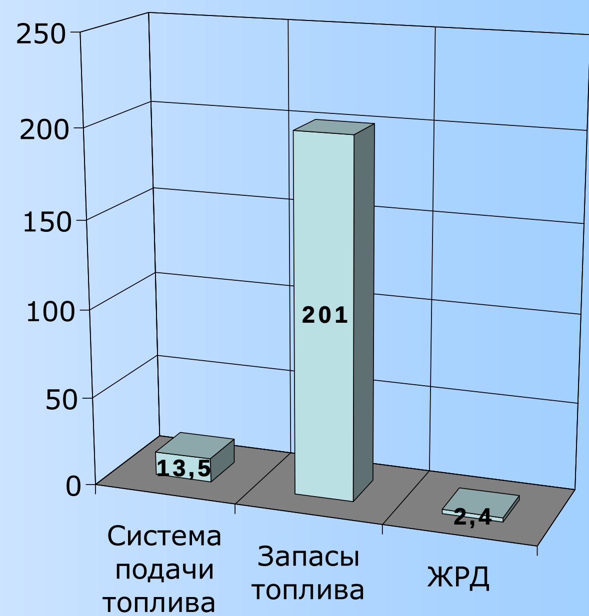
Comparative characteristics of systems of removal SP ST "Breeze-M" on basis of ADS and additional propulsion system

System of removal on the basis of gasification of remaining propellant



Total mass ~ 70 kg

System of removal with additional propellant budget



Total mass ~ 217 kg

Calculations are the result from improvement of characteristic speed of braking V = 637 m/c, burn-time – 215 s.

Parameters of small space tug and tether system

Tether system

- Tethermass,18kg
- Drummass,2kg
- Tether deployment System mass,4kg

Total mass~ 24kg
(deployed tether length 30 km)

Development cost~**$ 2million**

R&D cost for JAXA space tug is **$ 4million**

Small space tug

- Mass of engines with control drives, 3kg
- MST platform mass,3kg
- SD docking system mass, 4kg
- Guidance system mass,1kg
- Propellant stock and automation, 3kg

Total mass~ 14kg

Sequence of designing of onboard system of mitigation of orbital debris

Gasification of one of components (in that number, for example, most toxic - or most wasteful - kerosene) and it momentless emission

↓

Separate gasification of both components and them momentless emission

↓

Gasification and emission of both components with giving of focused impulse

↓

Gasification of each of the component and emission through GPE

↓

Gasification, emission through GPE, navigation, termination control movement on site of work GPE

Problems of increase of an impulse

The value of maximum impulse gas rocket engine (GRE)

$$\max I_{\Sigma} = \max\left(\int_{0}^{\tau_{раб}} \dot{m}_{\Sigma} \sqrt{2\frac{n}{n-1}RT\left(1-\left(\frac{p_a}{p_k}\right)^{\frac{n-1}{n}}\right)}d\tau + \int_{0}^{\tau_{раб}} F_a p_a d\tau \right)$$

$\max I_{\Sigma}$ is not sufficient to determine the total energy

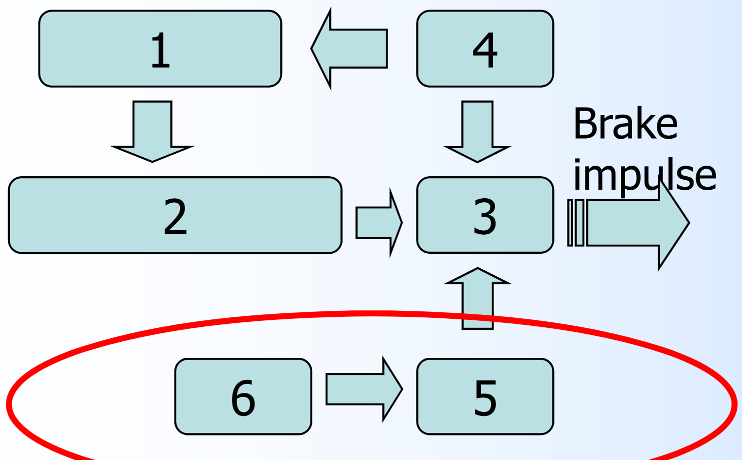
Aviation formula for determining the characteristic velocity

$$\Delta V_{хар} = I_{\Sigma}(\chi_1, \chi_2)\ln\frac{m^0_{ОЧ}}{m^к_{ОЧ}} \quad (1)$$

Constraints in the optimization criterion (1):

- mass gasification system;
- strength and stability of the structure of the fuel compartment:
- the volume occupied by the gasification system of residual propellants and designs GRE with drives;
- largest residual fuel and oxidizer.

The concept of increasing the specific impulse

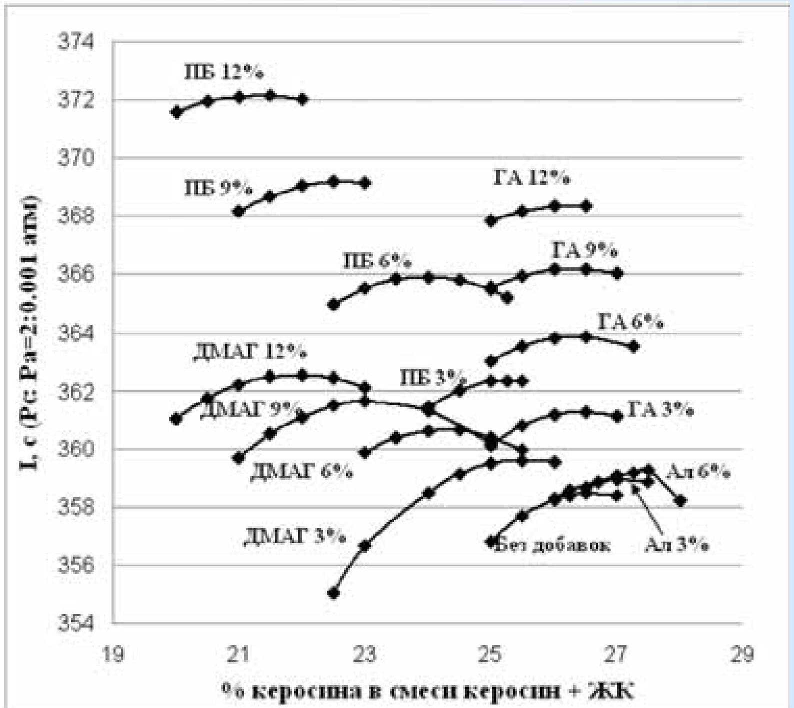


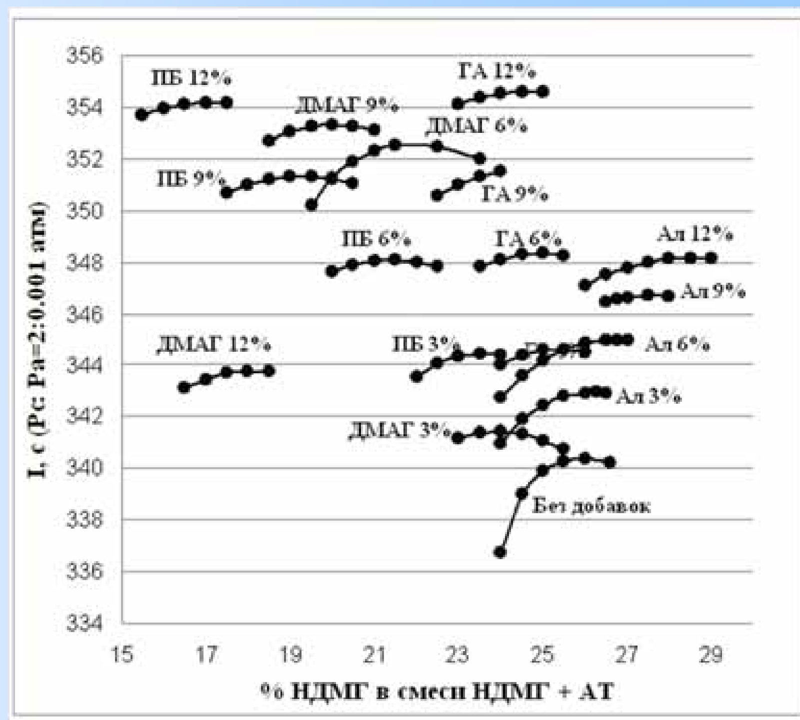
System Composition:
1. Device for the gasification of fuel residues;
2. Fuel tanks of the SV;
3. Propulsion implement braking impulse;
4. Control system ABSD;
5. System measuring additives in GRE;
6. Pressurized container with the additive.

Additional components of the energy

- **Nano-aluminum powder**
- **Aluminum hydride**
- **Dimetilgidrid aluminum**
- **Pentaborane (B_5H_{11})**

Changes in specific impulse with the introduction of additives





The calculations are for "clean" fuel vapor.

Actually, in the combustion chamber of the gas rocket engine (GRE) gasified components of rocket fuel arrive, containing to 50 % of impurity from the entered heat-carrier. Thus, the real specific impulse will be 15 - 20 % below the shown results; however the shown increase in specific impulse due to the introduction of additives will not change.

Stage , including means of de-orbiting using :

- Gasification of liquid residues of the PC and the use of GRE(OmSTU);
- LRE with the membrane feed CP (CNES/OTV, JAXA);
- SRE for the individual slip the selected object SD (CNES, JAXA);
- GRE (CNES, JAXA);
- NRE (ROSCOSMOS).

Stage НИиЭР, including means of de-orbiting using :

- Tether system (CNES, JAXA, NASA, ОАО «РКК Энергия»);
- solar sail (ROSKOSMOS, CNES, Surrey University Surrey Satellite Technology, EADS Astrium)/ planned launch in 2011 year;
- inflatable balloon (RF, NASA).

Draft **OTV** estimated of CNES:

- cost SLV ~ **$ 180 million**;
- the cost of tug OTV ~ **$ 200 million**
- The total price of the mission of de-orbiting 14 objectives will be ~ **$ 380 million**;
- the cost of de-orbiting of per object SD **~ $ 27 million;**

Tether system de-orbiting per object SD **~ $ 8 million.**

Solar sail. Development of the University Surreu.
Project Cost **$ 1,5 million.**

Technology based on ADS :

- SRW, SR&EW on the testing of ADS amount ~ **$ 1 million**;
- Material manufacturing, refinement fuel compartment, ground tests ~ **$ 1 million**;
- other unaccounted-for costs (15%)~ **$ 0,3 million.**

Total, gross value of de-orbiting an object SD, taking into account the development and manufacturing of less than ~ **$ 2,3 million;**

Advantages of de-orbiting systems based on ADS

- **Additional development not required**, except GRE for which there are equivalents and prototypes; there is considerable experience in development of such engines. All elements are manufactured as complete units and are extensively tested;
- **Possibility** of practical realization of maneuver for de-orbiting and transfer to dropping zones of SLV SOS running on high-boiling and cryogenic liquid propellant components by using power resources of unspent remaining propellant by its gasification and oriented exhaust through RE nozzles;
- **Upgrading** of existing and designed LVs does not lead to significant design changes, decrease of achieved flight reliability, considerable payload loss, or complication of operational conditions;
- **ADS dry mass** is **0,5 – 0,7%** of LR SP dry mass;
- **Upgrade cost** for SP of existing LRs is **5-7%** of LR SP current cost which is significantly lower than the cost of using other de-orbiting systems the average cost of which is 10-15% of the stage current cost!

Developers:

Omsk State Technical University

Thank you for your attention

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