MAJOR TRENDS FOR SPACE DEBRIS MITIGATION IN NEAR-EARTH SPACE IN THE RUSSIAN FEDERATION

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ABSTRACT

Mitigation of space debris in Earth orbits is one of the key factors ensuring the long-term safety of space missions. Recent studies have made it possible to develop a number of proposals on space debris mitigation activities, including a new method of disposing spent upper stages, operations on spacecraft and launch vehicle stages passivation, as well as some others. An analysis on compliance of space systems commissioned by Roscosmos with the requirements of the national standard and UN Space Debris Mitigation Guidelines is regularly carried out. In 2016 the national standard GOST R 52925-2008 "General requirements for mitigation of space debris population in near-Earth space" was updated taking into account the best international practices in space debris mitigation.

1 SPACE DEBRIS LEGAL FRAMEWORK IN THE RUSSIAN FEDERATION

Space debris issue is a primary consideration of space-faring states and international organizations being one of the actual problems in regards to ensuring safety of space operations. The Russian Federation pays much attention to dealing with space debris problem.

The activities on space debris mitigation are included in the Russian Federal Space Program for 2016-2025. The national regulatory framework for space debris mitigation is the standard of the Russian Federation GOST R 52925 «Space technology items. General requirements for mitigation of space debris population». The requirements of this standard are harmonized with Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space. In 2016 GOST R 52925 was updated out for the purpose of its harmonization with an ISO 24113.

Main updates of GOST R 52925-2017 are as following:

- terms and definitions are specified: near-Earth space, term of ballistic existence, probability of successful disposal, break-up, etc.
- the requirement to maneuver spacecraft (SC) and launch vehicle orbital stage in a controlled manner to an orbit with a perigee altitude sufficiently above the LEO and GEO protected regions that long-term perturbation forces do not cause it to re-enter the LEO and GEO protected regions within 100 years is added.
- the new point on probability of successful disposal of space means which should make not less than 0,9 is entered. This probability is calculated proceeding from reliability of the subsystems applied for disposal. It is meant that there is a stock of all resources for disposal implementation.

The comparative analysis of GOST R 52925 requirements and the main international documents on space debris mitigation is provided in Tab. 1.

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Table 1. Comparison of GOST R 52925 requirements and the main international documents on space debris mitigation

		Indicator	IADC Guidelines	ISO 24113:2011	GOST 52925-2017 (will be accepted soon)
The objects concerning with flight		Operational debris	item 5.1	General requirements	General requirements
		Emissions (slag) of solid propellant engines		General requirements	General requirements
		Pyrotechnics		Combustion products <1мм	General requirements
Break up on orbit		Intentional destruction	item 5.2.3	General requirements	It is allowed, directly ahead of falling to Earth (an entrance in dense beds)
		Failure during operation	item 5.2.2 (tracking)	Probability of destruction $<10^{-3}$	General requirements
		Destruction after completion of operation	item 5.2.1	General requirements	General requirements
Collisions		With large objects	item 5.4	General requirements	Risk assessment
		With small objects	item 5.4		Risk assessment
Disposal after end of mission	GEO	Disposal after the end of mission	235 km + (1000・Cr・A/m); e <0,003	235 km + (1000・Cr・A/m); e <0,003; Probability of success at withdrawal> 0.9; within 100 years	235км + (1000・Cr・A/m)
		Bottom border of GSO area	- 200 km	- 200 km	- 200 km
		Protected area (inclination)	- 15° <latitude <15°	- 15° <latitude <15°	15° <latitude <15°
	LEO (MEO)	Reduction of orbital lifetime	item 5.3.2 (25 years are recommended)	Stay in the atmosphere after end of mission <25 years; probability> 0,9	Stay in the atmosphere after end of mission <25 years, probability> 0,9
		Transfer to burial area		Stays within 100 years	Stays within 100 years
		Restoration in an orbit	item 5.3.2	General requirements	
		Land risks	item 5.3.2	General requirements	General requirements

2 IMPLEMENTATION OF SPACE DEBRIS MITIGATION MEASURES

17 launches are executed in Russian Federation in 2016. 18 SC (14 domestic and 4 foreign) are inserted into orbits

The analysis of implementation of GOST R 52925 «Space technology items. General requirements for mitigation of space debris population» requirements is annually carried out.

There are some major space debris mitigation activities performed on Russian launch vehicles, boosters and SC in 2016:

- Restriction of formation of space debris during regular operations by means of an exception of separating elements during orbit-inserting of SC and their operation (boosters Volga, LV type Soyuz, SC Meteor-M, Meteor-MP, Ionosfera, Zond, Kanopus-V-IK, Kanopus-V, Lomonosov, Resurs, Obzor-R, Bion-M, SC type Express and small SC Aist).
- Minimizing of possibility of destruction during flight operations by means of choosing reasonable margin of safety of the SC constructive elements which are exposed to mechanical impact, protection installation on units of high pressure (fuel tanks, high-pressure tanks, pipelines, tight compartments, etc.) for the purpose of prevention of their breakdown and spontaneous destruction (boosters Volga, LV type Soyuz, SC Meteor-M, Meteor-MP, Ionosfera, Zond, Kanopus-V-IK, Kanopus-V, Lomonosov, Resurs, Obzor-R, Bion-M, SC type Express and small SC Aist).
- Reduction of probability of casual collision in an orbit by means of the corresponding choice of parameters of orbits, a collocation of SC in one area of deduction on the GEO, prediction of dangerous intersections, installation of correcting propulsion

systems with the raised stock of fuel for carrying out protective orbital maneuvers (SC Meteor-M, Meteor-MP, Ionosfera, Zond, Kanopus-V-IK, Kanopus-V, Lomonosov, Resurs, Obzor-R, Bion-M, SC type Express and small SC Aist)

- Exception of intentional destructions and other harmful actions on all launch vehicles, boosters and SC commissioned by Roscosmos.
- Minimization of probability of post mission destructions is reached by the following operations: pressure dumping in fuel capacities of boosters after their transfer to a disposal orbit (boosters Volga, LV type Soyuz), removal of the remains of fuel under high pressure, discharge of chemical sources of the current, shutdown of batteries from chargers, reburnings of the remains of fuel of the correcting propulsion system (SC Meteor-M, Meteor-MP, Ionosfera, Zond, Kanopus-V-IK, Kanopus-V, Lomonosov, Resurs, Obzor-R, Bion-M, SC type Express and small SC Aist)
- Reduction of post mission orbital lifetime in LEO in such a manner that to execute re-entry within 25 years (LV type Soyuz, boosters Volga, SC Meteor-M, Meteor-MP, Ionosfera, Zond, Kanopus-V-IK, Kanopus-V, Lomonosov).
- Restriction of long finding of SC and orbital stages in GEO protected regions after end of their mission by means of disposal in orbit on 250-300 km above GEO (boosters DM-SL, DM - SLB, DM-03, SC Obzor, SC type Express, SC type Yamal).

3 A STUDY TO IMPROVE BRIZ-M DISPOSAL SCHEME

Together with implementing the disposal measures, Russian experts are developing possible ways for improvement of parameters of disposal procedure including for Briz-M booster for the purpose of development and implementation of the scheme of its disposal from the protected GEO region.

The first stage of studying was a theoretical research on the possibilities for improvement of the used scheme of Briz-M disposal. Obviously, the improved scheme should include at least two delta-V maneuvers.

1st delta-V move an object for time ΔT from point 1 with the radius R1 on the near-GEO to the point 2 with the radius R2 on ΔR higher/lower than GEO (Fig. 1).

2nd delta-V make a point 2 as a perigee/apogee of the required disposal orbit with e ≤0.003 (Fig. 1).

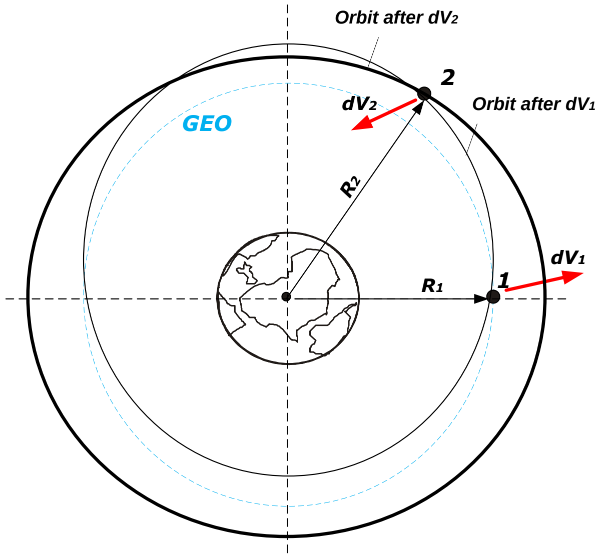

Figure 1. The suggested new scheme of disposal of Briz-M

Thus, components of the first maneuver were calculated using iteration for satisfaction to a condition:

$$R2 - |R1 \pm \Delta R| \leq 0.1\text{км} \quad (1)$$

Tangential and radial components of the second maneuver are calculated using formulas:

when reboosting above protected GSO area

$$dV_{TG2} = \begin{cases} 0, & for\ V_{Tr1} =< V_{cir} \\ V_{cir} - V_{Tr1}, & for\ V_{Tr1} > V_{cir} \end{cases} \quad (2)$$

when reeboosting below protected GSO area

$$dV_{TG2} = \begin{cases} 0, & for\ V_{Tr1} >= V_{cir} \\ V_{cir} - V_{Tr1}, & for\ V_{Tr1} < V_{cir} \end{cases} \quad (3)$$

Some results of these calculations are presented in Table 2 where the line with height of 260 kilometers corresponds to the minimum height of a perigee of Briz-M at disposal maneuver into a classical GEO orbit.

Calculation of excess of height of an orbit for Briz-M over protected GEO region according to IADC requirements: A/m≈0.02, C_R~1.3, h_2 ≈ 25км, ΔR ≈ 235 km + 25km ≈ 260km.

Table 2. Some results of calculations of parameters of maneuvers

N	ΔT	ΔR, km	Delta-V components, m/s				dV_{sum}, m/s
			dV_{R1}	dV_{TG1}	dV_{R2}	dV_{TG2}	
1	1h 00min	200	55.24	3.62	- 55.23	3.65	110.72
2	1h 15min	260	57.28	4.74	- 57.27	4.70	114.91
3	1h 30min	300	54.82	5.49	- 54.86	3.39	110.23
4	1h 00min	- 200	- 55.25	- 3.59	55.22	3.73	110.71
5	1h 30min	- 300	- 54.85	- 5.44	54.81	5.56	110.21

Thus, it was shown that there is a theoretical possibility to carry out complete disposal of Briz-M from GEO protected region after payload injection. It was also directly confirmed by check ups on the software used by ballistics experts when calculating the Briz-M flight program.

The following scheme on disposal Briz-M (Fig. 2) is suggested:

– the second delta-V maneuver is added;

– an acceptable reduction of the ΔT duration;

– refusal to hold the ranging session after $\Delta V2$ (the required disposal orbit can be determined using ranging measurements of session 3 and implemented $\Delta V2$ parameters from the TLM).

Let us consider in more detail the new scheme on an example of a payload launch performed on December 13, 2015 by GEO direct orbital injection with Proton-Briz-M. Fig. 3 presents the implemented operations. As a result, Briz-M was disposed into an orbit that impaired statistics on the upper stages imposing danger to the GEO region.

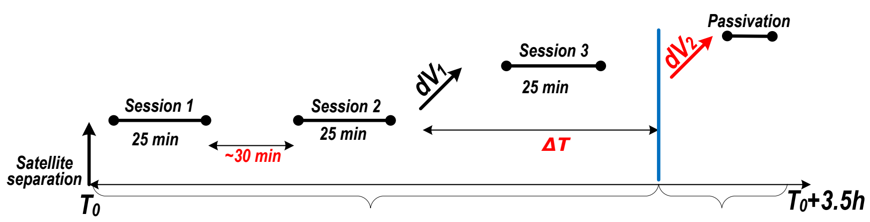

Figure 2. Disposal according to the new scheme

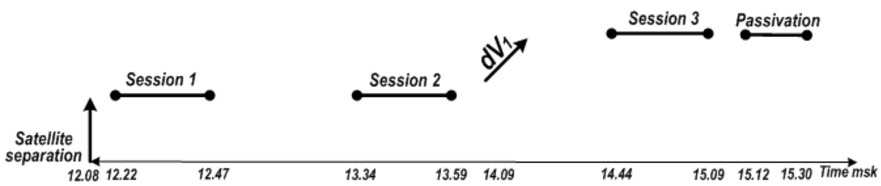

Figure 3. Briz-M performed operation after satellite separation

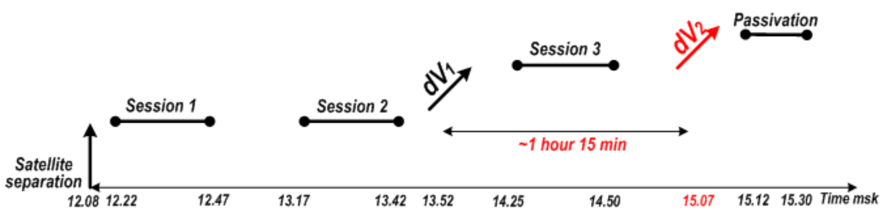

Figure 4. Suggested scheme for possible implementation

Fig. 4 corresponds to the improved and approved scheme. The analysis of parameters of a possible disposal orbit realized in this start shows that they completely meet all shown requirements.

Parameters of the existing disposal scheme:

- H_a ~ 35889km (~GEO)
- Hp ~ 33292km (-2492km)
- i ~ 0.207 deg
- e ~ 0.0223
- dV_1 ~ 118m/s

Parameters of the perspective disposal scheme:

- H_a ~ 36133km (+345 km)
- H_p ~ 36046 km
- i ~ 0.207 deg
- e ~ 0.001
- $dV1 + dV2$ ~ 118 m/s

The assessment of long-term evolution of the orbit parameters realized as a result of use of the proposed new disposal scheme of Briz-M for a period up to 2034 is carried out.

Figure 5 obviously shows that the requirement of missing of this orbit in protected GEO region after disposal implementation within at least 25 years will be met.

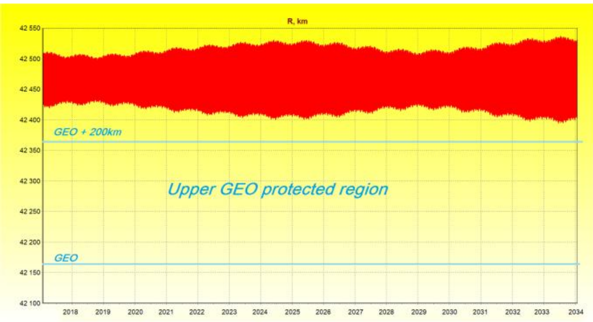

Figure 5. Numerical integration to generate the long-term Briz-M disposal orbit history (forces: Earth gravity (8x8), Sun gravity, Moon gravity, Sun pressure)

As a result of the analysis of Briz-M disposal scheme:

- possibility for improvement of the used Briz-M disposal scheme for the purpose of implementing its complete disposal from the protected region of GEO is established theoretical.
- practical implementation of the new scheme gave the chance to get approval from the developers of the booster flight program.
- the carried out theoretical studying and practical realization can be useful when carrying out similar researches on other types of launching vehicles and upper stages.

CONCLUSIONS

The Russian experts continue to improve methods and means of SC protection from impact of pieces of space debris and micrometeoroids. The main activity is ensuring safety of the ISS operation in the conditions of influence of space debris and micrometeoroids. Currently the ISS manned modules protection is performed by shielding designs.

The Russian Federation supports the international efforts on space debris mitigation and is already implementing on a voluntary basis corresponding practical steps in compliance with its own national mechanisms and the UN COPUOS and IADC Space Debris Mitigation Guidelines.