CONCEPTION OF RUSSIAN LAUNCHERS BUILDUP AND FOREMOST MITIGATION MEASURES

S.V. Chekalin, M.V. Yakovlev,
Central Research Institute of Machine Building
4, Pionerskaya Str. Korolev, Moscow Region, 141070 Russia

V.P. Blagun, S.V. Kulik
Russian Aviation and Space Agency, 41, Shepkina Str., Moscow, 129857 Russia

ABSTRACT

The report is devoted to the problems of building up the space launch capabilities during the transfer period of forming the Russian space launch capability system (SLCS). While developing the SLCS concept a special attention is being paid to the measures of mitigating man-made space debris population. Russian launch vehicle launches under the federal and commercial programs upto 2015 have been predicted. The measures undertaken in comparison with the obsolete tecnology of operating SLCS would reduce by more than two times the accumulation of SLV upper stages and boost engines in orbits and basically prevent their in-orbit breakups.

LAUNCH CAPABILITIES DEVELOPMENT PROBLEMS AND PROSPECTS

Currently in the conditions of negative consequences having taken place in the space industry due to the former USSR collapse and l shortage of the governmental financing the S/C launch programs are realized using launch vehicles developed in the 60-ieth and 70-ieth having the obsolete elements base (the Kosmos, Tsiklon, Molniya, Soyuz and Proton types). And orbital station service spacecraft and GEO space vehicles are launched only from the Baikonour space site, located in Khazakhstan. The on-ground space infrastructure objects are being operated out of the prolonged technical resources limits. The SLV operation environmental problems have become aggravated [1].

At the same time for the reconstruction (perestroika) period Russia obtained an access to the world space market and because of the Russian launch assets the leading development contractors managed to make commercial S/C launch contracts. The industry could make partial self-investments.

Under the evolved conditions the Russian launch capability system is being formed step by step within the framework of solving the first-priority problems:

- maintenance of the space launch capability potential on a sufficient level;
- move of the Russian launch capabilities to the world launch service market;
- assurance of Russia's guaranteed and independent access to space in prospect.

The work guidelines to form the Russian launch capability system and on-ground space infrastructure for the period of 2000 to 2005 are as follows;

- completion of updating the Soyuz and Proton basic launchers in order to prolong their life cycle and to maintain launch reliability and safety on the desired level;
- designing of reliable and cheap light-weight launch vehicles of the Rokot, Strela and Dnepr class on the basis of the dismantled missiles;
- updating and operational availability maintenance of the on-ground space infrastructure of the Baikonour, Plesetsk and Svobodnyi launch sites to support the planned launch program;
- conduct of R & D to design a new generation SLV family of the light-, medium- and heavy mass class aimed at their complete manufacturing cycle at the Russian Federation plants and launches off the Russian launch sites;
- development of highly efficient boost engines for medium- and heavy-weight launch

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expand the scope of the problems to be tackled.

Alongside with the strategy of developing expendable launchers to orbit-inject payloads within the period of up to 2005 advanced reusable space transportation systems are being developed under the R & D program "Integrated studies to support technical solutions, to optimise design parameters, to assess the efficiency and to develop key technologies of building a reusable space transportation system (RSTS) ("Orel") of the 21st century. It is supposed to conduct this R & D enlarging the experimental investigation scope.

Among probable types of reusable systems the following systems are under consideration:

-air-based partially reusable systems;

- partially reusable omni-azimuth launch vehicles incorporating a recoverable first stage;

- fully reusable two-or single-stage launchers.

Reusability introduction in launch vehicles is one of the efficient directions of their perfection concerning the reliability enhancement and operational costs cutback, but it demands transfer to the technologies of a qualitatively novel level.

8. In the period of forming the Russian space launch capability system the space launch vehicles of the Soyuz and Proton types are the basic launchers. They will account for the main amount of spacecraft launches within the federal and commercial programs up to 2005.

Updating of the Souyz (Souyz-2 and Avrora SLVs) and Proton (Proton-M SLV) envisages replacement of obsolete control systems, propulsion system improvement including fitting several stages with new engines, etc, raises the power capabilities and improves the SLV ecological safety factors.

As a promising launch capability system aimed at the Russian production facilities and launch sites is proposed the Angara SLV family with their stages being based on the universal rocket module (URM) equipped with the RD-191 oxygen/kerosene engine (fig 1,2).

The URM is taken also as a key component equipped with a rotating wing, tail fins, air - breathing jet engine, landing gear and a control system. Its developmental testing is supposed onboard a light-weight SLV of the Angara-1.2M SLV, type.

SPACE DEBRIS POLLUTION LEVEL AND SLV LAUNCH PREDICTION

The launch capability development focuses on the environmental problems brought about by the Russian launch vehicle and boost modules operation, and first of all on the near-earth space man-made debris pollution problem threatening the space mission safety. Up to 8500 artificial trackable objects (ATO) measuring over 10 to 20cm are registered in space. Alongside with cataloged ATO 80 to 100 thousand fragments measuring I to 10cm orbit the earth on low orbits.

Currently the main generators of orbital debris fragments are spacecraft and SLV stages breakups accounting for almost half of the cataloged artificial objects and for the bulk of untrackable but presenting collision risks small-size fragments.

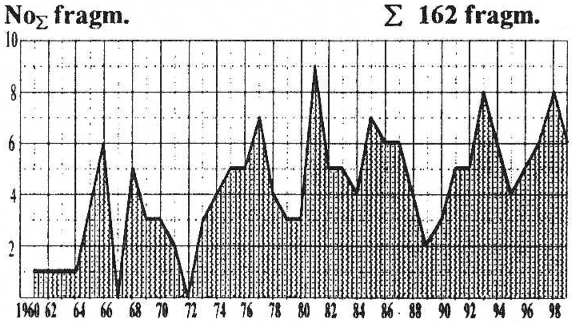
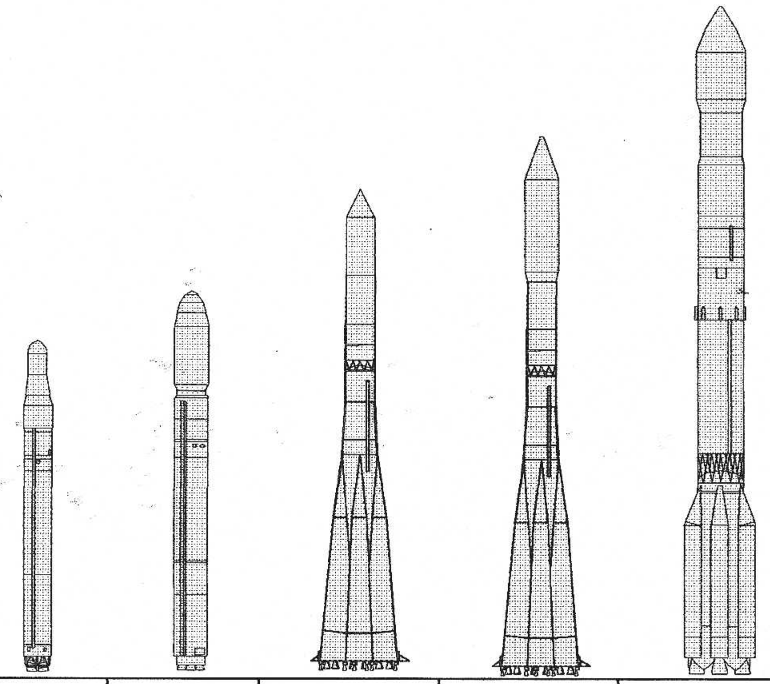


Fig.3. Annual in-space fragmentations

Table 1 Orbit object fragmentations distribution

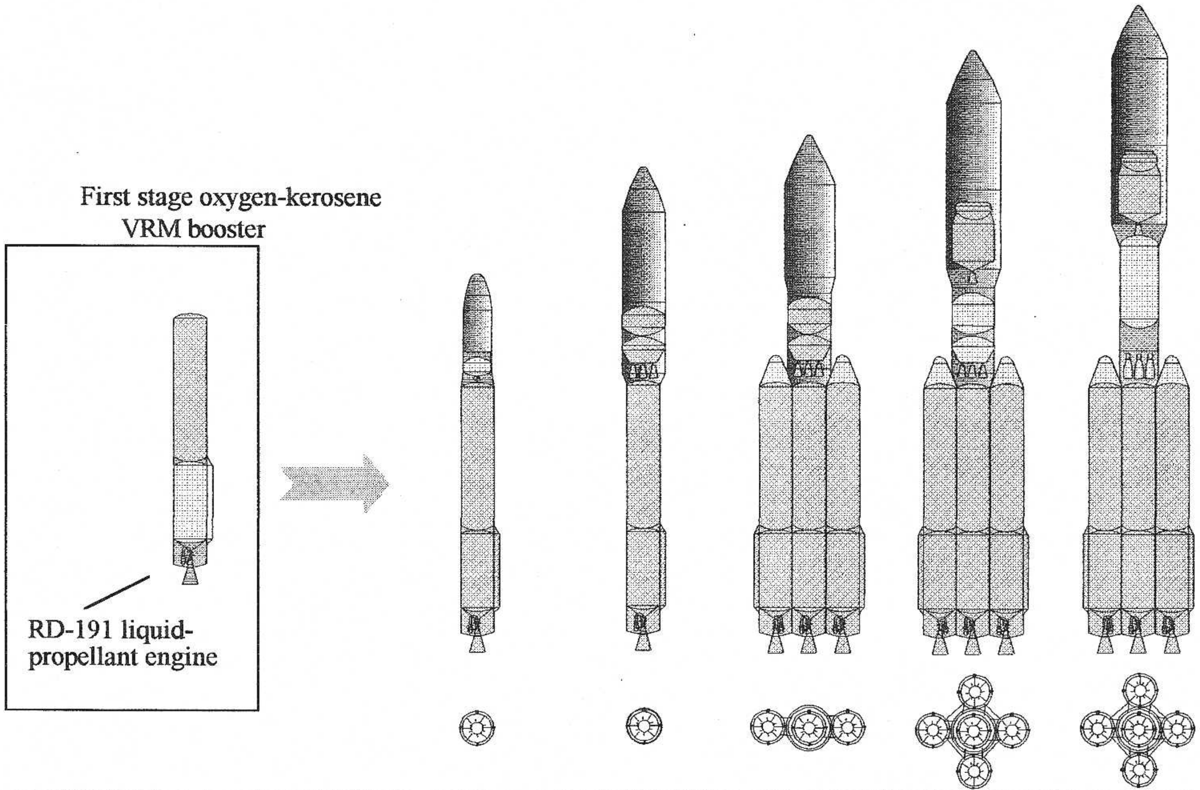
Orbit type	Number of fragmentations
Low (up to 2000km)	101
Medium-altitude and higly elliptical	59
GEO	2

The SLV stages account for 45% of explosions. Explosions take place due to the imperfection of propulsion systems and chemical batteries of spacecraft and rocket stages built by old technologies.



Space launch vehicles	Rokot	Dnepr	Soyuz-2	Avrora	Proton-M
Launch mass, t	107	211	310	360	700
Low orbit payload mass, t	2,0	4,7	7,4	11,8	22

FIG. 1. TRANSITION PERIOD OF LAUNCH CAPABILITY FORMATION



Space launch vehicles	A1.1	A1.2	A3	A5	A5-VOHB
Launch mass, t	147	172	480	778	790
Low orbit payload mass, t	2,2	3,6	14	24,5	28

Effects of explosions on orbital flight safety may be demonstrated clearly by the International Space Station safety assurance (fig.4). For example, if explosions terminate beginning from the moment of the standard ISS functioning (2002), then the impact risk (in percentage) of its Russian segment with a space debris fragment measuring 1 cm or more would be reduced by 7 times for its service life (20 years). Really it is impossible to speak about a specific time of chemical explosions termination in orbits even when transfer to a new technology takes place in association with the fact, that obsolete objects having been accumulated in orbits earlier may, as the practice shows, explode even after a long stay in space. But the expediency of the most rapid introduction of measures preventing such explosions are beyond any doubt

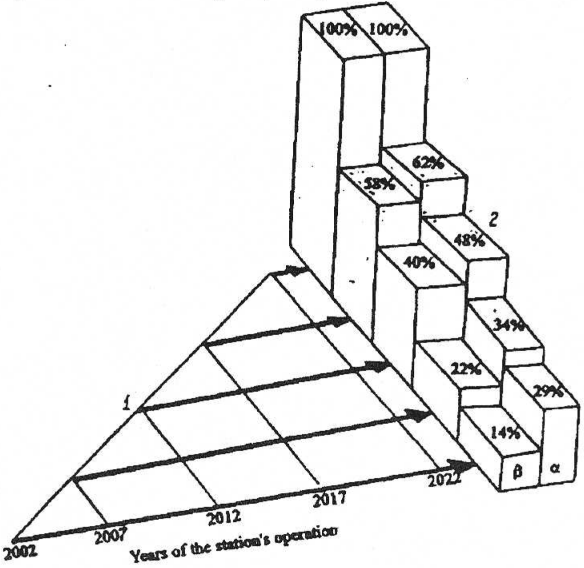


Fig. 4 Effect of in-orbit explosions on the safety of orbital flights (ISS as an example)

α- prevention of intentional and accidental explosions in orbits, numbering up to 65% of the total explosion number;

β- complete exclusion of on-orbit explosions/

1- the beginning of on-orbit explosions termination.

2 - relative reduction of the risk of the ISS (Russian segment) impact with space debris fragments ≥1 cm.

The S/C launch forecast for the period of up to 2015 (table 2,3) shows, that the expected average annual SLV launch number of different masses is about 50 launches and launchers - for about 25% of launches. On the average commercial launches would constitute one third of the annual SLV launches. Distribution the launches of Russian S/C among orbit regions in accordance with the forecast would be as follows: 65 to 70% to LEO (H<1500 km); 20% - to highly elliptical and highly circular orbits and 10 to 15% - to GEO.

Taking into account the maintained large volume of S/C launches and our own "contribution" to the artificial space debris pollution we are obliged to change over to a new technology of operating rocket and space assets in order to mitigate space debris population [2].

MEASURES UNDERTAKEN TO NITIGATE ARTIFICIAL SPACE DEBRIS POPULATION

The Russian Aviation & Space Agency has prepared an industry standard providing for the obligatory inclusion of requirements for space artifical debris mitigation in a Technical Assignment and other documents, regulating space item designing, fabrication and operation.

The basic requirements to space launch capabilities are:

- passivation of spent boost engines and SLV upper stages;
- restriction of their LEO life;
- operational separated elements minimization;
- prevention of operational element separation in GEO;
- spent boost engine removal from GEO to a burial zone.

As a probable step to prevent SLV upper stage concentration in LEO it is provided for injecting heavy SLV upper stages in LEO with its short flight duration and fall in the antipodal point and a S/C orbit injection by boost or apogee engines.

The ballistic lifetime of spent upper stages of light- and medium-weight launchers is supposed to be reduced by the use of a passive deceleration system. So, it is intended to fit the modernized Souyz-2 SLV upper stage with a passive deceleration system (a 10 m in

TABLE 2. PREDICTION OF RUSSIAN S/C LAUNCHES

Orbit types H_π/H_λ (H_{circ}), km	Inclination deg	Number of S/C to-be Launched 2001-2005	2006-2010	2011-2015
Low orbit				
180-470	51,6-97	63	64	62
500-1500	51,6-99	59	95	94
		122	159	156
Highly elliptical orbit				
600/12360	63	-	6	6
600/40000	63	14	6	10
1000/40000	63	4	6	4
500/250000	51,6	2	1	1
		20	19	21
Highly circular orbit				
10000	82	4	8	12
19100	64,8	18	16	10
		22	24	22
GEO	0	27	24	23
Departure orbit		-	4	3
	Σ	191	230	225

Table 3. PREDICTION OF RUSSIAN S/C LAUNCHES

Launch program and SLV types	Number of launches (average number of annual launches) 2001-2005	2006-2010	2011-2015
By Federal programs			
Light SLV	28 (6)	50 (10)	49 (10)
Medium weight SLV	97 (19)	111 (22)	110 (22)
Heavy weight SLV	30 (6)	20 (4)	21 (4)
	155 (31)	181 (36)	180 (36)
By Federal and commercial programs			
Light SL	58 (12)	75 (15)	79 (16)
Medium weight SLV	127 (25)	131 (26)	130 (26)
Heavy weight SLV	55 (11)	50 (10)	46 (9)
	240 (48)	256 (51)	255 (51)

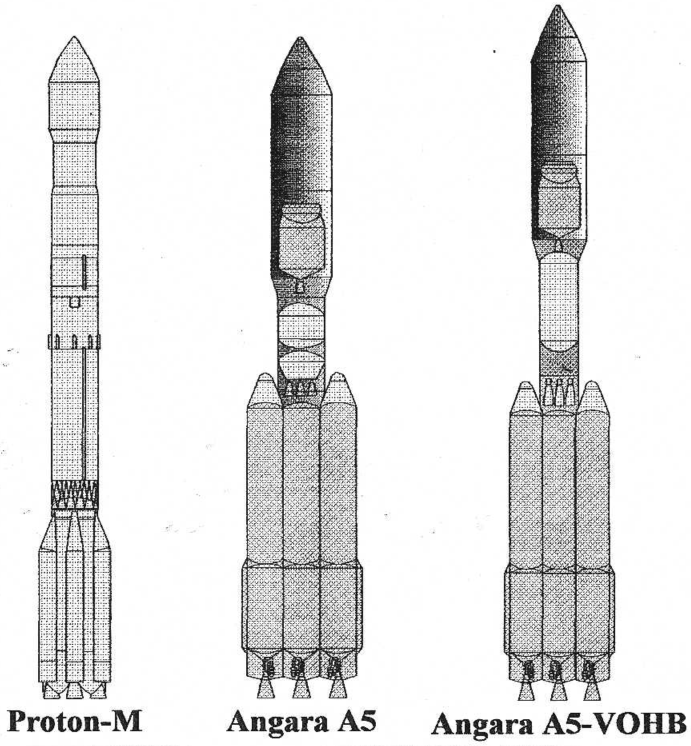
enabling to decrease the upper stage ballistic lifetime by 5 to 6 times (see. fig.5). The passive deceleration system flight testing is planned for 2002 when the Souyz-2 (IB) is flight-tested.

The need for expanding the set of the problems to be solved when moving to the world launch service market has caused alongside with the Souyz and Proton basic SLV and the boost engine DM designing of a set of new boost engines: a more compact Briz-M boost engine to fit the Proton-M SLV with and the Fregat and Korvet boost engines for the Soyuz-2 and Avrora launchers. The

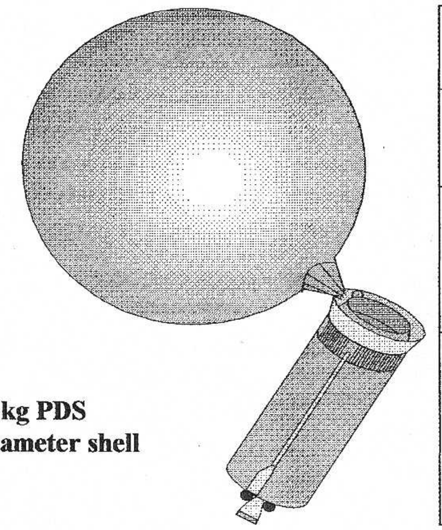
It is also intended to develop an oxygen/hydrogen boost engine standardized for the Proton-type SLV and an advanced heavy launcher enabling to significantly raise S/C masses to be orbit-inserted. It is intended to design in future high-efficiency transport modules equipped with new-type engines (electric or solar-heat engines). The characteristics of the boost engines to inject S/C in GEO are given table 4 and the parameters of the spent GEO S/C and boost engines burial zone in Fig 6.

1. Low orbit injection of SLV upper stage having short unpowered flight duration (less than 30 days)

2. Injection pattern with SLV upper stage fall on antipodal point and S/C insertion in operational orbit by boost block or apogee stage

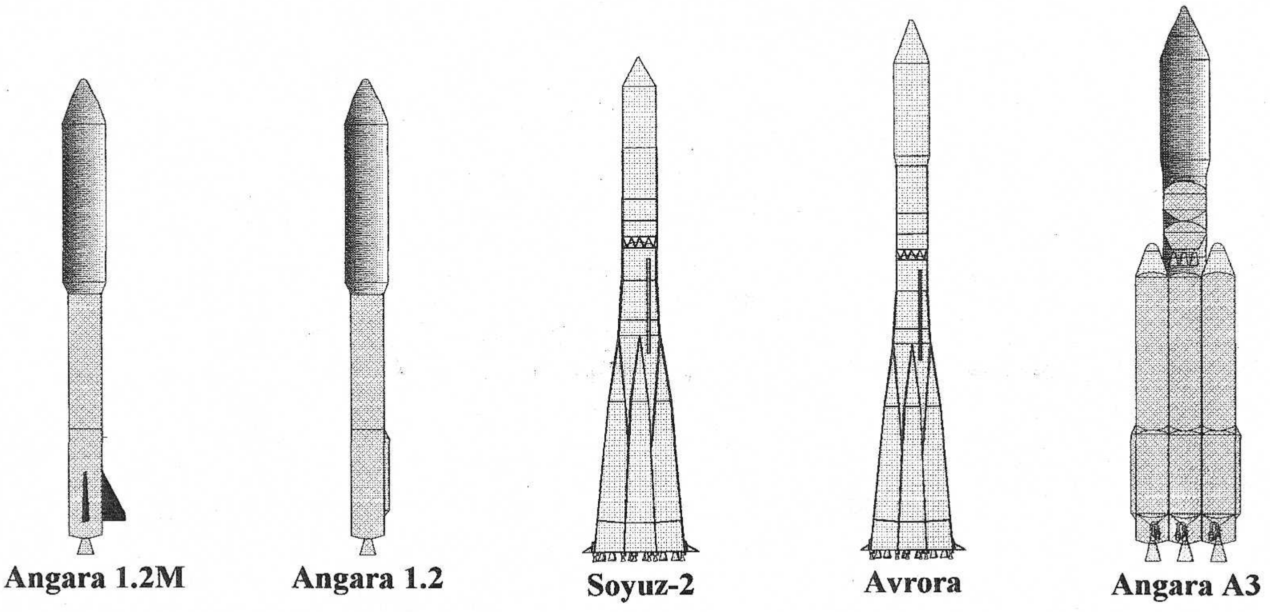


Passive deceleration system (PDS)



30kg PDS
10m diameter shell

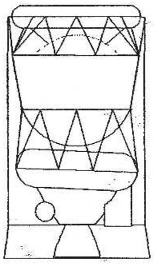
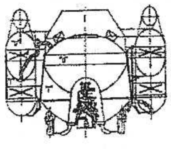
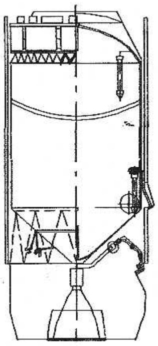
Injection orbits	Stage ballistic life without PDS	 With PDS
1. Low circular 200-550km	upto 80 days	upto 15 days
2. Elliptical 300/900km 250/2500km	upto 3 years	upto 0,6 years
3. High circular 700km, 900km	upto 20 and more years	upto 3 years



MAIN CHARACTERISTICS AND DETERMINATION OF A REQUIRED ALTITUDE OF REMOVING BOOST MODULES FROM GEO AFTER S/C SEPARATION

(the lower boundary of a burial zone is +200 km)

Table 4

Boost module general view			
Boost module	**DM(11S861-03)**	**Briz-M**	**OX/H boost module**
Space launch vehicle	**Proton-M**	**Proton-M**	**Proton-M**
Mass of boost module and S/C including adapters incorporated in SLV, kg	**25292**	**25310**	**25400**
S/C mass on GEO ("direct" injection pattern), kg	**3000**	**3000**	**4200**
Sustainer: **-propellant components** **- thrust, t/f**	**O_2+RF*-1** **8,5**	**NTO+UDMH** **2**	**O_2+H_2** **7,5**
Boost module dry mass after S/C separation, kg	**2114**	**1000(care tank)**	**3285**
Boost module dimentions after S/C separation, m: **- diameter** **- length**	**3,7** **6,3**	**2,3** **3,1**	**4** **8,2**
Boost module cross-section area after S/C separation, m2	**21**	**6,4**	**30**
Averaged reflection coefficient of boost module surface	**0,41**	**0,55**	**0,5**
Required boost module removal altitude, km	**239**	**238**	**240**

*** Rocket fuel**

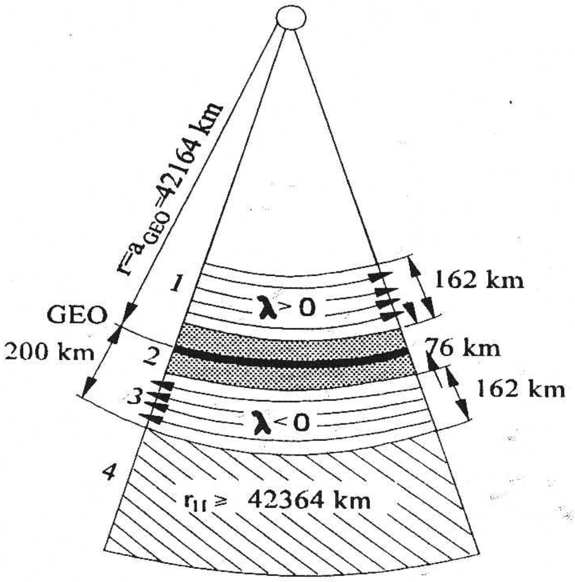


Fig.6 Active and spent GEO spacecraft disposition zones (view from the North Pole).

1. Eastward zone of maneuvering
2. S/C active functioning zone
3. Westward zone of maneuvering
4. Burial zone

The minimum altitude of removing DM-type, Briz-M and KVRB boost engines from GEO to a burial zone is 240km above the GEO altitude proceeding from the size-mass characteristics of the given boost engines and averaged coefficients of their surface radiation reflection.

Simultaneously with the new boost engine development measures to transfer to a new technology of their operation in order to mitigate space debris population are being discussed.

But firstly efforts to prevent accidental explosions of the two auxiliary engines SOZ separating from the boost engine DM have been made.

In 1996 jettisoning of the two SOZ engines of active DM blocks was prohibited while fulfilling commercial space missions and it was provided for complete depletion of their fuel in the "negative stabilization" regime or deceleration by a sustainer firing with the subsequent deorbiting and boost engine splash-down (table 5).

The SOZ engine safety problem is basically solved in the updated boost engine DM-3, where the SOZ engines change over from toxic self-igniting propellants to the primary simultaneously [3]. The ground developmental testing of these engines is planned to be over in 2001.

Regarding their subsequent evolutions these boost engines should not descend below the burial zone boundary. When a boost engine is not fitted with structural elements separating on transfer orbit (e.g. the DM boost engine which does not jettison its SOZ engine elements or the KVRB boost engine) it is possible to directly remove the boost engine from the spacecraft to a burial orbit (GEO) with the subsequent transfer of the separated vehicle to operational (GEO) orbit by its own propulsion system. In this case there is no need to increase the boost engine power reserves as compared with the option of its GEO injection, but a special operation to remove the engine is ruled out. Upon S/C separation the boost engine may be passivated right away in order to assure its long-term harmless stay in space, but in such a situation the vehicle's fuel rate of consumption will increase thus reducing its active service life in GEO, therefore selection of an injection pattern is a tradeoff and depends on the complex specific characteristics on the whole.

Also to be passivated are the Fregat and Briz-M boost engines, but the declared measures on removing them from operational orbit are just a declaration and they are to be studied and refered to the specific objectives of spacecraft orbit injection.

CONCLUSION

The preliminary evaluation of the efficiency of the measures under consideration being compared with the old launch capability operation technology shows, that these measures would reduce by more than two times the orbital SLV upper stage and boost engine concentration and would prevent practically their explosions in space alltogether.

The countermeasures of the first priority undertaken in this field by many nations to include Russia have enabled to somehow lessen the artificial space debris population growth. But this is an insignificant advance in this global problem tackling

MEASURES TO MITIGATE ARTIFICIAL SPACE DEBRIS POPULATION UNDERTAKEN DURING DM BOOST MODULES LAUNCHES (1996-2000)

Table 5

Series No	BM index	Launch date	S/C name	Final orbit	Environment protectoin measures
1.	DM3 No 1 L	09.04.96	ASTRA F-1	GTO	*
2.	DM1 No 1L	06.09.96	INMARSAT-3	GEO	*
3.	DM4 No 1L	24.05.97	TELSTAR-5	GTO	*
4.	DM2 No 1L	18.06.97	IRIDIUM	Low circular	**
5.	DM3 No 3L	28.08.97	PANAMSAT-5	GTO	*
6.	DM2 No 2L	14.09.97	IRIDIUM	Low circular	**
7.	DM3 No 2L	03.12.97	ASTRA-1G	GTO	*
8.	DM2 No 4L	07.04.98	IRIDIUM	Low circular	**
9.	DM3 No 7L	08.05.98	ECOSTAR-4	GTO	*
10.	DM3 No 9L	30.08.98	ASTRA- 1A	GTO	*
11.	DM3 No 10L	04.11.98	PANAMSAT-8	GTO	*
12.	DM3 No 4L	15.02.99	TELSTAR-6	GTO	*
13.	DM3 No 12L	21.03.99	ASIASAT-35	GTO	*
14	DM-SL No 1TL	28.3.99	DEMOSAT	GTO	*
15.	DM3 No 11L	21.05.99	TELESAT	GTO	*
16.	DM3 No 28L	18.06.99	ASTRA-1H	GTO	*
17.	DM3 No 18L	27.09.99	LM1	GTO	*
18	DM-SL No 3L	10.10.99	DIREK-TV	GTO	*
19.	DM3 No 15L	12.2.2000	GARUDA	GTO	*
20.	DM3 No 29L	1.7.2000	SIRIUS-1	Highly-elliptical	*
21.	DM-SL No 4L	29.7.2000	PANAMSAT-9	GTO	*
22.	DM3 No 22L	5.9.2000	SIRIUS-2	Highly-elliptical	*
23.	DM3 No 13L	2.10.2000	GE-2	GTO	*
24	DM-SL No 6L	21.10.2000	THURAY	GTO	*
25	DM3 No 19L	22.10.2000	GE-6	GTO	*
26	DM3 No 17L	30.11.2000	SIRIUS - 3	Highly-elliptical	*

* BM removal from its final orbit. Rejection of SOZ engine jettisoning with the simultaneous complete depletion of their fuel in the negative stabilization regime.

** BM reentry and splash-down at the expense of third firing of the BM sustainer using the remaining propellants.

GEO - geosynchronous earth orbit; GTO - geosynchronous transfer orbit.

operating rockets and space assets assuring the environmental safety are realized fully.

At the given moment Rosaviakosmos obliged the industry leading organizations to verify the adequacy of now available rockets and of those under development with the adopted standard requirements and to speed up the filfillment of concrete steps to further mitigate space debris generated during their items utilization in space.

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