SMALL SATELLITES AND SPACE DEBRIS ISSUES

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ABSTRACT

The objective of this report is the analysis of the tendencies in designing of small satellites (SS) and the effect of small satellites on space debris population. It is shown that SS to include nano- and pico-satellites should be considered as a particularly dangerous source of space debris when elaborating international standards and legal documents concerning the space debris problem, in particular "International Space Debris Mitigation Standard". These issues are in accordance with the IADC goals in its main activity areas and should be carefully considered within the IADC framework.

1. SMALL SATELLITES AND FUTURE SPACE ACTIVITY

Small satellites (SS) are developed applying the most perfect technological approaches thus assuring enhancement of the developed space systems efficiency. The ultimate goal is to design small satellites based on a separate electronic microcircuit (IC). In so doing they mean to design functionally completed spacecraft (S/C), which could be manufactured serially and launched in space by a group, comprising numerous S/C by one launch vehicle. Such spacecraft may be used to solve the navigation, communications, remote sensing as well as many other problems. Transfer to small satellites can be associated with forthcoming technical revolution in the space technology sphere by analogy with the computer technology revolution, when bulky machines were substituted by high capacity small-size personal computers. At the same time the S/C miniaturization inevitably brings about their resource capability limitation and may cause the space debris population growth.

A generally adopted classification of small satellites depending on their sizes and masses is not available currently, but they distinguish the following space object groups:

- small satellites:	500 < m < 1000 kg
- mini-satellites :	100 < m < 500 kg
- micro-satellites:	10 < m < 100 kg
- nano-satellites :	1 < m < 10 kg
- pico-satellites :	m < 1 kg

Nano- and pico-satellites are of a special interest. A distributed system of such objects may fulfill functions of one or several large-size spacecraft. Orbital pico-satellite constellations numbering up to several hundreds of objects may be used to solve the problems which can not be tackled by single large-size spacecraft. These problems include, for example, deployment of distributed antenna systems up to several kilometers in size, orbital earth magnetosphere investigation systems and others.

Satellite constellations integrating tens or hundreds of cheap spacecraft are not only inexpensive to deploy, but may become a new reliability standard. If several spacecraft of the system fail, then the remaining S/C will be able to replace them successfully.

The published data make it possible to analyze the world trends of S/C mass changes for the period of up-to 2015. The analysis results are presented in Fig.1.

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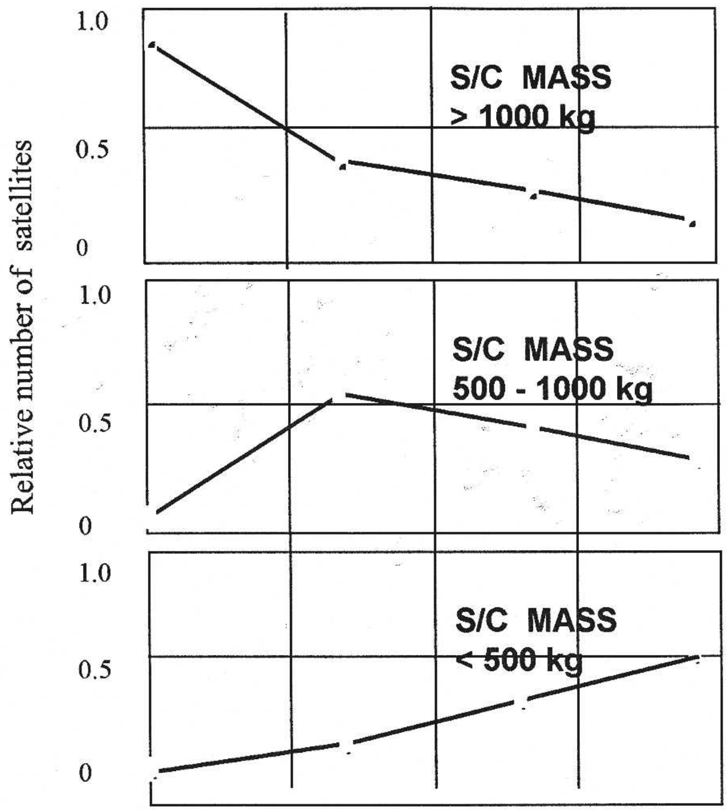

Fig.1 World tendencies of the spacecraft weight variation

In the given figure the ordinate axis depicts the relative quantity of spacecraft weighing over 1000 kg, 500 to 1000 kg and under 500 kg. It is seen, that a general trend to reduce S/C masses is observed, so by 2010 more than half of launched spacecraft will be attributed to the mini-satellite category weighing under 500 kg. The total number of S/C launched by 2010 will constitute more than 600 units (objects). For instance the Goddard Center (USA) is studying a project of designing a system of micro- and nano-satellites (of the mass of 10 kg and less) for investigating the earth magnetosphere, which would comprise up to several tens of satellites.

Some Russian projects of small satellites designing are given in table 1.

The analysis of the published projects shows, that small satellites will be used mainly in orbits having the apogee less than 2000 km. In this region the trend of accelerated development of programs to lesign satellites weighing less than several tens of kilograms draws our attention. Some of the mentioned projects have been already implemented. For example in January 1999 eleven small satellites were launched by a Minotaur vehicle (see table 2).

Table 1. RUSSIAN SMALL SATELLITE PROJECTS

Designer	Name of Satellites	Mission	Satellite mass, kg	Orbit, km	Full Constel lation	Current Num. in Orbit	Start of Deploy-ment
Reshetnev Applied Mechanics R&P Association	"GONETs-D" "GONETs-R"	Communication	230 950	1400 1400	36 48	6 -	1998 2002
Lavochkin R&P Association	"MKA-O"	Remote Sensing	480-610	LEO	3	-	-
Frunze Arsenal Design Bureau	"MKA-GEO"	Remote Sensing	330-550	LEO	12	-	-
TsSKB-Progress State R&P Rocket and Space Center	"MKA-B"	Remote Sensing	< 650	LEO	3-5	-	-
Makeyev Design Bureau State Rocket Center	"MKA"	Remote Sensing	< 350	LEO	1-3	-	-
Khrunichev State R&P State Center	"MONITOR" "GLOBSAT"	Remote Sensing Communication	350 150	400-500 LEO	4 3-6	- -	-
Polyot Production Association	"KOSKON"	Communication	860	1000		1 (exp)	2001
Korolev Rocket and Space Corporation "Energia"	"SIGNAL" "COURIER/	Communication	350 500	LEO LEO		-	2001

Table 2. SMALL SATELLITE TESTS IN JANUARY 2000

№	Name	Mission	Mass, kg	Size, cm
1	JAWSAT	Mini-Payload Adaptor Frame	101.2	68.6x68.6x76.2
2	ASUSAT	Remote Sensing	5.9	34.3x25.4
3	OPAL	Pico-Spacecraft Launcher	19.1	42x23.5
4	OCS	Optical Calibration Sphere Experiment	17.7	48.3 (container)
5	FALCONSAT-1	Charging Hazard Investigation	47.2	45.7x45.7x42.5
6, 7	DARPA PICOSATS	Micro-Electromechanical System Test Experiments (two tethered satellites)	0.25 each	2.5×7.6x10.2 each
8	JAK	Informational	0.17	2.5×7.6x10.2
9, 10	THELMA, LOUISE	Lightning Detector	0.22 each	2.5×7.6x20
11	STENSAT	Radio-Communication	0.23	2.5×7.6x10.2

Of a special interest are two tether-bound pico-satellites each weighing 0.5 kg. The tether length is about 30 m. The SS cross-sectional dimension does not exceed 10 cm, therefore to assure the radio visibility a special gold wire was interwoven in the tether to increase the satellite-reflected radar signal level. The given circumstance demonstrates the postmission effect of pico-satellite usage: spent small satellites become **invisible** space debris fragments, which may present a real threat to active spacecraft.

2. SPACE DEBRIS GROWTH DUE TO SMALL SATELLITES

Let us consider more in detail the effects of small satellites from the point of view of space debris population. At the altitudes of more than 800-2000km space objects deceleration due to residual atmosphere is absent practically. Within this region there were known space debris maximums and the artificial fragments cascade effect is predicted. In case small satellites are used in this region it would be necessary to provide for procedures of their postmission disposal into the upper atmosphere or to burial zones if the appropriate recommendations will be adopted by world community.

Within the region of orbits having perigees less than several hundreds of kilometers spacecraft deceleration by the residual atmosphere plays a substantial role. With the spacecraft size lessening the ballistic coefficient changes in accordance with the relation:

$$(A/M) \sim 1/\rho \cdot r,$$

where : $A \sim r^2$ - S/C cross-section area;
$M \sim \rho \cdot r^3$ - S/C mass;
ρ - S/C average density.

So, on condition of constant density the spacecraft deceleration will grow with its dimensions decrease. But it follows from the analysis of available published data, that with transfer to the mini-, nano- and pico-satellites the spacecraft average density grows as is shown in Fig.2.

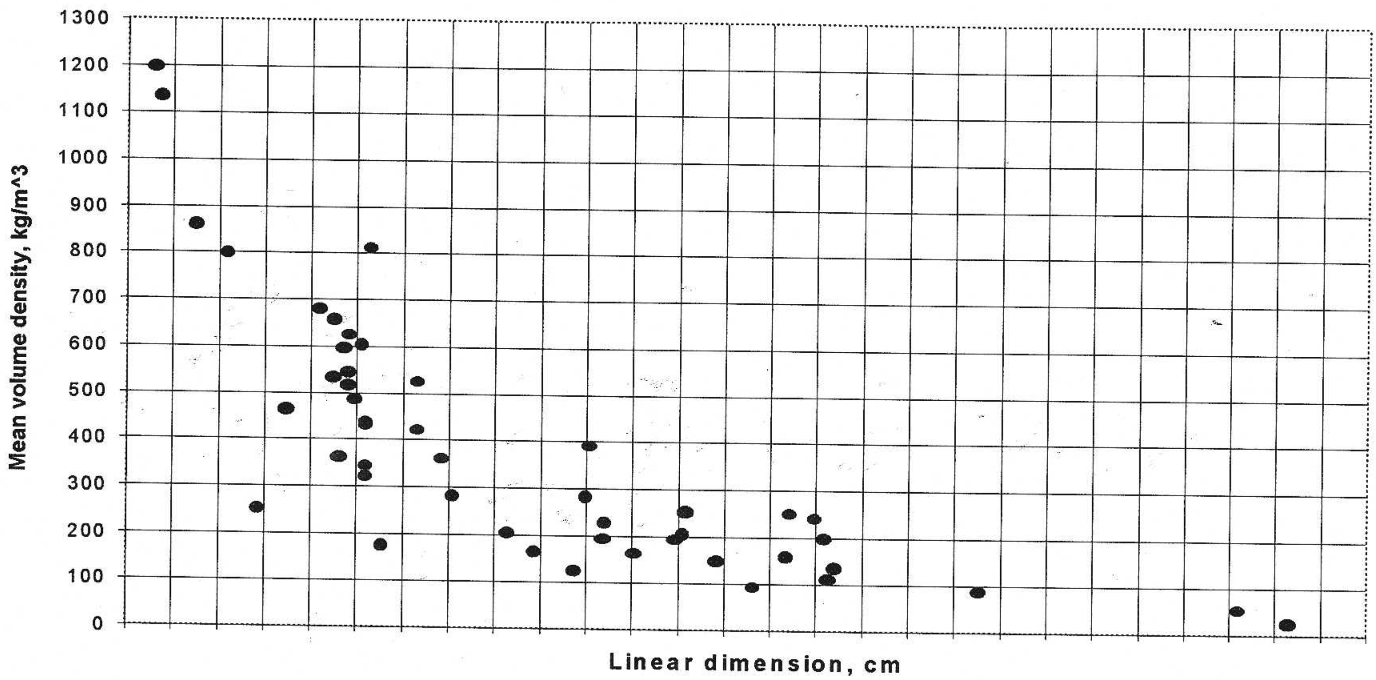

FIG.2 AVERAGED SMALL SIZE SATELLITE DENSITY

With the change of S/C dimensions from 200 to around 10 cm the S/C average density grows by an order of magnitude. The stated circumstance is not unexpected but it reflects the apparent desire of designers to enhance the economic efficiency of S/C inner volume usage. Due to the mentioned reasons the above-said statement about an accelerated small satellite deorbiting needs to be additionally specified. The following should be noted as general trends of changing the space debris population in case of extensive use of small satellites:

- a rapid growth of the space debris due to small satellite constellations deployment and necessity of their fast replenishment (the small satellite active lifetime is 2 to 3 times less as compared with the standard-make S/C);
- limited capabilities to use small satellite properties for space debris mitigation;
- highest growth of space debris generated by small satellites should be expected in orbits of the great practical value.

3. FUTURE INVESTIGATIONS

The investigations of space debris growth due to small satellite shall be carried out within the framework of the Inter-Agency Space Debris Coordination Committee (IADC). The discussion should be aimed at working out a coordinated point of view about the issues of designing, operation and utilization of small satellites including the following aspects:

In respect to small satellites tracking (IADC, Working Group 1):

-observation of nano- and pico-satellites on the background of small-size space debris fragments and their motion trajectory prediction;

-coordination of procedures of exchanging small satellite orbital data between states and organizations engaged in space-fairing activities;

-updating of methods and means of small satellites observation.

In respect to space debris modeling (IADC, Working Group 2):

-working out of more realistic space activity scenarios for the nearest future taking into account small satellites usage;

-the small satellite influence on the cascade processes evolution;

-specification of small satellite ballistic properties and small satellite deceleration processes in the LEO region.

In respect to space debris mitigation measures (IADC, Working Group 4):

- capability of using small satellites in the GEO and medium-altitude orbits region;

- recommendations to techniques of small satellites postmission disposal as to burial zones or to the upper atmosphere;

- peculiarities of controlling nano- and pico-satellites which are basically **invisible**.

So, small satellite influence on space debris is the all embracing question which should be analyzed carefully in all fields of IADC activity.

An early solution of the problem of mitigating space debris population in near-earth space would enable to further use efficiently the small satellite technology in space activity.

4. CONCLUSION

1. The SS use is a prospective space activity area, but it may lead to a considerable space debris growth.
2. The issues of SS influence on space debris population should be carefully investigated within the framework of IADC. These issues are in accordance with the IADC goals in its main activity areas.
3. Small spacecraft to include nano- and pico-satellites should be considered as a particularly dangerous source of space debris when elaborating international standards and legal documents concerning the space debris problem, in particular “International Space Debris Mitigation Standard”.