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THE STATE-OF-THE-ART IN RESEARCH OF TECHNOGENIC SPACE DEBRIS IN RUSSIA: PROPOSALS FOR INTERNATIONAL COOPERATION

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ABSTRACT

The exploration and use of Outer Space for the past two decades has been dramatically intensified. Seventeen countries have possessed the capability to launch space objects by 1990; by 1995 this figure may reach twenty ones. At present around 7,000 traceable objects with the total mass of 3,000 metric tons are orbiting the Earth. By the year 2000 the mass of or biting objects will have probably reached 4,000 tons.

A great number of existing objects and the obvious tendency of their further growth in the future lead to an expanding risk of spacecraft partial or even lethal damage in such an environment.

INTRODUCTION

In Russia, research of technogenic (i.e. man-made) space debris addresses the following issues:

1. Development of "cause-and-effect" model of debris producing events in Outer Space.

2. Refinement of space-time model of technogenic debris pieces distribution around the Earth.

3. Development of models simulating interaction between pieces of technogenic debris and spacecraft body.

4. Elaboration of proposals for monitoring technogenic debris.

5. Study of present ground test-base capabilities and feasibility to build new facilities to estimate spacecraft vulnerability to technogenic pieces; experimental development of design options increasing impact resistance.

6. Development of Design Codes and Design Rules for spacecraft capable to operate in orbital debris environment.

7. Study of feasibility to establish debris-minimization policy and Ecological Certification System applied to spacecraft and launch vehicles.

The development of "cause-and-effect" model of debris-producing events in Outer Space will allow us to decrease uncertainties in debris source assessment and estimate contribution of each source to the debris population. According to our current estimates, generation of orbital debris have the following causes:

- combustion of solid propellant (that yields alumina specks with characteristic size from 1 to 10 micrometers);
- paint and heat insulation peeling produced by oxygen atoms, solar radiation and alumina specks;
- generation of "secondary" particles by collision of debris pieces with spacecraft body;
- deliberate fragmentation caused by explosions of pyrotechnic charges and various space experiments;
- fragmentation caused by accidents;
- population growth due to upper stages left in orbit and spacecraft after end-of-life.

At present, the growth of technogenic small-size population is also evoked by "grinding effect" of collision between big and smaller fragments. Our estimates reveal that this effect does take place at 1,000-1,400 km altitudes. True, its intensity is relatively low (spacecraft will be grinned to small pieces in about 1,000 years). However, further population growth at those altitudes can substantially stimulate the "grinding" process.

Contemporary space observation systems are capable to reliably track rather big fragments with characteristic size greater than 10 cm. Technogenic pieces of smaller sizes are practically nontrackable. Known experimental results obtained from Space Shuttle, Mir, Salyut-6, Salyut-7, Solar Max, LDEF confirm that small pieces contribute to a substantial hazard to space objects.

SATELLITES FOR SPACE DEBRIS RESEARCH

Equipment for tracking small technogenic pieces should comply with stringent and, to some extent, contradictory requirements addressing the needs for global scale observation and high sensing capability. To control the population of small debris we explore the possibility to use space-borne optoelectronic equipment applied in astrometry, or small satellites with micro meteoroid sensors. For example, fig.1 depicts sizes of fragments detectable on the sun-illuminated arc with space-borne astronomic instruments versus critical acquisition range. These relationships show that astrotrackers are capable to detect fragments with size more than 1 cm at a distance shorter than 10 km, fragments over 6.5 cm are detectable with infrared telescope at distances up to 400-600 km, and telescopes of the HST-class (HST=US Hubble Space Telescope) are believed to lock on 3mm fragments at 1,000- 10,000 km range.

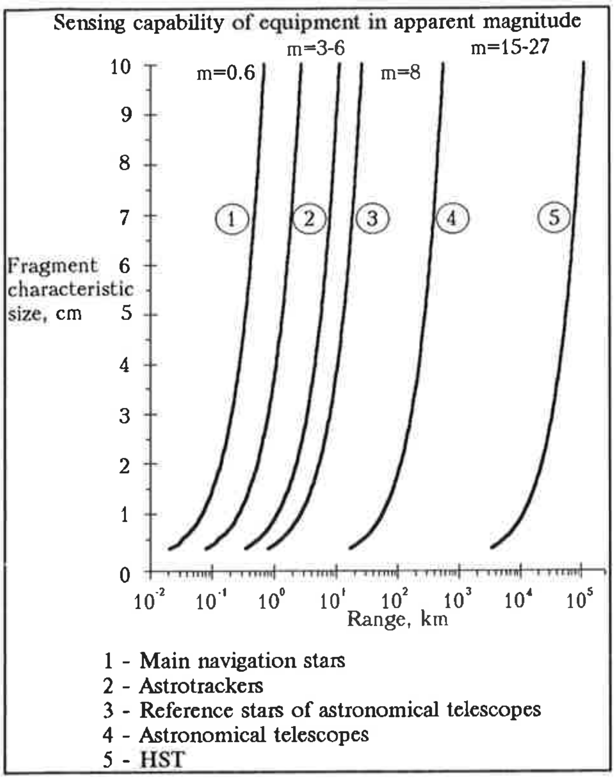

Figure 1. Critical acquisition range versus fragment size for various levels of sensing capability of equipment.

Micro meteoroid sensors on small satellites operating in a certain range of altitudes are applicable for collecting data on technogenic particles crossing their orbits. These data may be further used as input to computational models estimating distribution of a small population in a wider Outer Space domain. We develop and study models for distribution of fragments after break-up of different spacecraft.

Fig.2 shows density distribution of technogenic pieces versus altitude in case of spacecraft break-up in a 700-kilometer circular orbit. Results of this projection disclose that fragment density maximum will coincide with the altitude of the wrecked space objects within range of 100-200 km.

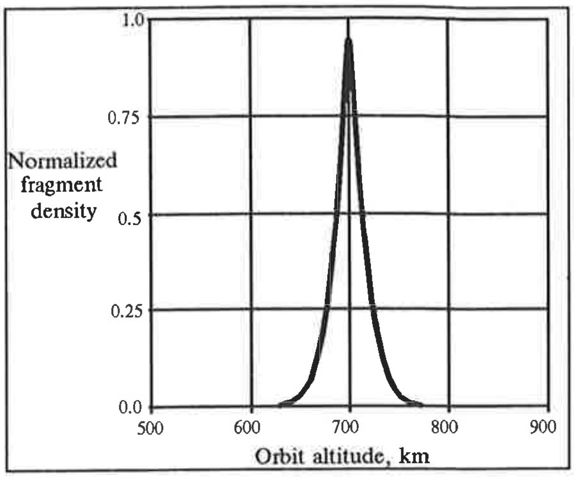

Figure 2. Normalized density of fragment distribution versus altitude in case of hypothetical spacecraft break-up in a circular 700-km orbit.

INTERNATIONAL COOPERATION

To better formulate debris-control standards to minimize orbital debris population it is thought necessary to join all the efforts of space-related and other nations on acquisition, processing and exchange of information about technogenic debris in Outer Space including date on spacecraft failures. It would be relevant to exchange this information via national coordination centers responsible for the analysis of technogenic debris problem. The international cooperation may also be plausible for establishing design rules, codes, ground-based experimental development procedures to build spacecraft capable to operate in technogenic space debris environment.

Russia has gained some experience to design debris-hardened spacecraft survivable under certain conditions of high velocity impact. For reference, Venera-13, Venera-14, VEGA deep space probes and Astron-1 satellite can be mentioned.

Fig.3 presents diagrams of each country share in space accidents and other debris-producing events that contaminate Outer Space with long-living fragments. Fig.3 data bear witness to the comparatively low Russian share in long-living fragments. Applying the ratio of long-living debris population to the number of space accidents as a figure of merit one can conclude that Russian space objects tend to the "ecologically clean" category.

For example, from 7,000 traceable and controlled objects 4,000 were created by 142 explosions and other accidents. The largest orbital break-ups were:

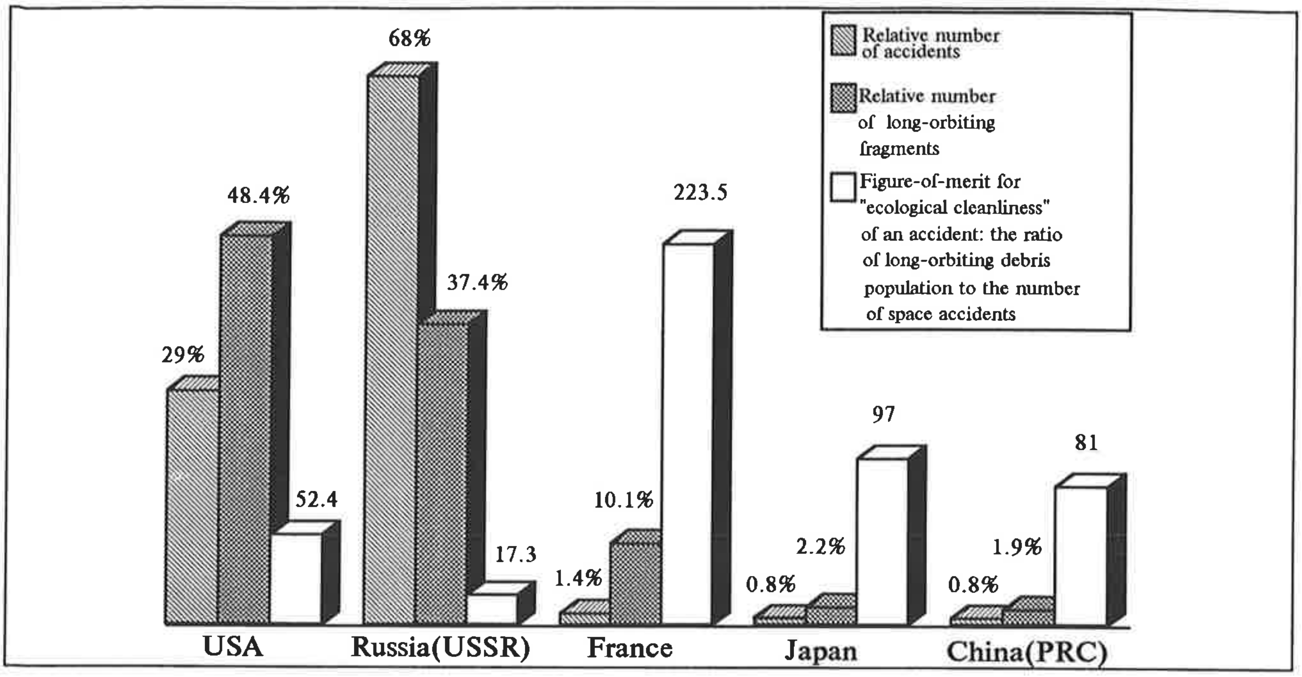

Figure 3. Share of various countries in generation of orbital debris population.

1. France	Spot 1 - Viking	475 pieces
2. USA	Nimbus-4	356 pieces
3. Russia	Kosmos 1275	299 pieces
4. Japan	GMS (Himawari)	166 pieces
5. China	Lang March	81 pieces

Of 142 break-up cases 96 ones were caused by Russia, 41 by USA, 2 by France, 1 by China and 1 by Japan. The majority of break-ups of Russian hardware did not cause large quantity of debris which re-entered from their orbits to high density atmosphere and burned up because majority of such cases had happened on low Earth orbits. After 89 break-ups of Russian spacecraft 4,006 objects were created and they were tracked and included in catalog. 2,591 objects from that quantity re-entered from their orbits within a short period of time a only 1,415 ones stayed in orbit. After 38 breakups of US fragments objects 3,238 were created 1,358 of them re-entered from orbit and 1,880 ones were in space.

Ground experimental study of debris generation mechanisms would be of great importance for establishing effective surveillance of Outer Space. Russia possesses a unique experimental test base that can be widely used, for instance, in experimental development and design of space objects in compliance with "minimum damage" criterion. This problem can be solved as reliably as it was previously done in case of natural adverse factors challenge. The approach to specify recommendations on spacecraft debris protection is depicted in Fig.4.

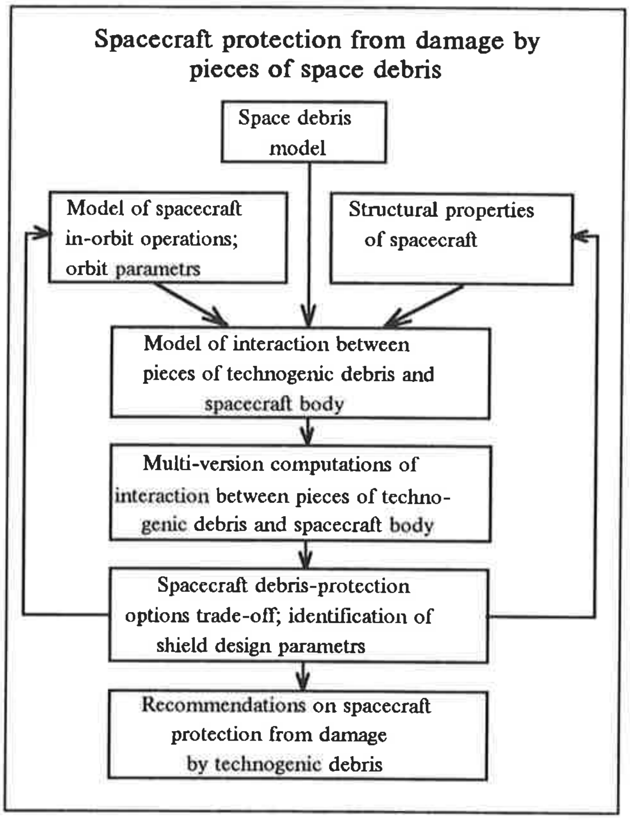

Figure 4. The approach to specify recommendations on spacecraft protection from damage by technogenic debris.

One of the most important activities to decrease the debris population refers to the development of debris-minimization polices and internationally adopted legislative restrictions to remedy this dangerous situation in Outer Space.

In order to overcome the mounting crisis all space-related nations should be recommended to purposefully improve the technology of space exploration, and, first of all, to avoid usage of explosives in space; then, to voluntarily adhere to sharing information on effectiveness of such space technologies. In particular, they possibly agree to officially publish not only design parameters of space projects and systems but also data on possible Outer Space contamination. Such a publication could be treated as a space qualification card, a quality assurance certificate that could serve as an instrument to increase the competitiveness of projects and orientate taxpayers in various countries which project to support. The decrease of small debris population could also be achieved by posing limitations on solid-propelled interorbital transfer stages (tugs) that eject a huge amount of alumina specks into Outer Space. Other mutually acceptable steps could also be discussed.

Russia has a considerable satellite constellation of about 250 operational spacecraft in orbit therefore we assume it's particularly important for us to keep track on all new knowledge about Outer Space gained by different countries and apply that knowledge to minimize negative input due to some unfortunate situations in our space exploration activities.