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SPACE DEBRIS MEASUREMENT, ANALYSIS AND STUDY A TOOL FOR GLOBAL COOPERATIONS

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ABSTRACT

Space activities and development have opened some new unprecedented frontiers for science and technology, and have created new hopes and goals for human society. At the same time like any other development in human history, there have been adverse effects on the environment. Of particular concern are the orbits around earth, which are polluted by space debris. Nonfunctional satellites, fragments due to satellite breakups, upper stages, etc. have created a kind of pollution that is highly dynamic.

More than 26000 objects have been officially cataloged in forty years of human space activities. One third of these are still in orbit. The cataloged objects are usually larger that 10cm in diameter in LEO and 1m in diameter in higher orbits. By January 1, 2000 about 8500 objects in orbit are cataloged, and approximately about 1000 objects exist which are not cataloged yet.

Measurement of debris is usually done either by radar or by optical instruments. About five countries are active in radar measurement and six countries in optical measurement. United states and Russia are also actively involved in cataloging.

In this paper after reviewing the current status of existing space debris, measurement, and cataloging activities, a suggestion is made for creating a global network for debris measurement, analysis, and study, for taking advantage of existing global possibilities and capabilities. This in turn will be useful in multinational activities involving space fairing and user nations.

INTRODUCTION

Orbital debris includes any man-made object that was launched for a definite purpose, but it does not follow any practical and useful mission, any more. Nonfunctional spacecraft fragments due to satellite breakups, upper stages, and objects released in spacecraft operations are different kinds of orbital debris. They have created a kind of pollution that is highly dynamic, and are of considerable concern in space operations. Orbital debris has originated since the first satellite, Sputnik I, was launched in 1957. Fragmentation of space objects has the largest share in space debris population, Figure (1). It is interesting to note that only 6% of space objects in the earth orbits are functional spacecrafts. Non-functional spacecrafts have a considerable share of 22%, rockets upper stages have a share of 17% of orbital debris, while they are both potential sources for fragmentation debris.

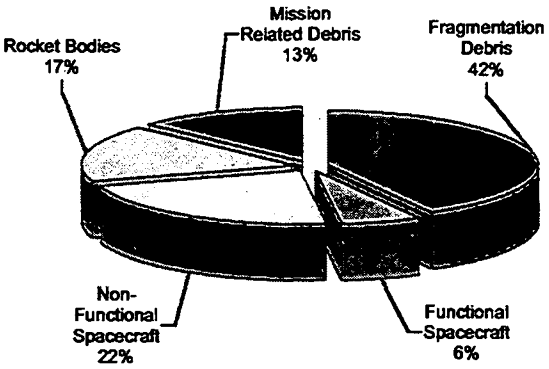

Figure 1. Space Objects in Earth Orbit Including Space Debris [1]

Due to the increased launching activities in commercial and non-commercial satellites business, over the past few years, the amount of space debris has been growing at an increasing rate. At the present, it is estimated to be about 8,600 objects with diameters of more than 10 centimeters, which are in known earth orbits. The figure depicts that 94% of man-made space objects are orbital debris.

Of particular concern are the orbits around earth, which are polluted by space debris. The orbital space around earth can be divided into three significant regions:

Low Earth Orbits (LEO)
Semi-Synchronous Orbits
Geo-synchronous Earth Orbits (GEO)

LEO region has a height between 200 and 2000 km. The risk of collision in LEO is much higher than in GEO, because of the higher relative velocities and the much smaller regional volume. In LEO the average relative velocity between any two orbiting objects is about 10 km/s. At this speed a 1 kg orbiting object has the kinetic energy equivalent to a 10-ton object at speed 360 km/hr. The 1-kg orbiting object can destroy a typical LEO satellite of mass 500-1000 kg [1].

Semi-synchronous orbits from 10,000 to 20,000km high are important for navigation. GPS satellites use these orbits.

GEO is about 36000 km high. Due to lack of atmosphere drag, the orbital lifetime is much longer in GEO than LEO; thus, a GEO satellite is likely to orbit the earth for many years.
So, special considerations are needed in these regions. Figure(2) shows the distribution of debris in different orbital distance. Note that higher density can be observed in three aforementioned regions.

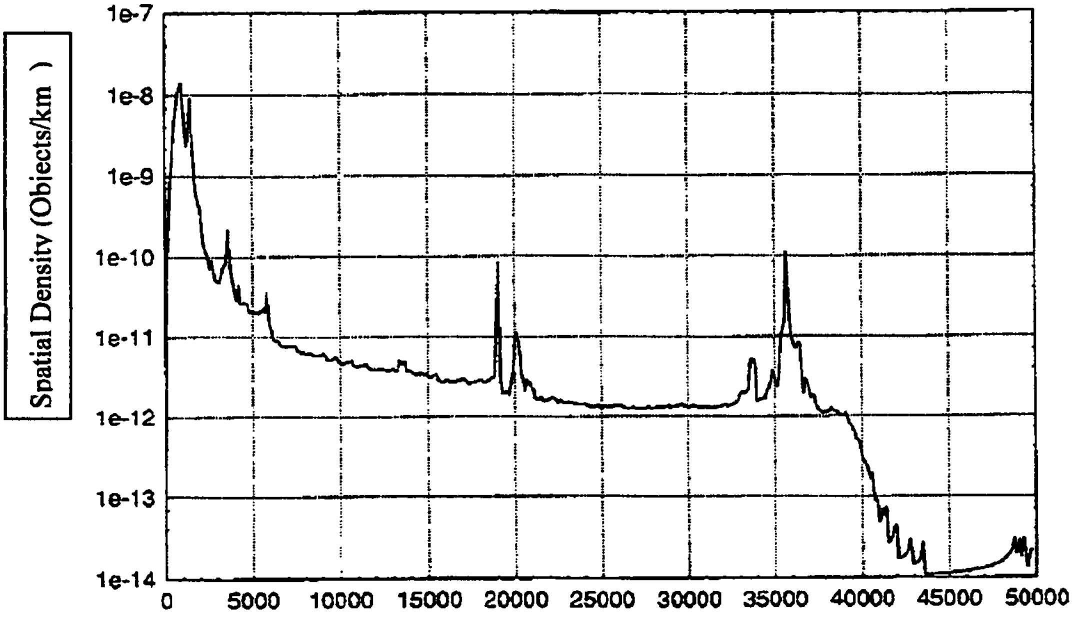

Figure 2. Spatial density of the 1994 U.S. Space Command Satellite Catalog[2].

The growth of cataloged objects in orbit at the end of each year is presented in Figure(3) with the break down of object type.

The figure shows monthly number of objects in earth orbit by object type.

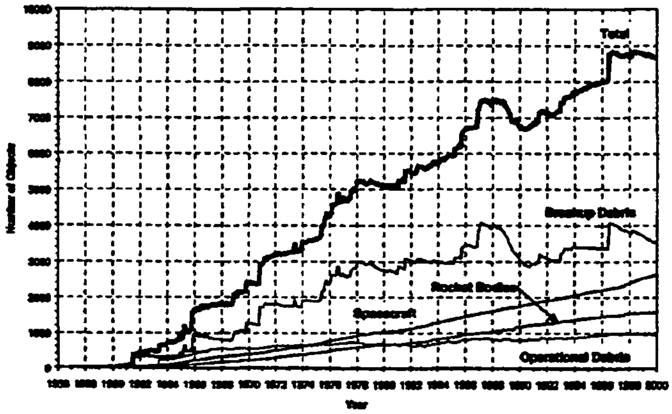

Figure 3. Growth of cataloged debris population[3]

ORBITAL DEBRIS MEASUREMENTS

Orbital debris can be detected by both ground-based and space-based measurements. The main advantage of space-based sensors is that they can be much closer to orbital debris than ground based sensors. It provides data on debris that are very difficult to detect from Earth. On the other hand, it is much more expensive to detect space debris from space. Generally orbital debris measurements fall into three categories:

- Radar measurements
- Optical measurements
- Research on retrieved surfaces

The capabilities of sensors are function of altitude. Figure (4) shows the US Space Command sensor altitude limitation. It can be observed that the operation system capability to detect objects depends strongly on the altitude.

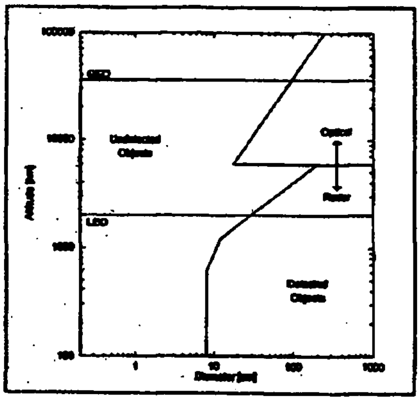

Figure 4. US Space Command sensor altitude limitation on debris measurement [4]

RADAR MEASUREMENTS

Radars generally have been used for space debris measurement in LEO. There are about five countries that have radar capabilities for observation of debris with sizes smaller than 10-30 cm in diameter beneath 1000km, they are Germany, Japan, Ukraine, Russian Federation and United States. Typically, radar measurements have been used for space debris in low Earth orbit (LEO), while optical measurements have been used for high Earth orbit (HEO). Ground-based radars are well suited to observe space objects because of their all-weather and day-and-night performance. The radar power budget and operating wavelength are limiting factors for detection of small objects at long ranges.

From radar measurements principally, the following space object characteristics can be derived; note that all of the following parameters will have some degree of uncertainty[]:

(a) Orbital elements, describing the motion of the object's center of mass around Earth;

(b) Attitude, describing the motion of the object around its center of mass;

(c) Size and shape of the object;

(d) Orbital lifetime;

(e) Ballistic coefficient, specifying the rate at which the orbital semi-major axis decays;

(f) Object mass;

(g) Material properties.

The existing and planned radar capabilities for observation of debris for sizes smaller than 10-30cm in diameter are given in Table(1).

Table(1) Radar facilities for debris observation [5]

Country	Organization	Facility	Type	Primary operation mode	Configuration	Field of View	Wave-length (m)	Sensitivity diameter (m)	Status
Germany	FGAN	TIRA	Dish	Mixed	Monostatic	0.5	0.23	0.02 at 1,000 km	Operational
Germany	MPIfR	Effelsberg	Dish	Stare	Bistatic with TIRA	0.16	0.23	0.009 at 1,000 km	Experimental
Japan	Kyoto University	MU Radar	Phased Array	Stare	Monostatic	3.7	6.4	0.02 at 500 km	Operational
Japan	ISAS	Uchinoura	Dish	Mixed	Bistatic	0.4	0.13	0.02 at 500 km	Experimental
Japan	ISAS	Usuda	Dish	Mixed	Bistatic	0.13	0.13	0.02 at 500 km	Experimental
Ukraine/Russian Federation	—	Evpatoria	Dish	Stare	Bistatic	0.1	0.056	0.003 at 1,000 km	Development
United States	NASA/NSF	Arecibo	Dish	Stare	Bistatic	0	0.13	0.004 at 575 km	One-time experiment
United States	NASA/DOD	Haystack	Dish	Stare	Monostatic	0.1	0.03	0.006 at 1,000 km	Operational
United States	NASA/DOD	HAX	Dish	Stare	Monostatic	0.1	0.2	0.05 at 1,000 km	Operational
United States	NASA	Goldstone	Dish	Stare	Bistatic	0	0.035	0.02 at 500 km	Operational
United States	DoD	TRADEX	Dish	Mixed	Monostatic	0.61/0.30	0.23/0.10	0.03 at 500 km	Operational

NASA's main source of data for debris in the size range of 1-30cm is the Haystack radar[6]. The Haystack radar, operated by MIT Lincoln Laboratory, has been collecting orbital-debris data for NASA since 1990 under an agreement with the U.S. Air Force. Haystack statistically samples the debris population by "staring" at selected pointing angles and detecting debris, which flies through its field of view. The data are used to characterize the debris population by size, altitude, and inclination. From these measurements, scientists have concluded that there are over 100,000 debris fragments in orbit with sizes down to 1cm.

Japan has decided to strengthen the monitoring setup necessary to forecast potential collisions[7]. According to a plan by the Science and Technology Agency, a dome-shaped radar facility and a large optical telescope with an aperture of 1 meter and a range three times that of an ordinary telescope will be constructed in Okayama Prefecture, which is considered the best site in Japan for monitoring space at a total cost of 2 billion yen. This radar facility, that is scheduled to go into operation in 2004, will be able to track objects 1 meter in diameter at an altitude of about 600 kilometers.

OPTICAL MEASUREMENTS

Debris can be also detected by optical measurements. Optical measurements have been used for higher orbits. A telescope can detect debris when the object is sunlit, while the sky, background is dark. There are about six countries that have optical capabilities for optical observation of debris namely France, Japan, Russian Federation, Switzerland, United Kingdom and Northern Island and United States.

Debris larger than 1m in diameter can be detected in GEO by ground based telescopes. The existing and planned optical capabilities for optical observation of debris are summarized in Table(2).

Table (2) Optical facilities for debris observation [8]

Country	Organization	Telescope Aperture (m)	Field of View (deg)	Detection Type	Limiting Magnitude	Status
France	ESA	1	1	CCD	19	In development
France	French National Centre for Scientific Research	0.9	0.5	CCD	19	In development
Japan	JSF[a]/NAL[b]/NASDA	1.0	3.0	CCD	19.5	In development
Japan	JSF[a]/NAL[b]/NASDA	0.5	2.0	CCD	18.5	In development
Japan	Sundai	0.75	0.04	CCD	17	Operational
Japan	CRL	1.5	0.28	CCD	18.7	Operational
Russian Federation	RAS[c]	1	0.2	CCD	19	Operational
Russian Federation	RAS[c]	0.6	0.2	CCD	18	Operational
Russian Federation	RSA[d]	0.6	0.2	TV	19	Operational
Switzerland	University of Berne	1	0.5	CCD	19.5	Operational
United Kingdom of Great Britain and Northern Ireland	Royal Greenwich Observatory/MOD	0.4	0.6	CCD	18	Two telescopes operational, United Kingdom and overseas
United States	NASA	0.3	1.5	CCD	17.1	Operational
United States	NASA	3	0.3	CCD	21.5	Operational

[a] Japan Space Forum.
[b] National Aerospace Laboratory of Japan.
[c] Russian Academy of Sciences.
[d] Russian Space Agency.

NASA is using two optical telescopes for measuring orbital debris: A 3 m diameter liquid mirror telescope, which is referred to as the LMT; and a charged coupled device equipped with 0.3m Schmidt camera, which is commonly referred to as the CCD Debris Telescope or CDT[9].

The LMT consists of a 3 m diameter parabolic dish that holds four gallons of liquid mercury. The dish is spun up to a rate of 10 revolutions per minute. Centrifugal force and gravity cause the mercury to spread out in a thin layer over the dish creating a reflective parabolic surface that is as good as many polished glass mirrors.

RESEARCH ON RETRIEVED SURFACES

Remote sampling of debris from orbit provides data on debris that are very difficult to detect from Earth. Space based sensors contain both radar and optical measurements. The main advantage of space-based sensors is that they can be much closer to orbital debris than ground based sensors.

Debris measurements can be also followed by research on retrieved surfaces and impact detectors. The Long-Duration Exposure Facility (LDEF) is an example covered by more than 30,000 craters visible to the naked eye; 5000 of which had a diameter larger than 0.5 mm. The largest crater, 5mm in diameter, was probably caused by particle of 1mm[].

Table 3. Examples of retrieved spacecraft and surfaces [10]

Name	Orbit	Duration In Orbit	Stabilization	Exposed Area
Salyut 4 and 6	350 km 51.6 degrees	1974-1979	Various	~7 m^2 of sensors and cassettes
STS-7 Window NASA	295-320 km 28.5 degrees	June 1983	Various	~2.5 m^2
Solar Maximum Solar Maximum	500-570 km 28.5 degrees	February 1980-April 1984	Sun-pointing	2.3 m^2
STS-52 (Canada/NASA)	350 km 28.4 degrees	October 1992	Various	1 m^2
LDEF (NASA)	340-470 km 28.5 degrees	April 1984-January 1990	Gravity-gradient	151 m^2
EURECA (ESA)	520 km 28.5 degrees	July 1992-June 1993	Sun-pointing	35 m^2 of spacecraft plus 96 m^2 of solar arrays
HST Solar Array (NASA/ESA)	610 km 28.5 degrees	May 1990-December 1993	Sun-pointing	62 m^2
Mir/EUROMIR 95 (RSA/ESA)	390 km 51.6 degrees	October 1995-February 1996	Gravity-gradient	20 x 30 cm (cassette)
Mir	390 km 51.6 degrees	1986-1998	Various	~15 m^2 of cassettes and other elements
Mir (Canada/Ukraine)	390 km 51.6 degrees	November 1997-February 1999	Various	1 m^2
SFU (Japan)	480 km 28.5 degrees	March 1995-January 1996	Sun-pointing (except 1 month IR telescope operation)	50 m^2
Space Shuttle Orbiter (NASA)	300-600 km 28.5-51.6 degrees	1992-present	Various	100 m^2

GLOBAL COOPERATION BY MEAN OF DEBRIS STUDIES

Even though space activities are mainly developed in few countries, but almost all nations are using the space technologies and products. In this regards all users are in some degrees involved in generation of debris. In another view debris, in its own right creates danger and cost that is reflected on consumer price directly or indirectly. Thus, we can expect research centers and academia to have interest in debris related research all over the world.

From the forgoing discussion on debris measurements, it is observed that even though the space based study of debris might give better measurements, but still the main activity is performed on earth. For selecting a proper site some general parameters can be considered:

1. Geographical Latitude
2. Clear and dark sky
3. Low smog and dust
4. Water vapor density
5. Aerosols Density

The current sites are mainly located in northern America and Western Europe and Russia, however, many location in other countries are suitable for establishment of observation facilities, while, the educated manpower is also available in some of these countries to take part in debris measurement and study.

Here, taking into consideration the reasoning presented here, we propose a new international cooperation scheme in development and decimations of space science and technology

- Setting up observation centers in suitable sites other than traditional places like Europe.

The cost of establishing of the site is bored mainly by the Space Fairing Nations (SFN)

- The operating cost of the center is bored by the host country (HC).
- The manpower is provided by both countries as necessary, with emphasis on

providing mainly consultation and technical leader ship from SFC.

- The measurement and analyzed information is released to interested parties, with priority given to participating countries.

There are advantages to this cooperation:

- Those who use space technology will provide budget for space research.
- Knowledge of space science and technology is decimated in practical and efficient manner.
- Involving all space technology users in space research, knowing that they are directly or indirectly benefited from it.
- Measurements that are more versatile are provided.
- Manpower is used where it exits and is not involved in space research at this time.

This cooperation paves the way to open the door for space research in many countries that are interested and have interested educated personnel. These countries also provide some financial resources that is otherwise not available to space research communities.

REFERENCES

[1] Position Paper on Orbital Debris, updated 2000, International Academy of Astronautics, 2000, p3

[2] Ibid, p7

[3] Orbital Debris: A Technical Assessment. Committee on Space Debris Aeronautics and space Engineering Board Committee Commission on Engineering and Technical Systems National Research Council, USA, 1995, P66.

[4] Position Paper on Orbital Debris, Updated 2000, International Academy of Astronautics, 2000, pp11.

[5] Ibid, p29.

[6] Technical Report on Space Debris, Text of the report adopted by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, USA, 1999, p6.

[7] Radar Measurements, available: "http://www.orbitaldebris.jsc.nasa.gov/measure/radar.html"

[8] COSMIC LITTER: Japan Moves to Counter Space Debris, available:

"http://jin.jcic.or.jp/trends98/honbun/ntj980630.html"

[9] Technical Report on Space Debris, Text of the report adopted by the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, USA, 1999, p8.

[10] Optical Measurements, available: "http://sn-callisto.jsc.nasa.gov/"

[11] Ibid, p9.