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How Can Small Satellites be used to Support Orbital Debris Removal Goals Instead of Increasing the Problem?

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ABSTRACT

Orbital debris is a serious concern for the NASA, DARPA, Air Force organizations and the commercial space industry. Since 2005, the space debris environment has been unstable and began a collision cascade effect per NASA. A recent International Orbital Debris Conference focused on the need to find solutions for Orbital Debris Removal and manage any space debris increase potential. The purpose of this paper is to explore what orbital debris issues can be address by Small Satellites. The paper will discuss a technology supported by Small Satellites to resolve the Orbital Debris problem. It will concentrate on mitigation of debris sizes from 1cm to 10cm, which are unable to be tracked by current ground systems capabilities but can cause serious damage or destroy spacecraft. Requirements will be for the LEO orbit, where there are known significant numbers of debris of this size. A Method will be proposed, by which a small spacecraft can be used to sweep volumes of specific orbits to remove or collect debris.

ORBITAL DEBRIS

Orbital debris is any obsolete man-made object in Earth orbit. These objects include spacecraft, upper stages of launch vehicles, debris released during spacecraft separation from its launch vehicle or during mission operations, debris created as a result of spacecraft or upper stage explosions or collisions, solid rocket motor effluents, paint flecks and thermal blankets. It is estimated that there are 19,000 objects larger than 10 cm and that there are 500,000 objects between 1 and 10 cm in diameter.[2] The number of particles smaller than 1 cm probably exceeds tens of millions.[2] The most concentrated area for orbital debris is Low Earth Orbit (LEO). These are orbits with altitudes less than 2000 km. Large orbital debris (> 10 cm) objects are tracked routinely by the U.S. Space Surveillance Network.[2] Objects as small as 3 mm can be detected by ground-based radars, providing a basis for a statistical estimate of their numbers.[2] Assessments of the population of orbital debris smaller than 1 mm can be made by examining impact features on the surfaces of returned spacecraft, although this has been limited to spacecraft operating in altitudes below 600 km.[2] Figure 1 shows objects in low earth orbit (LEO) that are being tracked. 95% of these objects are orbital debris.[2] Even though the objects are not actual size, the image provides a clear message regarding the serious issue of orbit debris in LEO.

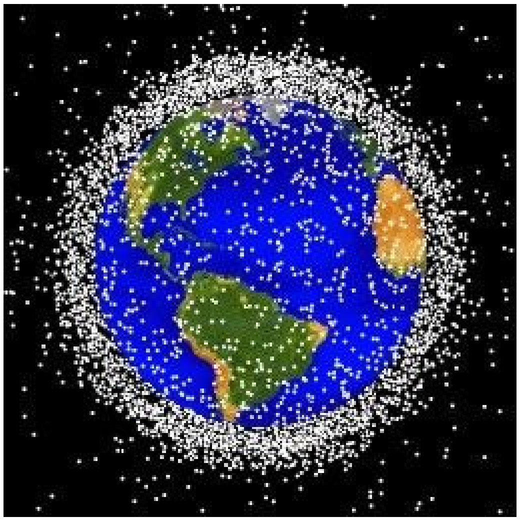


Figure 1: Debris in Low Earth Orbit (NASA Image[2])

PROBLEM DEFINITION

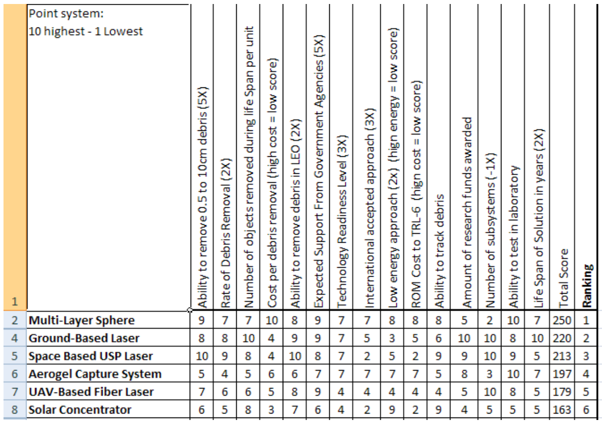
The average impact speed of orbital debris with another space object is 10 km/sec.[2] At this speed, 1 cm diameter objects and larger will cause loss of functionality of a satellite due to impact.[2] Many objects less than 1 cm can still cause significant damage to spacecraft.[2] Objects greater than 10 cm are tracked by the United States Space Surveillance Network.[2] Spacecraft can maneuver around these objects because their orbits are well known. Objects less than 10 cm are too difficult to observe with ground based telescopes and radars and therefore cannot be tracked, preventing spacecraft from maneuvering around them.[2]

ATK TRADE STUDIES

ATK performed a trade study of six different system concepts to minimize or mitigate the orbital debris problem. Four of these investigated methods of heating the debris particles surface to induce ablation resulting in a thrust force that will de-orbit the particles. Heating was accomplished by either lasers (ground based, air based and space based) or a solar concentrator. The fifth system involved using an inflated multi-layer sphere to capture and break up the debris. The sixth system used a large piece of aerogel to capture the debris.

All the trade study concepts were rated and then ranked based on key evaluation figure of merit criteria. Scores were assigned to each using a point system with 10 being best and 1 worst. Each trade study Lead provided initial scores based on figure of merit scores for each design category. Then each concept was evaluated and compared to each other and ranked. Table 1 shows the result.

Table 1: ATK Trade Study Results



1	Point system: 10 highest - 1 Lowest	Ability to remove 0.5 to 10cm debris (5X)	Rate of Debris Removal (2X)	Number of objects removed during life Span per unit	Cost per debris removal (high cost = low score)	Ability to remove debris in LEO (2X)	Expected Support From Government Agencies (5X)	Technology Readiness Level (3X)	International accepted approach (3X)	Low energy approach (2x) (hign energy = low score)	ROM Cost to TRL-6 (hign cost = low score)	Ability to track debris	Amount of research funds awarded	Number of subsystems (-1X)	Ability to test in laboratory	Life Span of Solution in years (2X)	Total Score	**Ranking**
2	**Multi-Layer Sphere**	9	7	7	10	8	9	7	7	8	8	8	5	2	10	7	250	1
4	**Ground-Based Laser**	8	8	10	4	9	9	7	5	3	5	6	10	10	8	10	220	2
5	**Space Based USP Laser**	10	9	8	4	10	8	7	2	5	2	9	9	10	9	5	213	3
6	**Aerogel Capture System**	5	4	5	6	6	7	7	7	7	7	5	8	3	10	7	197	4
7	**UAV-Based Fiber Laser**	7	6	6	5	8	9	4	4	4	4	4	5	10	8	5	179	5
8	**Solar Concentrator**	6	5	8	3	7	6	4	2	9	2	9	4	5	5	5	163	6

One of these concept systems investigated has mass and estimated power requirements such that a small satellite can be used to deploy and implement it in low earth orbit. Coincidentally, it is also the highest ranking system, the multi-layer sphere approach.

SMALL SATELLITE CAPABILITY

A small satellite can fit into the fairing of any launch vehicle today and is assumed to have a maximum total mass of 500 kg and be able to deliver up to 3 kW of power. Following is a more detailed description of the Multi-Layer Sphere approach to minimize hazardous space debris in low earth orbit.

Multi-Layer Sphere (MLS) Concept

A lightweight, multi-layer material in the shape of a sphere, deployed in space (see figure 2) can break-up large debris particles creating particles to break up other particles causing effective "Mass Fission" debris depletion. The purpose of the MLS is to convert high velocity 1 to 10 cm debris particles into multiple lower velocity shield-able (< 1cm) debris particles. Figures 3 and 4 depict the net structure in its stowed and deployed configurations. Note that Figure 4 shows only half of the sphere deployed for clarity.

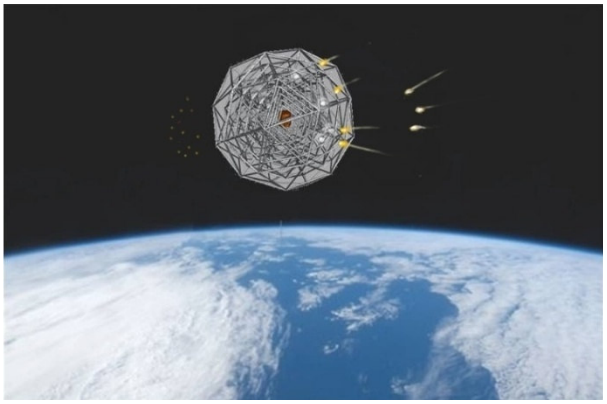


Figure 2: MLS in Action

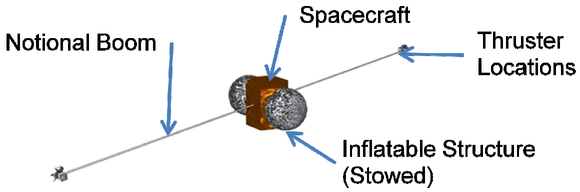


Figure 3: MLS Stowed

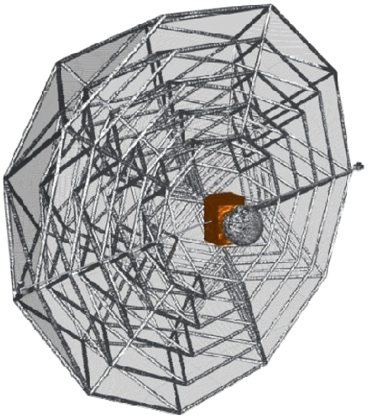


Figure 4: One-Half of MLS Deployed

The MLS is constructed of spaced discrete material. The particles are broken up upon impact on the outer layer. The particles are then further broken up when impacting subsequent material layers and upon impacting other particles causing a "mass fission" effect. The surviving particles are expected to be small enough such that the spacecraft can be effectively shielded to protect against damage. Figures 5 and 6 show the breakup of the particles based on test data and a simulation. Destruction of debris has been demonstrated using a 1 cm spherical aluminum mesh and a 6 km/sec particle impact speed. Data on debris larger than 2 cm and impact speeds greater than 8 km/sec are not available. The "mass fission" mechanism has not yet been demonstrated by test.

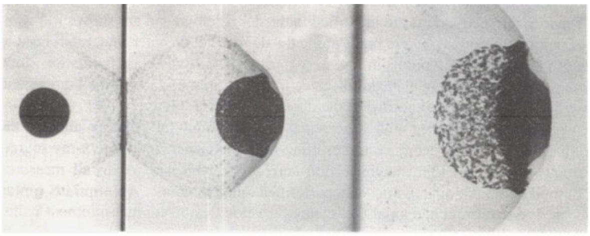


Figure 5: 6 km/sec, 1 cm particle impact test[1]

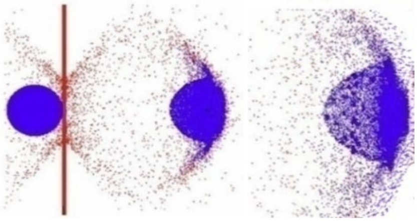


Figure 6: 6 km/sec, 1 cm particle during hydro code simulation[1]

Spacecraft Maneuverability and Mission Life

The spacecraft should be maneuverable enough to sweep out a Low Earth Orbit torus volume at a specific orbit as illustrated in figure 7.

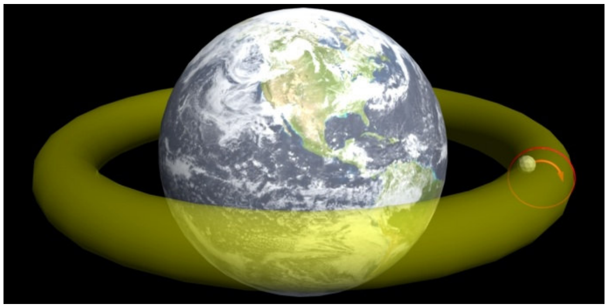


Figure 7: Low Earth Orbit Torus

The mass of the material, in kilograms, of the MLS is one-half the square of the radius in meters. Therefore, the mass of a 20 meter diameter net would be 200 kg, 40% of the mass of a small satellite.

The mission life is expected to be 1 to 5 years and will depend on the time it will take to sweep the maximum available debris particle field, the MLS spherical diameter and available fuel. The maximum number of allowable impacts on the sphere is estimated to be 50,000 to 100,000. Therefore, 5 spacecraft will be required to eliminate 500,000 medium sized debris particles.

Recommendations for Further Study

The MLS needs further conceptual development, design and testing as follows.

- Develop MLS study task list and schedule
- Feasibility study – evaluate new and emerging technologies
- Assessment of key subsystems for MLS spacecraft
- Perform theoretical fission effect calculations
- Sweep analysis – theoretical orbit on interest and calculate spatial and size distribution
- Material system evaluation and analysis – complete hydro code calculations
- Develop MLS cost estimate for flight MLS demonstrator
- Develop truss deployment scheme
- Impact testing for development of material/frame using the feasibility study, systems evaluations and assessments results
- Final MLS technology report to contain the final results and identify next steps in MLS development
- Demonstrate “Mass Fission” mechanism
- Fully develop the nested layer forming concept
- Station keeping/variable orbit concept
- Obtain data on particles > 2 cm
- Obtain data on impacts > 8 km/sec
- Obtain funds to develop a working prototype that can be used as a space demonstrator

CONCLUSION

To answer the question about how small satellites can be used to support orbital debris removal goals, it was shown here that a small satellite is capable of supporting the Multi-Layer Sphere, a potential means of breaking up medium sized (1 cm to 10 cm) debris in low earth orbit such that the remaining particles are too small to be considered a hazard to shielded spacecraft.

References

1. S.R. Beissel, C.A. Gerlach, G.R. Johnson, “Hypervelocity impact computations with finite elements and meshfree particles,” International Journal of Impact Engineering 33 (2006) 80-90.
2. http://orbitaldebris.jsc.nasa.gov/index.html