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A Market for Cleaning Up Space Junk?

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Abstract

The problem of orbital debris is now understood to a clear and present danger to the space community and the global telecommunications infrastructure. A welter of research into the issue and scores of proposals to clean up the orbital environment have been conducted, but any such missions face difficult issues. This article examines the nature of the problem with orbital debris, examines the technical, legal and funding issues facing attempts to clean up the orbital environment, before discussing possible avenues to resolving present difficulties.

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Introduction: Two Near Misses

In March 2012astronauts aboard the International Space Station (ISS) were suddenly forced to take shelter in lifeboats to avoid an approaching remnant of the defunct Russian Cosmos 2251 communications satellite. This was the *third* such incident in three months; in January, the ISS was forced to maneuver away from part of a cloud of remnants of a blown-up Fengyun 1C weather satellite, and before that, to avoid yet another roaming part of Cosmos 2251.[2]These and other incidents have precipitated public handwringing by major space nations, major conferences, and urgent calls to do something about what is becoming the dangerous proliferation of space debris, now amounting to hundreds of thousands of objects circling the earth. Yet earlier this year MDA, amajor space robotics and satellite company was forced, despite a very detailed business plan, to call off a contract with Intelsat, the world's biggest satellite service provider,in satellite servicing plan that would have seen key technologies developed and deployed to clear up the orbital environment.It was another near miss of a different kind; that of a golden opportunity to have kick-started a market for cleaning up space.

These two "near misses" have reminded the international community of the dangers of the presence of orbital debris, while showing the difficulties in resolving this issue, which is also an emerging global governance problem that, if unresolved in the coming decades, could become a major economic and strategic issue not only for major space powers such as the U.S. and Russia, but also for the global telecommunications industry.The question therefore is, when there seems to be a clear, urgent need to solve orbital debris problems, and significant interest in resolving the issue from both the private and state sectors, what is being done to address the problem? This paper looks at the issue of orbital debris from a series of angles; quantifying the nature of the issue, examining the concomitant legal, governance, business and technical issues of orbital debris removal, then moves to an analysis of the main proposals to help clear up the orbital environment, before reaching a conclusion and offering potential steps forward to the realization of a commercial market.

Space is Crowded, Congested, Contested

Five decades following Sputnik-1, orbit is cluttered, congested & competitive.[3]The first known break-up of an artificial satellite occurred in June 1961, when America's Transit 4-A exploded, producing 294 trackable pieces of debris. Decades later, there are now approximately 700,000 items circling the earth, of which only about 21,000 larger than 10 cm in diameter are tracked. Presently, thespace environment up to the Geostationary Earth Orbit (GEO) that runs 36,000 km around the earth now contains about 6,000 tons of materials alone.Low Earth Orbit (LEO- 200 to 2,000 km) is congested with 14,000 objects (including 2,600 dead satellites) larger than 5-10 cm in diameter. About 43% of these objects are attributed to the Peoples Republic of China (PRC), 27.5% to the U.S. and 25.5% to

[2] Malik T., "Space Junk Forces ISS Astronauts to Take Shelter in 'Lifeboat' Capsules," *Space.com*, 24 Mar 2012; http://www.huffingtonpost.com/2012/03/24/space-junk-iss-astronauts_n_1376963.html; Malik, T., "ISS Dodges Space Debris From Chinese Satellite," *Space.com*, 29 Jan. 2012 http://www.huffingtonpost.com/2012/01/30/iss-dodges-debris-from-de_n_1241167.html

[3] Schulte, G.L., Deputy Assistant Secretary of Defense for Space Policy for the U.S. Department of Defense, speech, 27th National Space Symposium in Colorado Springs, http://www.spacefoundation.org/media/space-watch/schulte-space-congested-contested-competitive, accessed 26 Apr 2012.

Russia.[4] In terms of all orbits, Russia accounts for 6,087 objects/37.8%, the U.S., 4850 /30.1% and the PRC 3,615/ 22.4%; in terms of mass, Russia is responsible for 53%, and the U.S. 19% overall.[5]

How dangerous are these objects? “Shrapnel,”i.e. untracked 1 cm or bigger particles that comprise 98% of objects in orbit are *all* potentially lethal; a 1 cm object moving at 7.78 km/second has the kinetic energy to debilitate or destroy a $500 million satellite. Other objects include an astronaut’s glove, cameras, a wrench, pliers, a tool bag, and a toothbrush.

When large objects collide, they produce huge quantities of smaller debris. There are now 30-50 untracked fragments for each one tracked.[6]If that sounds bad, the orbital situation became measurably and catastrophically worse following two major disasters for the orbital environment. The first was deliberate; in January2007 the PRC mounted anti-satellite missile test on the Fengyun-1C weather satellite, launching a ballistic missile at the satellite that obliterated it, causinga spreading debris “cloud” of 3,000 trackable and 150,000 particles larger than 1 cm,many of which will remain a danger for over 100 years. This single event increased the number orbital debris particles in LEO by 15%.[7]Then in 2009, a collision between the Iridium 33 satellite and the 16-year-old Russian Cosmos 2252 satelliteproduced 1.5 tons and 2,000 tracked/100,000 untracked debris objects. Combined, the two incidents increased debris in LEO by 60%. A next catastrophic collision is likely to yield as many fragments as the Iridium-Cosmos collision and the Fengyun 1C breakup combined.[8]

This is not a static situation. Each year 30-40 launches inject 60-70 new objects into orbit. In a 182-page landmark report in 2010, the National Research Council reported that the orbital environment has already reached “tipping point,” the threshold of the so-called “Kessler Syndrome” where there is now enough debris and junk for it to start a cascade of collisionsthat will make LEO unusable in decades from now.[9]In LEO, trackable objects are

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[4]Ansdell M., “Active Space Debris Removal: Needs, Implications and Recommendations for Today’s Geopolitical Environment,” 2 Jun 2010, Princeton University, http://www.princeton.edu/jpia/past-issues-1/2010/Space- Debris-Removal.pdf.accessed 5 Apr 2012.

[5]For objects: As of 1/4/12, cataloged by the U.S. Space Surveillance Network; Data from *Orbital Debris Quarterly News*, 1/12 issue. For mass: as of 1/12, cataloged by the US Space Surveillance Network, source: Jones K., Fuentes, K., Wright D., “A Minefield in Earth Orbit: How Space Debris Is Spinning Out of Control,” *Scientific American*, 1 Feb 2012, http://www.scientificamerican.com/article.cfm?id=how-space-debris-spinning-out-of-control, accessed 5 Apr 2012.

[6]Klinkrad, H. “Space Debris Mitigation Activities at ESA,” Feb 2011; Kessler D.J., Johnson N.L., Liou J.-C., Matney M., “The Kessler Syndrome: Implications to Future Space Operations,” *AAS 10-016*, *Advances in the Astronautical Sciences*, American Astronautical Society, v. 137, 2010, pp. 47-62.

[7] Rose, F.A., Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, “Space Sustainability Through International Cooperation,” International Symposium on Sustainable Space Development and Utilization for Humankind, Tokyo, 1 Mar 2012: http://www.state.gov/t/avc/rls/184897.htm, “Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs,” 1 Sep 2011, *National Research Council*, http://www.nap.edu/catalog.php?record_id=13244, p. 11.

[8] Soons, A., International Association for the Advancement of Space Safety,Executive Director “Active Debris Removal: An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space,” presentation at the International Symposium on Sustainable Space Development and Utilization for Mankind, 1 Mar 2012, Tokyo.

[9]Moskowitz, C., “Orbital Debris Has Reached Tipping Point, Report Warns,” *Space News*, 5 Sep 2010, p. 13, Irene Klotz, “Space junk reaching "tipping point," report warns,” *Reuters*, 1 Sep 2011, http://www.reuters.com/article/2011/09/01/us-space-debris-idUSTRE7805VY20110901, “Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs,” 1 Sep 2011,

likely to collide with each other every three to six years; one analyst predicts the doubling of the lethal hazard at the LEO 850 km orbital height, and the annual probability of collisions in the 650-1,000 km region may both occur as early as 2035.[10]

While the LEO environment has received much attention for the proliferation of debris, the GEO environment also faces difficult issues. As of February 2010 there were 1,238 known objects in the GEO belt, of which only 391 were under some level of control; of these 594 were drifting; of the 21 GEO satellites reaching End of Life (EOL, see below) in 2009, only 11 were disposed of properly. To cope with this, operational satellites are increasingly forced to maneuver around debris to avoid collision; some 100 collision avoidance maneuvers have been performed to date, most occurring since 2008.The economic stakes are high. According to the Satellite Industry Association, there are now about 1,000 working satellites in earth orbit, producing revenues of US$168 billion.

What is to be done?

Orbital debris issues were first recognized as potentially threatening in the 1970s; in 1979 NASA first set up an office to look into the issue.[11]Then, in 1980, The American Institute of Aeronautics and Astronautics (AIAA) became the first body to publish a comprehensive technical and policy assessment of debris issues.[12]Through the 1990s, strides were made to set rules to limit debris creation, including setting up of the Inter-Agency Space Debris Coordination Committee (IADC) and the formation of mitigation guidelines. Now, significant steps to mitigate the space debris problem are advancing. In 2002, the IADC set international guidelines to minimize debris, which were adopted by the UNCommittee on the Peaceful Uses of Outer Space (UNCOPUOS). Critical was the "25-year rule" that all spacecraft missions in orbits of 2,000 km or less reaching EOL should be put into a position where they deorbit (fall to earth) in less than 25 years, and that GEO satellites reaching EOL have enough fuel to hoist themselves into "graveyard"disposal orbits 2-300 km above the geostationary belt. The FCC passed a similar regulation in 2004.[13] In 2009,UNCOPUOS put long-term sustainability of outer space activities onto its agenda and will, in 2014, prepare a report on a consolidated set of current practices, operating procedures, technical standards, guidelines and policies dealing with debris to be applied on a voluntary basis.[14]

Further, in 2010, the EU set out a draft "Code of Conduct," a comprehensive set of guidelines to minimize debris generation, whichcould become the basis of an international soft law regime.[15]The U.S. is considering its response; meanwhile the primary U.S.

National Research Council, http://www.nap.edu/catalog.php?record_id=13244

[10]McKnight D., "Pay Me Now or Pay Me More Later: Start the Development of Active Orbital Debris"

[11] NRC report.

[12] No author, "AIAA Position Paper on Space Debris: 30 Years On," Orbital Debris Quarterly News, Jan 2012 p. 2-3 see also Kessler, D.J. "Sources of Orbital Debris and the Projected Environment for Future Spacecraft," *AIAA International Meeting and Technology Display, AIAA-80-0855*

[13] Federal Communications Commission, Mitigation of Orbital Debris, Second Report and Order, 19 FCC Rcd 11567 (2004), licensing.fcc.gov/myibfs/download.do?attachment_key=782032

[14]Horikawa H., incoming Chair of UNCOPUOS, "Long-term Sustainability of Outer Space Activities," 1 Mar 2012, presentation at the International Symposium on Sustainable Space Development and Utilization for Mankind 1 & 2 Mar 2012, Tokyo; United Nations Committee on the Peaceful Uses of Outer Space: Scientific and Technical Subcommittee. See: Terms of Reference and Methods of Work of the Working Group on the Long-term Sustainability of Outer Space Activities of the Scientific and Technical Subcommittee, Vienna from 7-19 Feb 2011; UN Doc. A/AC.105/C.1/L.307 of 24 Jan 2011.

[15] Council Conclusions concerning the revised draft Code of Conduct for Outer Space Activities, Council of The European Union Brussels, 11 Oct 2010,
http://www.consilium.europa.eu/eeas/foreign-policy/non-proliferation,-disarmament-and-export-control-/outer-

objective is to improve data sharing and monitoring; the U.S. Joint Space Operations Center, or JSpOC which monitors the orbital environmentprovided over 1,100 notifications to nations around the world, including Russia and PRC in 2011 alone.[16]

Dr. Nicholas Johnson, chief scientist for orbital debris for NASA at the Johnson Space Center, calculates that removing 1-5 pieces of debris beginning 2020 would stabilize the LEO population.[17] A recent study for the International Academy of Astronautics suggested removing 10-15 large intact objects from LEO per year would be advisable.In 2011, the ESA Space Debris Office recommended mass removal LEO debris as soon as possible.[18]

Since the Iridium 33-Cosmos 2251 collision,a large number of commercial proposals have emerged proposing to clean up orbit. This paper focuses on the LEO and GEO regimes. These consist of two main areas; active debris removal (ADR) and on-orbit servicing (OSS). ADR, usually to tackle LEO objects, is defined as removing objects (including spent rocket stages) from orbit above and beyond currentmitigation measures. OSS, typically aimed at GEO-based objects,includes refueling operational satellites to increasetheir lifetimes, and/or to safely lift dead, redundant or failed satellites to "graveyard" orbits. In LEO, in particular,the scale of the issue is daunting. Reducing 50% of the ISS-crossing orbital debris in the 1.5 cm to 3 cm requires the sweepingof about of 1,000 square km annually.[19]

Technical hurdles

ADR and OSS require the ability to visit the intended object, often to mate or grapple with it, even if it is uncooperative,(i.e. not designed to be repaired, or may be spinning or out of control),without harming other assets. If the object is in LEO, also to safely de-orbit the object. Generally speaking, orbital changes are complex and require much fuel. Such technologies are difficult but are well understood and significant advances over recent years and years could much such maneuvers routine; servicing of GEO satellites has long been considered the "Holy Grail" of space robotics and various business models have developed (see below). NASA in fact commissioned early studies in the subject in the 1980s, but plans to build a "space tug" for LEO and GEO missions were cancelled due to budget pressures.In 1997, Japan's ETS-VII mission demonstrated the ability to rendezvous and dock with itself in LEO as part of a technology demonstration to ensure the safe docking of the HTV (*Kounotori*) resupply vessel that visits the ISS.[20] Today the Russian *Progress* and Europe's ATV also routinely visit and robotically dock with the ISS. At time of writing, the private

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space-activities?lang=en, last accessed 26 Apr 2012.

[16] Rose, F.A., "Laying the Groundwork for a Stable and Sustainable Space Environment," United Nations Institute for Disarmament Research, Space Security Conference Geneva, Switzerland, 29 Mar 2012 http://www.state.gov/t/avc/rls/187090.htm, last accessed 05 Apr 2012.

[17] Liou J.-C., Johnson N.L., "A SENSITIVITY STUDY OF THE EFFECTIVENESS OF ACTIVE DEBRIS REMOVAL IN LEO," *IAC-07-A6.3.05* and Liou J.-C., Johnson N.L., "Active Debris Removal- The Next Step in LEO Debris Mitigation," 26th IADC Meeting, 14-17 Apr 2008, Moscow.

[18]Klinkrad, H., Johnson N.L., "Space Debris Environment Remediation Concepts," NASA- DARPA International Conference on Orbital Debris Removal, Chantilly, VA, 8-10 Dec 2009 and (same authors) "Mass Removal from Orbit: Incentives and Potential Solutions," 1st European Workshop on Active Debris Removal, 22 Jul 2010.

[19] Levin E., Pearson J., Carroll J., "Wholesale Debris Removal From LEO," *www.star-tech-inc.com/papers/Acta_Paper_Final.pdf* ,and "Wholesale LEO Debris Removal for Safe Space Operations," 15th Annual FAA/AIAA Commercial Space Transportation Conference. 15-16 February 2012.

[20] Kallender-Umezu, P. Pekkanen S., "In Defense of Japan: From the Market to the Military in Space Policy," (SUP 2010), p.164-5, 195-7.

venture SpaceX was mounting the maiden (test) flight of its *Dragon* resupply vessel to the ISS in May 2012. For OSS technologies, in 2005, bothNASA'sAutonomous Rendezvous Technology (DART)and the USAF's eXperimental Satellite System-11 respectively, demonstrated autonomous operations including autonomous proximity operations.[21]

In 2007in the joint Advanced Research Projects Agency (DARPA)-NASA Marshall Space Flight Center's*Orbital Express* technology program demonstratingautonomous OSS technologies, including rendezvous, proximity operations and station keeping, capture, docking, fuel and battery transfer. Boeing has developed a nonproprietary satellite-servicing interface using the technologies it developed for the project.[22]

In terms of robotics, the Canadian Special Purpose Dexterous Manipulator (*Dextre*) on the ISS is currently being used to demonstrate to fuel uncooperative satellites (see below). DARPA's Front-End Robotic Enabling Near-Term Demonstrations (FREND) project has full-scale rendezvous and autonomous robotic grapple testing.[23]

Public Sector Funded Research

A number of major efforts under way could prove crucial to creating a commercial market for ADR/OSS. NASA has taken a strong, public lead. In 2010, in a landmark study, the Goddard Space Flight Center concluded that "there are large classes of commercial satellites that could be economically viable to service" and that OSS to lift to safety and/or refuel certain classes of GEO satellites is feasible and in fact critical to the U.S.'s national interests.[24]The study recommended partnership between government agencies, industry and academia to pursue OSS. More importantly, a RFI attracted 42 responses from industry and 14 from government organizations.

There are now two major U.S. government funded technology programs that should yield technologies to make ADR/OSS technically routine.One is NASA's Robotic Refueling Mission (RRM) experiment on the ISS to demonstrate robotic refueling through 2012. NASA will make the data available from these demonstrations to any entity in the U.S. with the aim of kick-starting commercial OSS. Second, leaping forward from *Orbital Express*, the DARPA *Phoenix* programsets out by 2015 to demonstrate technologies to "harvest" and re-use valuable components from retired, nonworking satellites in GEO to create new space systems. The first mission will cut a communications antenna from "dead" satellite and fix it to another, which will be repositioned for operation.The program aims to develop a class oftiny 'satlets' to perform repairs on GEO satellites that would work with an on-orbit 'tender/ tool shed' with grasping mechanical arms based on FRIEND technology for removing the satlets and components.The program has attracted dozens of commercial and academic papers and proposals.

Europe is also investing in ADR/OSS technology development. Most prominently, in 2010, the German Space Agency DLR began work on on-orbit servicing demonstration, Deutsche Orbitale Servicing Mission (DEOS) similar in capabilities to *Orbital*

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[21] http://www.nasa.gov/mission_pages/dart/main/index.html

[22] Kallender-Umezu, P. Pekkanen S., "In Defense of Japan: From the Market to the Military in Space Policy (SUP 2010), p.162-3

[23] Lennon, J. A., Henshaw, C. G., and Purdy, W., "An Architecture for Autonomous Control of a Satellite Grappling Mission," *AIAA Guidance, Navigation, and Control Conference and Exhibit*, August 2008.

[24] On-Orbit Satellite Servicing Study Project Report, *National Aeronautics and Space Administration. Goddard Space Flight Center,* October 2010, http://ssco.gsfc.nasa.gov/servicing_study.html.

Express.[25] The goals of DEOS are to demonstrate the capture of a tumbling and non-cooperativeLEO client satellite and a controlled de-orbiting of the mated system.

Business Models

A plethora of academic and business studies have estimated of the costs and potential commercial viability of ADR or OSS.[26]ADR/OSS business models require cost effective techniques; a proper legal and policy framework to support and protect the parties involved; available and willing targets; and funding. Most basically, aside from a welter of legal and political issues (discussed below) the cost of removal must be much lower than launch costs per kg.[27]The first question therefore is:*Is there a market?*The answer for GEO is a qualified yes. The answer for LEO is probably "no" for purely commercial ventures.

In GEO, about 20 new spacecraft are launched annually and about 150 non-operational objects are cluttering graveyard orbits.[28] In the four years to 2010, insurers paid out some $700 million in claims for satellite failures, including satellites placed in the wrong orbit. On average about GEO spacecraft a year gets injected into the wrong orbit, about 20 run out of fuel, and about 13 retire each year. In 2008 and 2009 alone, four GEO satellites were abandoned without performing EOL operations. One estimate claims that the next decade will see upto 140 satellites that would benefit from OSS services.[29]

Several academic theses have identified cost benefit models for OSS.[30]However, the challenge is determining the value of servicing; a simplest scenario is comparing the cost of OSS to the cost of replacing a failed satellite or the potential returns from a serviced satellite. To get a basic idea of the scale of the business proposal, the loss of the $150 million (plus $80 million lunch cost) Orion 3 satellite,which was dumped into the wrong orbit in 1999, cost insurers $265 million and $645 million in projected revenue losses.

A 2005 study looking at 162 commercial GEO satellites launched since 1995 estimated that an OSS system using present technologies could be commercially viable for the servicing of 10-20 satellites, based on a fee of $20.48 million per satellite and reasonable insurance premiums. Commercial telecoms satellites generate about 75% of the entire

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[25]Selding, P., "DLR Takes Step Toward In-orbit Servicing Demonstration," *Space News*, http:// www.spacenews.com/civil/022410-dlr-takes-step-toward-in-orbit-servicing-demo.html, Feb 2010,last accessed 11 Mar 2012; Sellmaier F., Boge T., Spurmann J., Gully S., Rupp T., Huber F., "On-Orbit Servicing Missions: Challenges and Solutions for Spacecraft Operations" *AIAA 2010-2159, SpaceOps 2010 Conference.*

[26] See, for example, Cerf M., "Multiple Space Debris Collecting Mission Debris Selection and Trajectory Optimization," and Liou J.-C., " Controlling the Growth of Future LEO Debris Populations with Active Debris Removal," *59th International Astronautical Congress 2008, Paper ID: 959*; Lillie Charles. F., "On-Orbit Assembly and Servicing for Future Space Observatories," *American Institute of Aeronautics and Astronautics Space 2006.*

[27] Levin E., Pearson J., Carroll J. Oldson J., "Orbital Debris: Time to Remove" *Google TechTalk*, 11 Aug, 2011

[28]Sullivan, B., "Technical and Economic Feasibility of Telerobotic On-Orbit Satellite Servicing," Ph.D. thesis, University of Maryland, 2005.

[29]Kaiser, C., Sjöberg, F., Delcura, J. M., and Eilertsen, B., "SMART-OLEV–An orbital life extension vehicle for servicing commercial spacecrafts in GEO," *Acta Astronautica, Vol. 63, No. 1-4, 2008, pp. 400–410.*

[30] Sullivan, B., "Technical and Economic Feasibility of Telerobotic On-Orbit Satellite Servicing," Ph.D. thesis, University of Maryland, 2005; Long, A., Richards, M., and Hastings, D., "On-Orbit Servicing: A New Value Proposition for Satellite Design and Operation," *AIAA Journal of Spacecraft and Rockets*, Vol. 44, No. 4, 2007, pp. 964–975; Bailey, Z. and Baldesarra, M., "The Economic Value of Space Telescope Servicing," *NRC Position Paper*, http://www8.nationalacademies.org/astro2010/DetailFileDisplay.aspx?id=429, March 2009, accessed 30 Mar 2011; Erdner, M., "Smaller Satellite Operations Near Geostationary Orbit,"Master's thesis, Naval Postgraduate School, September 2007.

annual commercial space revenue, but their 12-15 year lifetimes are largely dependent on fuel. To comply with UN mitigation rules, satellites sacrifice roughly six months of service by storing sufficient fuel to reach graveyard orbits, meaning up to $50 million in lost revenue per satellite. The study assumed that the"servicer"weighed 300 kg,had universal capture capability, couldbe launched by any major launch vehicle, had a 10-year mission life, and targeted only fully depreciated commercial satellite with at least 6 month's service life extension possible with a minimum purchase of services for 8 satellites.[31]

Similarly, a 2001 study using a cost-per-year approach found that a servicer must refuel 3-5 satellites to be cost effective.[32]Other studies have shown that orbital servicing for large constellations of satellitesmay have significant value.[33]In a major 2010 study, NASA found that a new spaceflight architecture that incorporates refueling and servicing could actually reduce costs of a mission.[34]

All the studies present a pretty strict set of rules for GEO. For LEO, theremoval of small, untracked objects in LEO may not be cost-effective or practical, according to some estimates.[35]

The Legal, Political and Insurance Frameworks

If technical hurdles are comparatively low, legal and political considerations issues concerning the definition of space debris, jurisdiction, legislation, control and liability related to ADR/OSS are more troubling.[36] Space law is based on the work of the Exploration and Peaceful Uses of Outer Space (UNISPACE) conferences in 1968, 1982, and 1989. Of five major treaties that comprise space law, two are pertinent to ADR/OSS issues; the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space- the Outer Space Treaty (OST) of 1967 and The Convention on International Liability for Damage Caused by Space Objects of 1973 (the Liability Convention).[37] The OST sets the principle of no "ownership" of outer space resources. The Liability Convention defines the liable party as the "Launching State."

The most prominent issues are lack of clear legal definitions of debris with concomitant and related, ownership, liability and insurance, IP and political issues. The key problems are:

(a) No binding legal definition of space debris, or standards for who can removedebris. Fragments and components as treated as individual objects in and of themselves.[38]

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[31]Galabova, K.K., Olivier L. de Weck, "Economic case for the retirement of geosynchronous communication satellites via space tugs," *Acta Astronautica*, 13 Dec 2005.
[32]Lamassoure, E. and Hastings, D. E., "A Framework to Account for Flexibility in Modeling the Value of On-Orbit Servicing for Space Systems," Master's thesis, Massachusetts Institute of Technology, June 2001
[33] Hubbard, R., "Satellite On-Orbit Refueling: A Cost Effectiveness Analysis, Master's thesis," Naval Postgraduate School, Monterey, CA, September 1996.
[34] Long, A., Richards, M., and Hastings, D., "On-Orbit Servicing: A New Value Proposition for Satellite Design and Operation," *AIAA Journal of Spacecraft and Rockets*, Vol. 44, No. 4, 2007, pp. 964–975.
[35]Soons, ibid.
[36]Weeden B., "Overview of the Legal and Policy Challenges with Orbital Debris Removal," *61st International Astronautical Congress, Prague, 2010*; Listner M.J., "The Legal and Political Issues of Space Debris Removal," *On Orbit Watch* http://www.onorbitwatch.com/feature/legal-and-political-issues-space-debris-removal, accessed 14 Apr 2012
[37]United Nations Office for Outer Space Affairs. http://www.unoosa.org/oosa/index.html.
[38] International Academy of Astronautics, "Position Paper on Space Debris Mitigation Implementing Zero Debris Creation Zones," 15 Oct 2005 *International Conference of Astronautics 12 Apr 2011*http://iaaweb.org/iaa/Studies/spacedebrismitigation.pdf; also: Weeden, B., "Overview of the Legal and Policy Challenges of Orbital Debris Removal." *Space Policy* 27 (2011) 38-43: 41.

(b) Under Article III of the Liability Convention, space objects still belong to the country or countries that launched them, the "Launching State."[39] Article VII of the OST says the state that launched the object has jurisdiction over it.[40]So the Launching State is potentially liable for any damage or loss caused during ADR/OSS of an object that may have been launched decades before even if it has nothing to do with the present action. Further, "Launching State" may refer to either the State that launches or procures the launching and/orthe State from whose territory or facility a space object is launched.Yet, 6,000 pieces of tracked debris that have no assigned Launching State, as do none of and the smaller objects. However, if a state is liable for any damage caused in the course of the removal, substantial insurance issues may apply for the company to be underwritten by a government.

(c) Neither the Liability Convention nor the OST cover who is at fault if a third party disturbs a piece of debris, which explodes and later collides with another satellite, orwho is liable for a removed debris object that lands on a house, private property, etc.

Thus there is no precedent of State practice for the transference of jurisdiction and control for the purposes of ADR/OSS, nor for it without having received permission from the State of registry, nor for actions of a space object of unknown registry.

(d) The U.S. International Traffic in Arms Regulations (ITAR) covers any U.S. components or technology onboard a spacecraft; ADR/OSS may be considered an "export," requiring either a change in the regime or legal waivers.

(e) *Political Issues*:a significant number of space objects are or were military or national security assets owned by the U.S., the Russian Federation (including objects launched by the former Soviet Union) and the PRC. Such actors are reluctant to allow foreign governments or NGOs to interact with these assets or even fragments. Concomitant to this; by their very nature as well as their dual-use attributes, ADR and OOS technologies involve significant strategic and military implications as they involve dual-use anti-satellite technologies, since the ability to repair satellite also means the ability to disable or destroy it.

In this light, the international community needs to create mechanisms to facilitate the rules and definitions respecting both the jurisdiction and control issue and the consent for ADR/OOS.Yet legal solutions may prove difficult. The International Court of Justice (ICJ) of the UN hears legal disputes upon the request of a member state deals with legal questions referred to it by authorized UN organs and other specialized agencies and its judgment is binding under Article 94 of the UN Charter.But hearings take years to judge.[41]

Further Implications for a Commercial ADR/OSS Business Approach

As issues with the Liability Convention imply, costs for any commercial parties may outweigh risk and implies that compensation payments and fault is difficult to establish without complex agreements and the consent of the Launching State requiring, in the worst case, ad hoc, one-off and piecemeal negotiations on the removal of every single object in orbit. Governments reluctant to disclose secrets of military satellites, or approve their removal, may also hinder progress.Further, new types of insurance policies will need to be written to cope with ADR/OSS.

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[39] See: Convention on International Liability for Damage Caused by Space Objects. http://www.oosa.unvienna.org/oosa/SpaceLaw/liability.html.

[40]Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. http://www.oosa.unvienna.org/oosa/en/SpaceLaw/outerspt.h tml.

[41] ICJ <http://www.icj-cij.org/court/index.php?p1=1> accessed 14 Apr 2012.

In terms of insurance, some positive news is emerging. Coverage for rare and catastrophic losses means insurance is often second largest expense for satellite operators.[42]Currently 10-15% average premium for a space mission covers the launch vehicle flight and the initial (first year) satellite operations while only a small portion of the total premium (i.e. about 1.5% of the satellite value per year) is for on-orbit operations after startup. Some believe that when the collision risk reaches a value of 1.5% per year, insurance premiums will likely increase, incentivizing change.[43] Further, once a collision with an insured satellite occurs, the urgency for ADR/OSS will likely accelerate. Recently, the insurance industry has starting reviewingthe business potential of the ADR/OSS market, which could provide diversification of portfolios and opportunities for new types of policies,and even lead to lower premium rates through reduced claim payments, for example.However, "the cost vs. benefit must be beyond discussion" for the insurance market to accept ADR/OSS, according to one senior insurance executive.[44]

Current Commercial Situation

Following the success of *Orbital Express* in particular, a rash of proposals has been floated by universities and companies proposing to clean up LEO and to promote ADR/OSS systems for GEO. This section only focuses on the most major and the most promising, and also more carefully examines the failed MDA-Intelsat bid mentioned in the introduction.

LEO: Despite doubts that LEO cleanup is impractical and uneconomical, several programs could help establish norms to enable the basis commercial ADR business, whether in LEO or GEO. This first section looks at LEO-based ADR.

CleanSpace One by Ecole Polytechnique Federale de Lausanne (EPFL)proposes to launch a small CubeSat satellite piggybacked on a commercial launch in 2016 to rendezvous, grab and deorbit either EPLF's Swisscube or TIsat picosatellites in a 630-750 km orbit. As a feasibility study, CleanSpace One uses an open, replicable standard CubeSat bus.[45]For in-orbit technology demonstration missions, double-unit or triple-unit CubeSats are foreseen for sophisticated payloads and higher power requirements.

Andrews Space, Inc. (U.S.) isdeveloping a *CubeSat Deorbit and Recovery System* (DRS) that uses an inflatable cone to deorbit and CubeSat-class spacecraft. Funded by NASA and DARPA contracts, Andrews plans a demonstration mission via a future SpaceX Dragon mission to the ISS. Technically DRS looks like an elegant solution; it is tiny and light (1.5kg). Prototype hardware has been fabricated and a flight test could be made as early as 2013 or 2014 for either for commercial model or a government mission for a cost of $2-4 million. Volume production of the system could bring costs down to $100,000 per system.[46]

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[42] Federal Aviation Administration "Commercial Space and Launch Insurance: Current Market and Future Outlook," Fourth Quarter 2002. Quarterly Launch Report, http://www.faa.gov/about/office_org/headquarters_offices/ast/media/q42002.pdf.; Lloyd's of London, "Consortium Delivers Satellite Revolution," http://www.lloyds.com/market/Issue2-2006-en/article3.htm., 19 Jan 2006, accessed 02 Mar 2012.

[43]Kunstadter, C., "Orbital Debris and Space Insurance,"*NASA-DARPA International Conference on Orbital Debris Removal*, Chantilly, VA, 8-10 Dec 2009.

[44]Sturmer A., "Impacts on the Insurance Industry" *Future of Space - Satellite Servicing Dubai* 1-3 Marcj 2010;Rora D. "In Orbit Servicing Insurance Aspects," *World Space Risk Forum* – Dubai 2010.

[45] CubeSats are standardized at 10x10x10 cm, weighing 1 kg offering all the standard functions of a normal satellite. The CubeSat standard also allows for double (10 x 10 x 20 cm) or triple (10 x 10 x 30 cm) versions. Picosatellites normally weigh less than 1 kg.

[46] Andrews J., Watry K., Brown K., "*Nanosat Deorbit and Recovery System to Enable New Missions*"

Two intriguing projects using tethers also have commercial potential.Tethers are long trailing "cords" that can maneuver spacecraft into different orbits. Electrodynamic tethers use the earth's magnetic field to induce a current and magnetic field that opposes that of the earth, causing drag. Momentum tethers transfer the momentum of one object to another by attaching and releasing the tether at specific points.Recent advances in electrodynamic propulsion show that these are both viable technologies for LEO-based ADR.[47]There are two current proposals with business models that can be considered candidates for ADR.

At aNASA-DARPA International Conference on Orbital Debris Removal in 2009, Star Inc., of the U.S. presented the *ElectroDynamic Debris Eliminator (EDDE)*, system comprising a dozen 100-kg propellantless net deploying nanosatellites that, the company claims, could "affordably" remove all debris objects over 2 kg from LEO in 7 years. Star claims that a phased deployment of two *EDDE* vehicles launched every year could, after 9 years, remove 9,000 tons of large debris or in 10-12 years nearly all large debris in LEO an average cost under $400/kg (an average annual cost of $84 million), or in 10 to 12 years, all intact legacy debris.[48]*EDDE* has received a 2-year $1.9 million grant from NASA will be tested in a Navy-funded trial beginning in September 2013.

Also,Tethers Unlimited (U.S.) is currently developing a*Terminator Tape* module for deorbiting microsatellite-class systems (<500 kg). A commercial system would deploy a 250-meter tape. A larger *Terminator Tether* that is proposedwould, according to the company, be able to deorbit most LEO spacecraft over several months. A 30-meter, version of the *Terminator Tape* experiment is due for launch in 2014.[49]

Another interesting technology class is in so-called Drag Augmentation Devices. The *Gossamer Orbit Lowering Device (GOLD)* proposed by Global Aerospace Corp., (U.S.), consists of a package fitted into a rocket upper stage or attached to a spacecraft that inflates a large, ultra lightweight balloon that increases drag. The main targets are satellites & objects in LEO, upper stages and uncooperative satellites up to 1,200 km. A 2-m diameter envelope could de-orbit a 10 kg sat from a 650-km circular orbit in 120 days, according to the company. A 54 kg system deploying a 37 m diameter envelope could deorbit a 1,200 kg satellite in one year, according to the company, and the system can be used for larger objects. *GOLD* is under internal R&D by U.S. government funding. Potential costs are $1-3 million or $1-5 million per 1,000 kg-class satellite assuming a launch cost of $10,000- $20,000 per kg. Insurance costs can be held to $100,000 per launch. The company says it can mount a test flight in under two years if funded.[50]

Of these proposals, *CleanSpace One* looksthe most promising. Success could set a precedent for international space law, establishing a customary norm that a nation can de-orbit a derelict space object registered to it through the use of another space object

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SSC11-X-325th Annual AIAA/USU Conference on Small Satellites; also, interview with Andrews, 02 Feb 2012.

[47]Successful demonstrations of key technology date back to the 1990s and continue through to today. The Naval Research Laboratory took the initiative of advancing the electrodynamic propulsion technology and is currently building a 3U CubeSat for the Tether Electrodynamics Propulsion CubeSat Experiment (TEPCE).

[48] Levin E., "Commercial Debris Removal" *3rd International Interdisciplinary Congress on Space Debris Remediation* Montreal, Canada, 11-12 Nov 2011, Levin E., Pearson J., Carroll J., "Debris Removal, Wholesale LEO Debris Removal for Safe Space Operations," *15th Annual FAA/AIAA Commercial Space Transportation Conference* 15-16 Feb 2012.

[49]Muylaert J., Asma C.O., Thierry Magin T., "In-Orbit Technology Demonstration Missions for Debris Mitigation," 4TH EUROPEAN CONFERENCE FOR AEROSPACE SCIENCES (EUCASS).

[50] Nock K.T., Gates K.L., Aaron K.M., McRonald A.D., "Gossamer Orbit Lowering Device (GOLD) for Safe and Efficient De-orbit," *American Institute of Aeronautics and Astronautics*; interview with Nock, 3 Feb 2012.

without the interference or objection of other nations. For example, if EPFL provides a neutral launching state, a neutral Swiss government-led ADR could obviate some of the legal, liability, ITAR and political worries mentioned above. The Swiss government could even pass a domestic space law to help facilitate foreign NGOs to create organizations under Swiss jurisdiction allowing third parties to perform space debris removal under Switzerland's jurisdiction as a Launching State. However *CleanSpace One* is only for single missions; commercial viability would have to be reconfigured to be reusable or replicable with multiple missions, inevitably pushing up the cost.[51]

GEO. Arguably the GEO market for OSS has been the one to capture the most interest, led by the MacDonald, Dettwiler and Associates Ltd. (MDA)- Intelsat deal, whose rise and fall highlights the potential and pitfalls of ADR/OSS.

Early this year MDAand Intelsat,terminated an anchor tenant contract that would have seen a$280 million for MDA's proposed on-orbit *Space Infrastructure Servicing (SIS)* to refuel up to five of Intelsat's commercial GEO satellites after 2015. The deal was significant because not only is MDA an accomplished space robotics maker with a strong track record, but it was flush with cash ($819 million, following the sale of one of its businesses) and had a well worked out, detailedbusiness plan. The credibility of the deal was reinforced by the fact the partner company was Intelsat, which operates the world's largest fleet of 52 satellites. The mission would have an on-orbit life of about 5 years and enough fuel to perform 10 or 11 missions. In addition, Intelsat's subsidiary that handles government business, had agreed to hunt for a U.S. government customer, with the partners initially confident about U.S. government interest.[52]

But even the backing of Intelsat proved insufficient to open the market. Crucially, when approached, the U.S. Department of Defense declined as it said it had already budgeted replacements. Then NASA failed include SIS on its crucial Technology Demonstration Missions Program, at which SIS was aiming to gain investment from, which could have provided up to $150 million.[53]

In this light, moves bythe *ViviSat*Mission Extension Vehicle (MEV) a50/50 joint venture of aerospace firms U.S. Space and ATK look problematical. ATK has proposed a MEV "space tug" concept for a small-scale in-space satellite-refueling spacecraft where *ViviSat*connects to the target satellite and becomes the satellite's new fuel source. *ViviSat*believes its approach is more simple and can operate at lower cost than that of MDA, while having the technical ability to dock with 90% of the 450 or so geostationary satellites in orbit, whereas MDA's proposal was designed to dock with about 75% of commercial GEO satellites. If launched, the MEV could be used to rescue fueled but incapacitated spacecraft, using its own motor and fuel to place it in the right orbit, and then moving to

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[51] Listner M.J., "Swiss Open Political Door for Space Debris Removal, *Space Safety Magazine*, 20 Feb 2012, http://www.spacesafetymagazine.com/2012/02/20/swiss-space-debris-effort-open-political-door-space-debris-removal/

[52] Boucher M., "MDA Signs Intelsat as Anchor Tenant for On-Orbit Servicing," *SpaceRef*, 15 Mar 2011, http://spaceref.ca/commercial-space/mda/mda-signs-anchor-tenant-for-on-orbit-servicing-service.html; Selding P., "Intelsat Signs Up for MDA's Satellite Refueling Service," *Space News*, 18 Mar 2011 http://www.sbv.spacenews.com/satellite_telecom/110318intelsat-signs-for-mdas-satellite-refueling-service.html Selding P., "Intelsat Eyes NASA Demo Program for Satellite Refueling Plan," *Space News*, 25 Apr 2011: http://www.spacenews.com/civil/110425-intelsat-eyes-nasa-program-sat-refueling.html;

[53]Selding P., "MDA, Intelsat Scrap In-orbit Servicing Deal," *Space News*, 17 Jan, 2012, http://www.spacenews.com/satellite_telecom/120117-mda-intelsat-scrap-deal.html

another target, perform station-keeping, relocation, and de-orbiting of satellites. The plan, while bold, is probably currently facing similar hurdles to those faced by MDA-Intelsat.[54]

Conclusions and Possible Ways Forward

The difficulties with making the leap from a good idea on paper to finding the funding and a detailed business model for the ADR/OSS are immense, as the fate of SIS clearly demonstrates. For the sake of clarity, this study has deliberately eschewed a plethora of studies because of the considerable distance between R&D and a workable business proposition. The fate of the so-called Orbital Life Extension Vehicle (OLEV) program, for example, is instructive. A European proposal somewhat similar to that of SIS, the OLEVprogram reinvents itself every few years, but never achieves significant funding. Several proposals under different consortiums have been publicized and then quietly scrapped over the past decade, with no significant investment in actual hardware.[55]

It is apparent that if a major U.S. or European space agency or governmental organization takes the lead, the case for a commercial market can be made. But the reverse is also true; without considerable investment by a government or national agency either to support R&D and or commercialization, or to provide an anchor tenant agreement, it is presently unlikely that a business model can be developed for either ADR or OSS. Then, prohibitive legal and political barriers also need to be overcome.According to the information publicly available so far, the commercial solutions proposed for ADR/OSS are waiting for legal and regulatory approval, while each tries to minimize possible liability through various unique solutions.

In this light, perhaps the most important task is adjusting the legal and liability frameworks, including, as mentioned, setting a standard and legally acceptable definition of space debris and establishingTransparency and Confidence Building Measures (TCBMs); for example, initial missions (whether backed by a government /governmental agency or commercial or both) couldfocus on non-controversial debris objects. For attributed debris, for ADR for example, the state that created the debris or would be responsible for removing it, either by way of its own ADR operation or by authorizing others to remove it.

TheSecure World Foundation, a U.S. space sustainability think-tank that is working for the UN and U.S. decision makers believes an international demonstration mission or some stripe is an essential step before any market can be created.[56]It has set the following issues as vital to promote ADR/OSS:

- The development of "best practices" or "rules of the road" and protocols for ADR operations, especially orbital rendezvous;
- The initialization of specific TCBMs;
- The clarification of the Intellectual Property rights situation;
- The development ofprotocols/agreements between Launching States and third party removal entities, and;

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[54]ViviSat Corporate Overview, company website:http://www.usspacellc.com/in-orbit-servicing/vivisat; Morring F. Jr. "An End To Space Trash?" *Aviation Week* http://www.aviationweek.com/aw/generic/story.jsp?id=news/awst/2011/03/21/AW_03_21_2011_p23-297586.xml&headline=An%20End%20to%20Space%20Trash?&channel=awst.

[55] The OLEV program has gone through several incarnations; see XXX above and ConeXpress-OLEV (CX-OLEV) http://space.skyrocket.de/doc_sdat/conexpress-ors.htm

[56]Weeden B. "Overview of the Legal and Policy Challenges with Orbital Debris Removal," 61st International Astronautical Congress, Prague 2010.

- ✧ Clarification of liability and the creation of a mechanism for transferring liability from Launching State to a third party removal entity.

Other leaders in the space community have come up with similar sorts of proposals. For example, The Aerospace Corporation suggests a following roadmap as (a) developing a legal framework and details to enable removal of each object (e.g., resolve liability issues), (b) developing international agreements that address concerns about dual-use of ADR/OSS, (c) creating a debris removal "X-Prize" with reward for successful removal of identified object, (d) identifying and reaching necessary agreements with owners for a small number of debris objects to serve as targets for removal, (e) getting designers to introduce "standard" fixtures and approaches to facilitate servicing and removal, (f) setting and publicizing goals for yearly removal beginning in ~2025 as an incentive for near term private investment, and (f) creating acleanup fund to pay for removal service in long term.[57]

Regarding liability, under the present legal mechanisms, untilthe ICJreviews a space liability dispute in the event of a major space debris incident, spacefaring nations are likely to rely on collective pressure or bilateral negotiations to recover damages from the launching country/ Launching State. There seems to be no policy panacea. Rather, its seems that a combination of efforts attacking the issues from different tracks is needed.

This is indeed progressing. For example, work toward improving the European Code of Conduct to an "International Code" began this year when U.S. Secretary of State Hillary Clinton started negotiations with the European Union. However negotiating such a code still faces internal opposition in the U.S. by those unwilling to have the U.S. become a signatory to any legally binding commitments. Also talk of a code often bleeds into a broader stalemate in the UN over proposals from China and Russia to introduce more binding and general arms limitation talks, proposing a "Prevention of the Placement of Weapons in Outer Space Treaty" (PPWT). Both the Bush and Obama administrations have strongly opposed the PPWT for a number of reasons, primarily because it is difficult to verify. Meanwhile PRC refuses to engage the U.S. on any code of conduct.[58]

Regarding MCTR issues, the negotiated initialization of Voluntary Non-binding Agreements (international agreements) along the lines of a WassenaarArrangementfor space, in which individual nations are left to regulate themselves and yet remain responsible to a collective reporting mechanism that fosters transparency, may prove useful.Other ideas include the establishment of international research consortia for R&D that could coordinate their actions under a neutral body such as the IADC, or International Organization for Standardization (ISO), which is working to standardize orbital debris mitigation processes.

In a strong sense, the market for ADR/OSS also faces a chicken and egg situation. For example, space agencies such as NASA or space research consortia, national agencies and commercial interests would be more likely to commit to standard mitigation and ADR/OSS if commercial industry committed to standardized building and operational procedures, instead of the options offered voluntarily by major satellite builders. Yet, both implicitly or specifically all sides seem to understand that the private sector cannot be expected to assume risk for the global commons of outer space, especially when so much of the issue is caused by historic actions of several governments.

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[57]Ailor, W. "Space Debris Remediation & On-Orbit Servicing: Concepts, Considerations, Moving Forward," Interdisciplinary Congress on Space Debris Remediation, McGill University, 11 Nov. 2011

[58]Deam J., "Need for Space 'Rules of Road' Grows along with Orbital Congestion, Rose Says," *Space News*, 23 Apr 2012, p. 11; Taverney T.D., "Working towards a space code of conduct," *The Space Review*, 16 Apr 2012, http://www.thespacereview.com/article/2066/1 accessed, 17 Apr 2012.

In terms of legislation, this March the United Nations Office for Outer Space Affairs (UNOOSA) announced that Legal Subcommittee of UNCOPUOS would discuss international space law including national mechanisms relating to space debris toward revamping the international legal regime, specifically the transfer of ownership of space objects, including issues of responsibility, liability and registration for 2013, as mentioned earlier.[59]

Funding issues: As stated, for commercial systems to work, thecost of removal must be much lower than launch costs per kg to make economic sense, it will take competitive bidding to establish the market.[60]A recent RAND study for DARPA found that concerns about the risks related to orbital debris may soon be crossing a critical threshold of alarm to provoke investment in ADR/OSS.[61]But it is difficult to make a business case without significant commitment of government funding.As noted, the removal of small, untracked objects in LEO may not be cost effective or practical.A number of approaches around this have been proposed from various sources including:

- ✧ A state/actor approach requiring nations and operators considered responsible for creating debris to fund R&D and or actual removal;
- ✧ A "fair share" approach where all launch and space systems operators, both public and private, contribute shares toward ADR/OSS system in proportion to their current share of the global launch and operations activities, and;
- ✧ A "Global Economic Fund" to seed programs, funded by the "fair share" approach noted in (b).

In line with these ideas, the International Association for the Advancement of Space Safety, a Netherlands-based NPO set up to pursue international cooperation and scientific advancement in space systems safety,feels the establishment of an Inter-Governmental Organizationmonitored and coordinated at both the national and international levels and backed operational and regulatory framework would facilitatepublic-private partnerships. This could provide both a TCBM mechanism and a working model: governments would subscribe to procure ADR/OSS on a commercial basis by levying a "space garbage collection" tax on final users of space-based (commercial) services.[62]

There are indeed several proposals to set up global funding systems that could segue through funding issues. One such comes from theSpace Frontier Foundation, a major U.S. space foundation promoting entrepreneurial space business. The foundationproposes the setting up of anOrbital Debris Removal and Recycling Fund (ODRRF) along the lines of the for U.S. former environmental Super Fund system. Under the ODRRF Scenario, private companies identify and prioritize candidate orbital debris and re-register debris for liability purposes,purchase insurance, remove debrisand collect payment from the ODRRF, while Launching Statesand satellite operators pay into the fund along principles that have, admittedly, still to be worked out.[63]

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[59] United Nations Office for Outer Space Affairs, "Growing pace of space activities calls for further development of space law," *Press Release* UNIS/OS/416, accessed 30 Mar 2012 http://www.unis.unvienna.org/unis/pressrels/2012/unisos416.html

[60] Levin E., "Orbital Debris: Time to Remove," ibid.

[61]Baiocchi D., William Welser W., "Confronting Space Debris," RAND, 2010, Library of Congress Control Number: 2010940008, ISBN: 978-0-8330-5056-4

[62]Soons, ibid.

[63]Dunstan, James E., "Legal and Economic Implications of Orbital Debris Removal: A Free Market Approach," International Conference on Orbital Debris Removal, Reston, VA, U.S., 8-10 Dec 2009.

Joseph Pelton, President of the International Space Safety Foundation and Chair, IAASS Academic Committee, has argued for the establishment of a global space debris fund to spur commercial ADR/OSS; he argues that trying to apportion funding responsibilities to nations that have caused space debris will not work. Instead, he recommends a “future oriented” way to fund entities licensed by UNOOSA, which would create an international register of objects to be removed and the process should be confirmed by a new convention; technology deemed to be dual use would not be eligible, and compensation for removal would be established on fixed basis of certain amount per kg and paid only after debris actually removed.Governments could make grants to “licensed entities” to help develop technology for removal and up to 10% of fund could be used to prevent future creation of space debris. Partial refund after a “clean launch” would create a strong economic incentive against future debris creation.[64]

While orbit is awash with debris, there is a wealth of great ideas on how to tackle the issue. It would seem logical that commercial ADR/OSS options ought to be developed, but this presently offers significant risks to the commercial sector, with no clear path through the legal and quagmire that remain, to reward. Technology demonstrations by the private sector could prove significant. However, it seems most likely that a commercial business modelwill have to be built on funding by NASA and/or DARPA for U.S. companies, and equivalent programs following on from DEOS and other proposals in Europe. While these government-backed initiatives still leave crucial and difficult legal and liability issues unsolved,solutions and ways forward are being advanced by creditable entities within the space community, particularly for funding issues. How much longer will these non-governmental proposals continue to exist on a twin track to governmental-based efforts? How far will the pressure of ideas and the growing urgency of the need to resolve the political and legal difficulties take us? These are questions that may be answered over the next 2-3 years. It is hoped that a lack of policy framework does not delay the use of needed debris removal operations in the future, when technical and funding solutions may be available. With all these factors and caveats in mind, it may be that a commercial market for ADR/OSS may evolve in the second half of this decade if crucial steps toward its creation are taken soon.

[64]Pelton J.N., President, International Space Safety Foundation (ISSF) and Chair, IAASS Academic Committee, “A Global Fund for Space Debris Remediation: A New Way Forward to Address the Mounting Space Debris Problem,” 16th ISUAnnual International Symposium, Strasbourg, 21 – 23 Feb 2012.