National Space Society

Position Paper:

Orbital Debris: Overcoming Challenges

May 2016 (with minor updates June 2017)

The National Space Society (NSS) recommends that all spacefaring powers commit to limiting future orbital debris and to cleaning up existing orbital debris as soon as possible.

Specifically, NSS recommends that:

1) After countries including Russia, China, ESA, India, and Japan agree to abide by the same rules, the Federal Aviation Administration (FAA), in coordination with other U.S. Government (USG) agencies, require as part of the existing issuance of licenses for launch to low Earth orbit (LEO), clear demonstration that the campaign will:
   A) Use the shortest-life and least-crowded orbit compatible with the mission;
   B) Safely deorbit or re-use dead spacecraft within two years post-mission;
   C) Launch satellites (if relevant) with standard "handles" to aid grasping and manipulation by service satellites;
   D) Launch satellites (if relevant) with easily accessible fuel tanks and easily replaceable, standard parts to facilitate spacecraft refueling, repair, or other rehabilitation; and
   E) Obtain insurance (as soon as it is available) to protect against liability claims and failure of spacecraft mitigation or orbital debris remediation.

2) The international space community phase out 25-year post-mission free orbital parking by periodically shortening the allowed post-mission periods down to two years, while grandfathering in all spacecraft launched and operated in compliance with regulations then in force.

3) Governments worldwide encourage insurance companies to participate in any national or international agreements dealing with orbital debris mitigation or remediation.

4) The United States openly and transparently begin removing, through public-private space agreements, old U.S. rocket bodies and dead satellites from LEO.

5) The United States actively seek to include Russia, China and other nations in its international, public-private efforts to clean up orbital debris. The 14-member Inter-Agency Space Debris Coordination Committee (IADC), which already includes Russian and Chinese agencies and NASA, and which has already published voluntary orbital debris *mitigation* guidelines, may be a good starting place to develop voluntary *remediatio*n guidelines. However, *all* spacefaring countries (including the public and private space-related entities within their borders), space-related intergovernmental entities, and emerging and extant *commercial* satellite companies eventually need to be included.

6) The U.S. Congress modify the 2011 Wolf amendment, which bars the use of Federal funds to conduct any bilateral science exchanges with China, such that cooperation with regard to space debris is permitted.

7) The White House create by executive order a new national entity called the Space Traffic Management Executive Committee (STM ExCom) to help carry out space debris cleanup in collaboration with analogous entities in spacefaring countries worldwide.

8) The space entities responsible for any spacecraft already in orbit be grandfathered under the policies in existence at the time of their design and construction, so that they are not penalized by any new anti-debris policy or rule, which the STM ExCom develops in coordination with international entities.

9) In coordination with spacefaring governments worldwide, remediation funding come from the following three sources and systems:
A) General government revenues;
B) A fee, established in coordination with the Satellite Industry Association (SIA), of perhaps 0.5% on the bills of all end-consumers of commercial satellite services;
C) Minimal "parking" fees while the spacecraft is in orbit, on all companies launching new spacecraft into Earth orbit, such fees to be imposed only after significant international parties including Russia, China, ESA, India, and Japan agree to abide by such a system.

10) The White House delegate contracting authority to the STM Coordination Office to fund commercial entities to carry out orbital debris cleanup through a

monetary reward system using Space Act Agreements for cleaning up orbital debris, including debris as small as 0.5 cm in diameter, in coordination with the U.S. Air Force (USAF) Joint Space Operations Center, the USAF Joint Interagency Coalition Space Operations Center (JICSpOC), and the international commercial Space Data Association.

11) The U.S. encourage all other spacefaring countries to utilize the International Space Station (ISS) to test and deploy orbital debris management technologies.

12) Spacefaring countries, along with public and private (commercial) space-related entities within their borders and space-related intergovernmental and multilateral entities, organize and participate cooperatively in an International Orbital Debris Convention, in compliance with Outer Space Treaty (OST) Article IX, to clarify ownership and other legal responsibilities and rights vis-à-vis orbital debris management, including those surrounding OST Articles VI and VIII.

Introducing the Problem

Orbital debris is any human-made and uncontrollable litter left in Earth orbit. It includes inactive satellites, rocket stages, and fragments created by collisions, explosions, and even normal operations. There are over 22,000 Earth-orbiting debris objects larger than a softball (10 cm) and around 700,000 shrapnel fragments between 1 and 10 cm.[1] The number of shrapnel smaller than 1 cm exceeds 100 million.[2] With relative impact velocities reaching higher than 34,000 mph,[3] even debris as small as 0.5 cm can take out spacecraft.[4]

The deliberate destruction in 2007 of the Chinese Fengyun satellite with an antisatellite weapon and the catastrophic 2009 collision between a defunct Russian Cosmos satellite and an operating Iridium satellite have together more than doubled the number of cataloged debris fragments.[5] NASA, analyzing data from six space agencies, estimates that if nothing is done about the growing quantity of debris and increasing number of satellites in Earth orbit, there will be another catastrophic collision every five to nine years and the pace will accelerate.[4] At least some who have been studying orbital debris for many years believe that we may have already reached a “tipping point” whereby orbital debris in congested Low Earth Orbit (LEO) altitude bands is colliding in a *runaway debris-generating cascade*, often called the Kessler syndrome. Although this assertion is controversial, and a debris cascade would take years to unfold, at some point a Kessler cascade would nevertheless make spacecraft operation in affected altitude bands virtually impossible.[6] [7]

Orbital debris is an ever-growing hazard to the International Space Station (ISS)[8] and the approximately 1,300 operating satellites, which represent only 6 percent of the 22,000 tracked objects in orbit.[9] Large structures planned for Earth orbit, such as commercial space stations, hotels, space solar power satellites, multi-satellite platforms, and settlements will be especially vulnerable to orbital debris, which will grow from future collisions—even if we put no new spacecraft into Earth orbit.[10] [11] However, *space companies are planning to launch over 10,000 new satellites into Earth orbits in the near future*.[12] [13]

The risk to satellites (providing services for television, radio, telephone, search and rescue, weather and climate reporting, navigation, and national defense) varies with debris object number, mass, and potential impact velocity within an altitude and inclination band. Although it is difficult to determine what percentage of satellite failures are due to orbital debris strikes, as opposed to other causes such as meteoroid impacts, the increasing amount of orbital debris is undoubtedly a factor in annual economic losses in the satellite industry. In this regard, claims paid out by insurance companies for on-orbit spacecraft failures just in 2013 reached $800 million.[14]

There are both non-technical and technical challenges to cleaning up orbital debris. Because the greatest current and future threat from debris lies in LEO (particularly from 560 km to 1020 km) and geosynchronous orbit (GEO) (35,786 km), this paper focuses on those altitudes. *Non-technical* challenges consist of 1) adverse economic factors, 2) policy and legal barriers, and 3) international/geopolitical sensitivities. *Technical* challenges include 1) inadequate Space Situational Awareness (SSA), which includes debris detection, tracking, and conjunction predictions and 2) lack of ready technology for removing or productively using orbital debris.

Phase Out Free Orbital Parking & Use FAA Licensing to Strengthen Orbital Debris Mitigation

In this paper, *mitigation* refers to any policy, activity, or technology that seeks to prevent orbital debris from being created or seeks to prevent debris from damaging a spacecraft. Current examples of debris mitigation include lowering a spacecraft at its end of life (EOL) to force the satellite to deorbit naturally within 25 years ("the 25-year guideline"), or raising the orbit of a GEO spacecraft at its EOL to a graveyard orbit 300 km higher than GEO,[11] or shielding a spacecraft so that it will not be damaged by debris

Mitigation is important to help slow the growth of orbital debris. However, e*ven without the thousands of planned launches and assuming 90% compliance with the 25-year deorbiting-after-use guideline,* orbital debris, because of future collisions, will *continue to increase for at least the next 200 years*.[11] From this it is clear that the 25-year guideline, although a step in the right direction, is inadequate.

Under U.S. Government Orbital Debris Mitigation Standard Practices,[15] satellite companies are not required to deorbit or otherwise move their satellites to higher-altitude graveyard orbits until 25 years have passed after the end of the satellite's mission. This policy, being adopted internationally, amounts to 25 years of "free parking" post-mission. While an improvement over the previous no-limit-while-dead-on-orbit situation, free orbital parking post-mission for any object that cannot actively avoid all dangerous conjunctions still endangers operating satellites and other operating spacecraft. Indeed, the Satellite Industry Association (SIA), in its 2015 position paper titled "Responsible Space Operations" states, "All satellites should be placed in an appropriate graveyard orbit, an orbit that decays rapidly, or disposed of through immediate atmospheric re-entry at the end of their lifetimes."[16] Therefore, **NSS recommends that the international space community, public and private, phase out 25-year post-mission free orbital parking by periodically shortening the allowed post-mission period down to two years, while grandfathering in all spacecraft in compliance with regulations and guidelines then in force.**

To further enhance mitigation, **NSS recommends that the Federal Aviation Administration (FAA), in coordination with other U.S. Government (USG) agencies, facilitate the licensing of *reusable* spacecraft and require (for licensing to LEO) clear demonstration that those companies will:**

1. **Use the shortest-life and least-crowded orbit compatible with the mission;**
2. **Safely deorbit or re-use dead spacecraft within two years post-mission;**
3. **Launch satellites (if relevant) with standard "handles" to aid manipulation by service satellites, assuming the expected lifetime in orbit of the satellite is such that re-use and re-fueling are likely;**
4. **Launch satellites (if relevant) with standard, easily accessible fuel tanks and replaceable parts to facilitate on-orbit refueling and repair, assuming that the expected lifetime in orbit of the satellite is such that re-use and re-fueling are likely; and**

5. **Obtain insurance (as soon as it is available) to protect against the failure of spacecraft mitigation.**

Were the U.S. to impose such standards only on U.S. satellite manufacturers and launch providers, the U.S. companies would be at a disadvantage in international competition. **Hence, NSS recommends that the FAA only enforce such regulations after they have been agreed to by significant international, government, and commercial parties.[17] Further, such regulations should only be enforced on industry five years after rulemaking is complete to allow the new requirements to be incorporated into designs. These recommendations should not result in any new type of license being issued by the FAA; instead the requirements for existing launch licenses will be enhanced to cover space debris related issues.**

The FAA, as the entity currently responsible for issuing launch permits based on its judgment of adequate liability insurance and safety characteristics, is the logical agency to judge the adequacy of deorbit plans and insurance policies. The FAA would be able to coordinate internationally with analogous institutions in other countries through a national Space Traffic Management entity NSS proposes below in the section, "Facilitating Remediation of Extant and Future Orbital Debris."

At this time, emergency services to deal with on-orbit deorbiting[18] or repair failure are not commercially available, so pricing such insurance would currently be difficult. Historically, however, insurance services have evolved as human societies, technologies, and activities advance. We expect the same to occur as orbital debris technologies and activities advance.

Insurance to protect against the failure of spacecraft deorbiting or rehabilitation would be fundamentally similar to purchasing insurance against launch vehicle failure. Ideally, however, rather than simply paying out damages, the insurance companies would pay commercial contractors to dispose of, rehabilitate, or recycle the orbital debris, along the lines described below.

In general, orbital debris cleanup would be expedited if insurance companies offered lower premiums to companies utilizing reusable rocket stages, automatic deorbiting mechanisms, or other technologies aiding either orbital debris mitigation or remediation. Because any effort to enhance the safety of the space environment cannot succeed without the active involvement of the commercial satellite industry, the SIA would need to be closely engaged with insurance companies as the latter develop services for orbital debris cleanup. For all these reasons, **NSS recommends that the U.S. Government,[19] the SIA, and the larger space community encourage and facilitate the participation of insurance companies in national**

and international agreements dealing with orbital debris mitigation and remediation.

Even Enhanced Mitigation Insufficient; Remediation (Cleanup) Needed

Orbital debris *remediation* refers either to the active debris removal (ADR) or the rehabilitation of defunct spacecraft through on-orbit servicing (OOS) to produce operational ones.[20] OOS can entail refueling and/or repairing inoperable spacecraft, or reusing them through a process called "cellularization," whereby functioning units are attached to defunct spacecraft to rehabilitate them.[21] [22] Orbital debris remediation or "cleanup" also includes the eventual possibility of recycling defunct spacecraft parts or metal for on-orbit assembly and fabrication.[23]

Orbital bands with the largest number of objects pose the greatest *current* risk or threat to satellites. However, the orbital bands with the highest *overall mass* represent the greatest *future* threat, because more mass eventually generates more destructive collisional debris.[7] Based on these criteria, and accounting only for *trackable* objects 10 cm or larger in LEO, orbits around 780 km are *currently* the most hazardous, and orbits around 640 km, 780 km, 840-860 km, and 920-1000 km pose the greatest *future* threat.[7] The good news is that NASA estimates that the LEO environment can be stabilized during the next 200 years with an active debris removal rate of five large objects per year carefully selected on the basis of mass and collision probability.[20]

Unfortunately, in terms of future debris creation, only around 40% of the about 6300 tons of material in Earth orbit is in LEO. The rest is in higher orbits,[11] half in and near GEO, and most of the rest between LEO and GEO (see Figure 1). Worse yet, the most dangerous debris, at least in LEO, consists of perhaps a million objects between 0.5-10 cm, which can take out a spacecraft yet are currently too small to detect and track.[1]

It therefore behooves the space community to quickly move beyond mere mitigation, and put increased effort into *remediation* of debris objects 0.5 cm and over in size.[4] To carry out such remediation effectively, a great improvement in international SSA, which includes orbital debris detection, tracking, and conjunction reporting, will also be necessary. Again, SIA involvement would be crucial to the development of successful orbital debris cleanup.

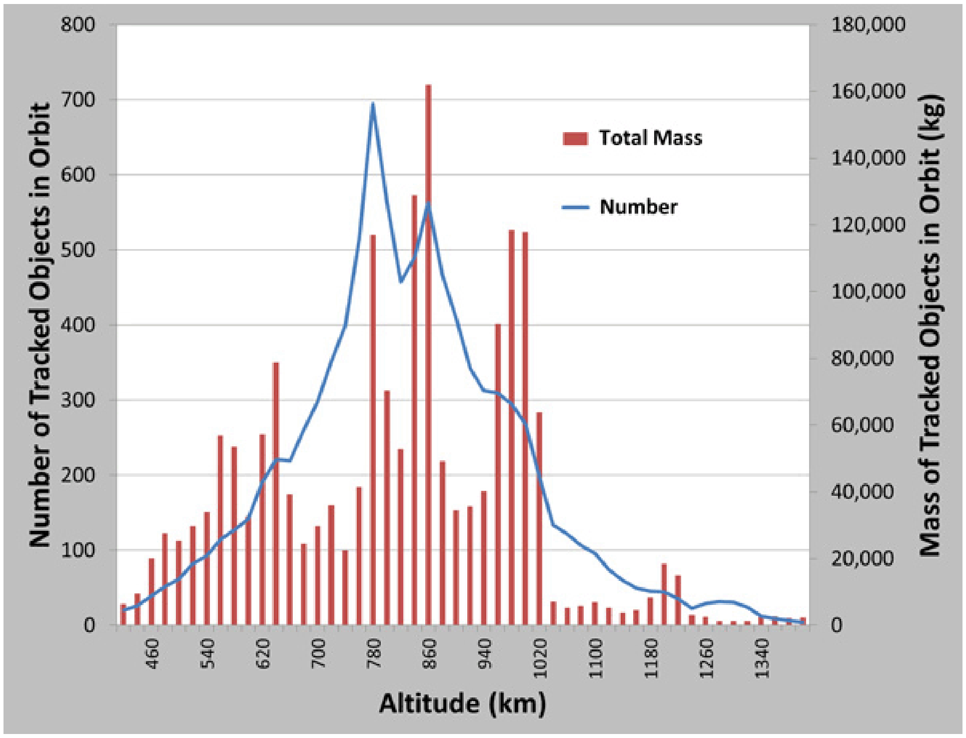


Figure 1: Number of tracked objects in LEO and the total mass as a function of altitude. Image credit: Darren McKnight and Patrick Dingman.[7]

Overcoming Inadequate Space Situational Awareness

Before orbital debris can be removed, stored safely, or rehabilitated through refueling or repair, it must be tracked in real time and down to a size that is still dangerous yet cannot be practically shielded against, i.e. 0.5 cm.[4] The U.S. Air Force (USAF) Joint Space Operations Center (JSpOC), through its Space Surveillance Network (29 telescopes & radars), tracks more than 20,000 debris objects roughly the size of a softball (10 cm) or larger. Using several sightings for each object being tracked, JSpOC, only determines the object's position every 90 minutes and gives conjunction predictions seven days in advance and with error-bars of 1.5-10 km.[24] Satellite owners know that 9,999 out of 10,000 warnings will likely be false alarms. Therefore, they ignore most warnings. Better tracking of objects, including those smaller than 10 cm, could lead to much fewer false alarms and better satellite owner compliance.[25]

Fortunately, the U.S. Naval Research Laboratory (NRL), Geospace Science and Technology Branch, has recently patented its Optical Orbital Debris Spotter (OODS), a compact, *low cost*, low power space debris concept that can be integrated into larger satellite designs or flown independently on board nano-satellite platforms.[26] The OODS throws up a laser light sheet capable of detecting debris as small as 0.01

cm near the host spacecraft for near real-time characterization of debris fields. Because this technology is just now emerging, however, it will have to go through a period of testing and development before deployment.

Hand-in-hand with emerging small debris detection technology, at least eight new detection and tracking systems are also emerging, and *three are commercial* (see Annex A). On the potential buyer side of the market are large commercial operators such as Intelsat, Iridium, GlobalStar, Orbcomm, Eutelsat, and others. They may buy directly or become indirect buyers through organizations like the Space Data Association (SDA) or the Commercial Space Operations Center (ComSpOC), which could provide analysis of raw SSA data for them. Small and single-satellite operators may simply buy data piecemeal for their satellites. Universities may buy data for research purposes.[27] [28] Driving SSA commerce is the fact that the best available SSA data can help a company or government avoid catastrophic collisions and needless, fuel-depleting avoidance maneuvers.

The FAA, because it already has a role in commercial space launch operations through its Office of Commercial Space Transportation (DOT/FAA/AST), may be able also to play a role in facilitating commercial SSA. In this regard, House Representative James Bridenstine on April 12, 2016 announced a draft of the American Space Renaissance Act (ASRA) that, along with many other things, strengthens FAA/AST's role in the facilitation of commercial space in general. ASRA Title III, Section 301 calls for a large increase in funding for FAA/AST and also would establish the position of Assistant Secretary of Transportation for Commercial Space Transportation to give AST and commercial space issues a direct line of communication to the Secretary of Transportation.[29]

The USAF is not standing still concerning SSA, however, and is already looking for data from commercial providers. To help bring this about the USAF's Joint Space Operations Center (JSpOC) recently began a pilot program known as the Commercial Integration Cell within a new entity called the Joint Interagency Coalition Space Operations Center (JICSpOC) to get more refined SSA data from commercial operators.[30]

For all the above reasons, **NSS recommends that the U.S. Government prioritize funding for public-private partnerships to test and refine SSA technologies, including those for detecting and tracking debris between 0.5-10 cm in diameter, in coordination with JSpOC and JICSpOC.** Because enhanced SSA will directly benefit the U.S. space industry, there is no reason that the U.S. should wait for international agreements before moving forward on this recommendation.

Remediation (Cleanup) of Existing Debris in LEO

Overview of Orbital Debris Objects in LEO

Tracked debris larger than 10 cm in diameter can range all the way up to 9-ton rocket bodies and 5-ton satellites. Most tracked multi-kg LEO objects are defunct, but intact, satellites or rocket stages. Three-quarters of the total mass of these objects consists of objects over a ton. Therefore, ton-class bodies (roughly half satellites and half rocket bodies) make up most of the mass (1,693 tons) of approximately 2200 tons in LEO, leaving another 4100 tons of debris in higher orbits.[31]

Ton-Class Objects Make More Shrapnel in LEO

Removing orbital shrapnel in LEO without addressing their source, i.e. collisions between large orbiting objects, would be like bailing water out of a boat while ignoring the hole in the boat's hull. The greatest danger will come from inevitable (without active intervention) catastrophic collisions between ton-class passive debris objects, producing both immediate and eventually greater financial loss due to consequent shrapnel.[32] [33] For this reason, **NSS recommends removing multi-ton objects from LEO as soon as possible.** Although other countries may benefit from the removal of U.S.-origin large objects, U.S. industry will benefit to an equal or greater degree. Since this activity will be paid for out of general revenue or potentially a tax on satellite-based services worldwide, there will be no handicap imposed on U.S. satellite manufacturers or launch service providers in international competition.

Geopolitical Considerations

The ISS can serve as a testbed for emerging orbital debris cleanup technologies and techniques[34] and offers us an ongoing way to engage the international community and overcome geopolitical rivalries, especially with Russia. However, the ISS is currently scheduled for decommissioning in 2024 and this future loss of cooperative engagement with Russia will be particularly unfortunate given that Russia and the United States were the major producers of debris composed of empty upper stages, a major source of future debris in LEO.[31]

Launching governments, through their classification of technology "secrets" and their dual-use technology transfer rules, have shown themselves to be very sensitive about the attributes and capabilities of their satellites, especially military ones. Therefore, to induce international cooperation to remove, repurpose, recycle, or rehabilitate large debris objects, *it is best to start with much less sensitive, but still* *dangerous, upper stages* (i.e. usually mostly aluminum-alloy tanks), which make up about half of the LEO debris mass. Although passivation (i.e. expelling remaining fuel and discharging batteries) now keeps such stages from exploding, they remain dangerous in their uncontrolled and tumbling state. Even so, capturing aluminum tanks should be a lot less complicated than grabbing or manipulating satellites with solar arrays, antennas, and/or nuclear reactors.

About 693 tons of the spent stages in LEO, representing 41% of LEO-debris multi-ton mass, consist of *Russian* rocket bodies (see Figure 2). *Removing only Russian rocket bodies from LEO could reduce future shrapnel creation by nearly 62%*.[35] This exceeds the 48% reduction that would occur if *all non-Russian* mass were removed from LEO.

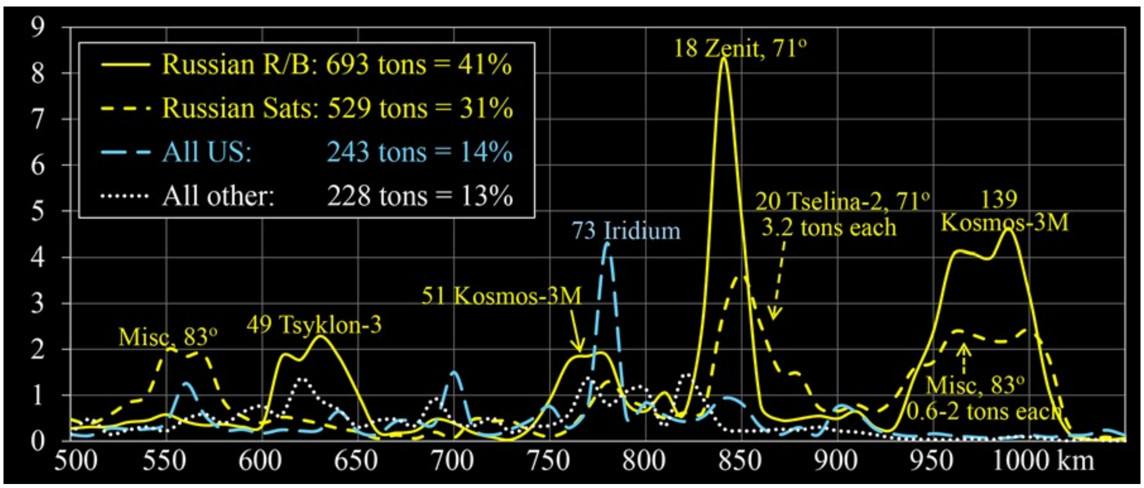


Figure 2: LEO Mass Ownership, Tons/Km Altitude.[36]

Nevertheless, **NSS recommends that the U.S. transparently begin removing, through public-private Space Act Agreements,[37] old U.S. rocket bodies and dead satellites from LEO**, which accounts for just over half of the *non-Russian* mass in LEO. This removal will set an example, while testing the requisite technology. Recommendations for funding public-private partnerships to remove orbital debris are listed below.

As the U.S. Government, in coordination with U.S. companies, takes steps to clean up its own debris, the U.S. should approach Russia for bilateral collaboration. A good start would be for talks between Russia and the U.S. on the range of space operations and safety considerations, i.e. SSA, respective catalogs of space objects, national research and regulations for debris mitigation, conjunction analysis, etc. Ideally, these talks would lead to U.S./Russia bilateral orbital debris agreements, which would deal with about 86% of the mass in LEO.

There is nothing for the U.S. and other countries to lose and much to gain by reaching out to Russia to clean up orbital debris. *The same goes for reaching out to China*, which has recently been signing space agreements with Russia for cooperation in space. Although the 2011 Wolf amendment effectively bars NASA from engaging in bilateral space agreements with China, there is growing debate over whether that legislation is counterproductive and should be overturned.[38] For dealing with either country, provisions of the International Traffic in Arms Regulations (ITAR) may also need to be amended.

Continuing to exclude China, the source of much orbital debris, from civil space cooperation will not prevent it from developing its own capabilities.[39] Space weather, scientific research, exploration, disaster response, and global environmental monitoring are areas where the U.S. and China could collaborate with each other and other interested countries in a way that would lower tensions while achieving positive gains.

No country alone can affordably clean up debris sufficiently to remove the threat of catastrophic collisions, and both Russia and China are key players in cleaning up orbital debris. **NSS therefore recommends that the United States actively seek to include Russia, China, and other nations in its international, public-private efforts to clean up orbital debris.**

The 14-member Inter-Agency Space Debris Coordination Committee (IADC), which already includes Russian and Chinese agencies and NASA, and which has already published voluntary orbital debris *mitigation* guidelines, may be a good starting place to develop voluntary *remediatio*n guidelines. However, *all* spacefaring countries (including the public and private space-related entities within their borders), space-related intergovernmental entities, and emerging and extant *commercial* satellite companies eventually need to be included.

To facilitate cooperation with China, NSS also recommends that the U.S. Congress modify the 2011 Wolf amendment, which bars the use of Federal funds to conduct bilateral science exchanges with China, to allow cooperation on matters related to orbital debris. Congress should also consider allowing exchanges in areas of overwhelming common interest such as planetary defense and space weather, in addition to space debris.

Facilitating Remediation of Extant and Future Orbital Debris

The worldwide space community and the public it serves require national and international entities to cooperatively generate policies and guidelines for orbital debris cleanup. From the standpoint of international law, spacecraft and their debris are the responsibility of each space-faring government.[40] Therefore, to honor this responsibility in matters of remediating existing or future debris, **NSS recommends that the White House create by executive order a *new national entity* called the Space Traffic Management Executive Committee (STM ExCom) to help direct space debris cleanup in collaboration with analogous entities in spacefaring countries worldwide**.

Such an entity would be in keeping with Title III, Section 304 of draft bill ASRA, which calls for the Secretary of Transportation, in coordination with the Secretaries of Defense, State, Commerce, Administrator of NASA, Director of National Intelligence, and others, to designate a lead USG agency for space traffic management activities and services, except for those related to national security assets.[41]

STM ExCom could be established *in full compliance with existing international treaties and law.* Under Article VI of the Outer Space Treaty (OST),[40] the U.S. Government has agreed to authorize and continuously supervise the space activities of both its governmental agencies and its non-governmental entities. Ideally, to be an effective actor in orbital debris related efforts, the STM ExCom and its connected offices would:

1) Be established quickly through executive action;
2) Function within the executive branch of the U.S. Government (USG);
3) Have permanent core staffing from relevant USG agencies to limit the need for hiring additional USG personnel;
4) Have input from relevant USG agencies and private experts connected to space;
5) Be flexible and nimble, i.e. able to react quickly and constructively to changing circumstances;
6) Have the ability also to form ad hoc committees composed of USG employees *and civilians* in order to plan actions and solve problems; and
7) Be able to interact cooperatively and transparently with national and *international* entities and persons, both public and private.

As it turns out, a national entity already exists that fulfills the above conditions and could *serve as a model* for a separate orbital debris management entity. The National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT ExCom), was created by Executive action in 2004, serves under the White House, and deals nationally and *internationally* with planning and problems arising from the Global Positioning System (GPS) and Space-Based PNT. Our proposed STM ExCom would therefore be structured and staffed similarly, but with important variations, to the PNT ExCom. (See the notional organizational diagram for the STM entity in Figure 3 and Annex B for other details.)

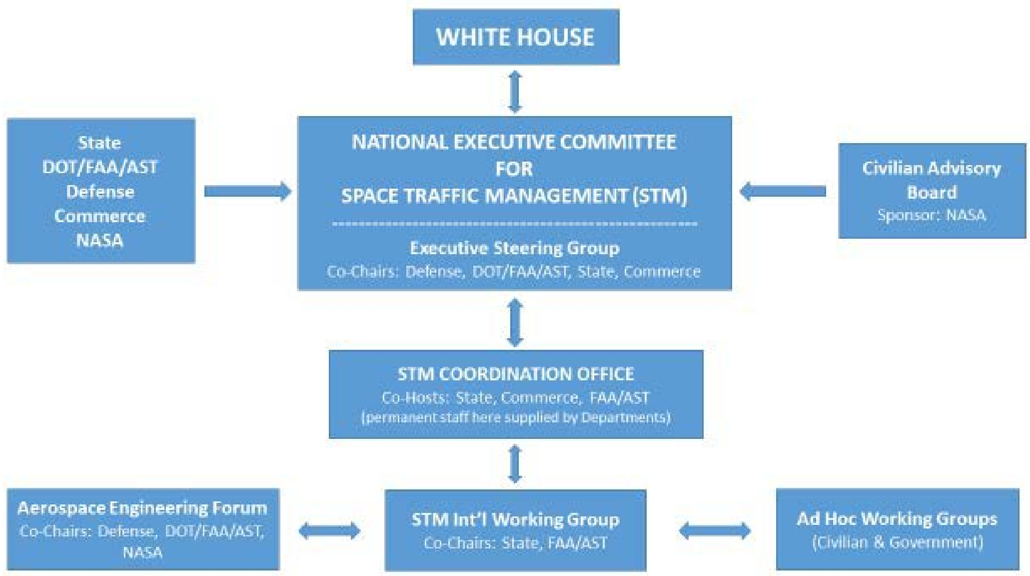


Figure 3: Notional diagram of STM ExCom units. Image credit: Al Anzaldua, NSS.

The organizational chart above is only notional, and we expect it to be refined. Although the STM ExCom would be the overall supervisory body, the *STM Coordination Office* would organize the actors, coordinate the action, carry out day-to-day work, and house permanent staff provided by relevant Federal agencies.

Note that **NSS recommends an International Working Group connected to the STM Coordination Office.** The International Working Group, co-chaired by State and FAA/AST, would be the body coordinating with the International Telecommunication Union (ITU), United Nations Office for Outer Space Affairs (UNOOSA), spacefaring countries, and international space entities, such as the Space Data Association.

NSS recommends that the space entities responsible for any spacecraft already in orbit be grandfathered under the policies in existence at the time of their design and construction, so that they are not penalized by any new anti-

debris policy the STM ExCom develops nationally, or in coordination with international entities.

Economic Aspects Affecting Remediation

Adverse Economic Incentives in LEO

Almost all current users in LEO are public entities providing social benefits.[42 43] Publically provided societal benefits, such as national security, science, climate and weather monitoring, disaster response, natural resource management, and space exploration, are not particularly responsive to prices and markets. Although we are poised for massive growth in commercial LEO operations,[12] total private revenue currently from LEO only amounts to $3 billion.[42 43] Complicating the picture, governments, especially their military agencies, are not yet open to mutually agreed-upon regulation of the LEO commons. The challenge therefore is to incentivize debris cleanup in LEO, even while the majority of currently operating satellites in that orbital band are government-owned and providing social benefits.

Consumers of Public and Private Satellite Services: Pay Now or Pay More Later

Commercial satellite companies providing communication services for television, telephone, radio, and Internet tend to operate in GEO. This will soon change, however, because commercial entities are making plans for services to be supplied from LEO as well.[12] Therefore, an economic incentive already exists to clean up debris in GEO, and there will soon be one in LEO. However, the technical challenges to carry out remediation at any altitude are daunting because of varying trajectories; tumbling debris; lack of adequate SSA of both small and large debris; and fueling systems and electronics emplaced without thought to later repair, replacement, or resupply.

Developing and utilizing technology and international systems for orbital debris cleanup is bound to be expensive. If the past is any indication, public and private space entities will eventually pass on these costs, either through taxes or higher service fees, to the consumers of satellite services. However, the consumers of commercial and government-provided satellite services need to understand that *they are already in a "pay now or pay more later" situation*. If we wait until there are more catastrophic orbital collisions, we will suffer disruption of satellite services, and bills for cleanup will be much higher than if cleanup proceeds proactively.[44] For this reason, our proposed funding mechanisms below entail proactively bringing in funds, either directly or indirectly, from end-consumers of satellite services before cleanup costs rise further.

Funding Sources for Debris Cleanup

To pay for orbital debris remediation, **NSS recommends that funding come from the following three sources and systems:**

1) **General *government* revenues;**
2) **A fee, established in consultation with the Satellite Industry Association (SIA), of perhaps 0.5% on the bills of all end-consumers of *commercial* satellite services worldwide;**
3) **Minimal "parking" fees while the operating or defunct spacecraft is in orbit, *on all companies* launching new spacecraft into any Earth orbit. Such fees could be partially refundable upon spacecraft deorbiting, rehabilitation, or placement into secure salvage orbits. To avoid handicapping U.S. providers, such fees should only be imposed after an international agreement on this topic with significant spacefaring countries including Russia, China, ESA, India, and Japan is put into effect.**

The proposed STM Coordination Office described above, working closely with the FAA/AST and Department of Commerce, and in consultation with international entities such as SIA and the Space Data Association (SDA), would ideally assess parking fees based on a calculation of the increased relative debris-creation threat that each new launch represents, and scaled to modestly underestimate the resulting costs. That calculation in turn would be scaled based on the inclination[45] and an estimate of the mass density of the orbit into which the new spacecraft is being launched, with higher fees being assessed on companies launching large, long-duration spacecraft into the most densely crowded LEO orbits. Space companies will therefore likely try to avoid launching into the most crowded orbits, and this will help to hold down the threat.

Some considerations to take into account when implementing orbital parking fees may be (a) to make the parking fee applicable only if effective debris control measures are not incorporated, (b) only apply them post-decommissioning if the satellite is not otherwise disposed of or positioned at the appropriate graveyard orbit (or perhaps better, at a designated recycling location), or (c) limiting the fee to a small fraction of payload value and/or launch costs.

In implementing such fees, it is imperative that they be designed in such a fashion that (a) they do not unduly burden new companies, (b) they do not unduly burden very small or very large satellites, and (c) they do not unduly burden new space applications

Concerning funds gathered from end-consumers of commercial satellite services, we suggest that the charge appearing on the end-consumer's bill be specifically identified as an "Orbital Debris Remediation Fee." The one-half penny on every $1.00 collected on every end consumer of commercial satellite services would have two very beneficial effects: 1) it would raise over $500 million/year,[46] and 2) it will instantly make consumers aware that there is a need for orbital debris remediation in the orbital band from which they are receiving satellite service. Consumers will also realize that they are playing an important part in maintaining satellite services that they receive.

What would be the most effective use of funds gathered under the above three systems? **NSS recommends that the White House delegate contracting authority to the STM Coordination Office to fund commercial entities to carry out orbital debris cleanup through a monetary reward system using Space Act Agreements within a public-private service-acquisition strategy.**

The Executive Branch has contracting authority as implied from the theory that the U.S. Government is charged with performing public duties, and to fulfill these obligations, contract formation is not only proper, but necessary.[47] As a practical matter the U.S. Congress often limits or adjusts Executive contracting authority through legislation (e.g., the NASA Authorization Act of 2010).

The *STM Coordination Office*, working closely with the FAA, would award the reward money under public-private partnership agreements to private companies only upon a company achieving pre-negotiated pay-on-performance milestones, the last milestone being successful debris remediation. Insurance companies, paying for deorbiting in lieu of satellite company action, would also pay for remediation through a similar acquisition strategy. In this way, no entity need pay for expensive development projects, or for failures, but *only for mutually agreed-upon results*.

Sufficiently high monetary rewards will entice private entities to compete for space agreements by testing and developing various technologies to remediate both large and small debris. Moreover, private companies attempting such remediation would necessarily have to collaborate, perhaps via sub-contracts, with SSA entities in order to carry out successful remediation. Thus, SSA entities would be able to evolve their detection and tracking technologies based on involvement in actual remediation efforts instead of theoretical ones.

Overcoming the Lack of Ready Technology for Debris Remediation

The length of time that orbital debris persists depends on its altitude. Debris persists a few days if under 200 km (125 mi); a few years if between 200 km and 600 km (370 mi); decades if the debris is between 600 km and 800 km (500 mi); and centuries if over 800 km. The difficulty of detection and tracking with Earth-based sensors also increases with increasing altitude, as does the difficulty faced by Earth-launched remediating spacecraft, especially those using chemical propulsion. This situation, therefore, favors space-based sensors and remediating spacecraft using non-chemical propellants or non-propellant propulsion utilizing electric motors reacting against the Earth's magnetic field.

Many technologies have been proposed for orbital debris *remediation*. The idea behind these proposed technologies is either to remove debris, repurpose defunct satellite parts, or rehabilitate defunct satellites by refueling or repair. We describe below several of the more promising debris remediation technologies and practices. Unfortunately, few of these emerging debris cleanup technologies have been developed beyond Technology Readiness Level (TRL) 4. We therefore cannot predict which technological approaches will become cost-effective to remediate the variety of orbital debris at various altitudes. Moreover, the best remedies will differ depending on a debris object's altitude, orbital inclination, size, shape, type, ownership, and launching state(s).

<u>Ground-Based Lasers to Deflect or Remove Debris</u>

One proposed way to deal with large debris objects is simply to nudge them with ground-based pulsed-lasers to prevent collisions. Because only 6% of future shrapnel in LEO is likely to come from multi-ton collisions over 1000 km in altitude, nudging debris below 1000 km could be useful in the immediate future.[48] Simply nudging large objects to avoid collisions would leave the objects mostly intact, however, with the potential for later collisions.

Ground-based pulse lasers could theoretically deorbit small objects in LEO by nudging them to slow their velocity. In this concept, a powerful ground-based laser would ablate the front surface off a debris target to slow and thereby deorbit it (see Figure 4). Although the exact lowest to highest debris size-range susceptible to ground laser deorbiting is currently unknown, an optically equipped and sufficiently powered laser should be able to deorbit small kg objects in the 10 cm to 1meter size range. Larger objects, because of their lower surface area to mass ratios, would take longer and longer as mass increases, until deorbiting by laser becomes impractical due to cost and extended time needed for the deorbiting. For this reason, deorbiting multi-ton debris objects with ground-based lasers is not practical.[48]

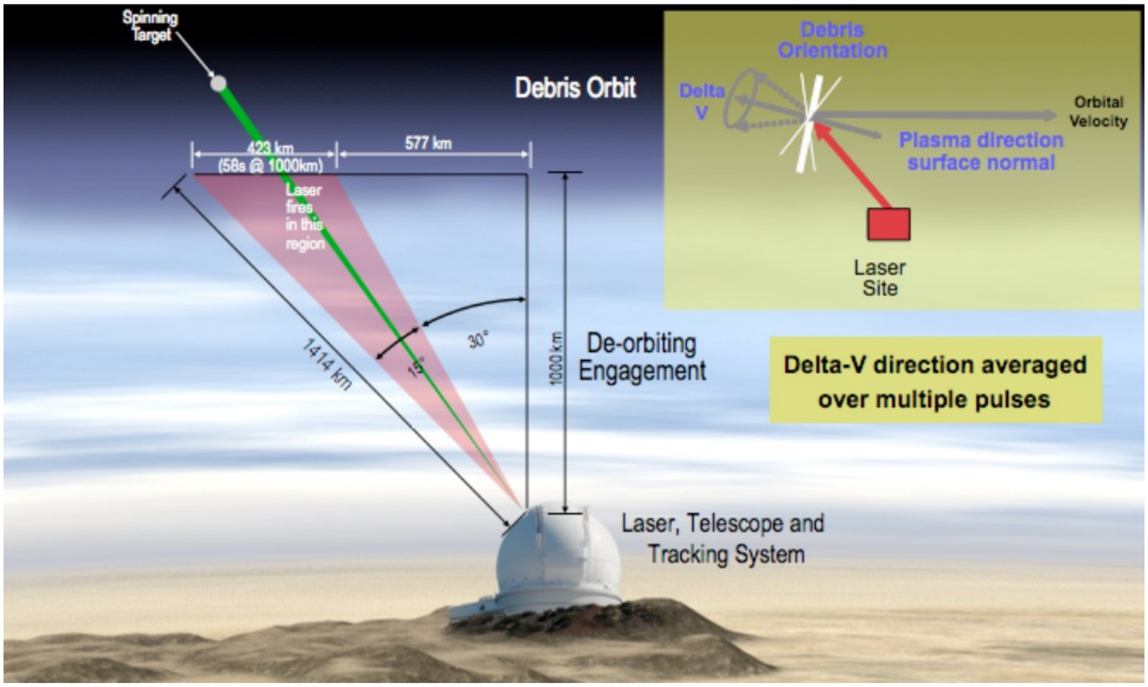


Figure 4: Phipps et. al. Laser Orbital Debris Removal (LODR) Concept.[49]

Space-Based Lasers to Remove Debris

Space-based high-power lasers for large debris removal is geopolitically contentious and such systems would be very costly. However, low power space-based lasers to remove small debris objects might be affordable[48] and more geopolitically palatable, if transparently operated, civilian-based, and international in scope.

If small object tracking dramatically improves, however, the pulsed-ultraviolet-laser technology that Claude Phipps is developing may provide an affordable way to remove such small debris.[50] This technology would consist of active small debris removal using laser ablation directed from a spacecraft such as the ISS. Ablation on the forward end of small debris objects would slow them down, causing them to deorbit more quickly. Cost analysis by Phipps estimates a cost of less than $1,000 to deorbit each small object within a few months—not exactly cheap, but likely to be much less expensive than other technologies for removing this dangerous threat.

The thorny geopolitical issues that even a low-power space-based laser system would raise could be ameliorated by keeping such systems civilian-based, transparent in consensus-selection of targets and timing, and with military veto power.

Propellantless Remediation Vehicles in LEO

NASA Johnson Space Center has proposed minimizing the LEO debris count of objects larger than 10 cm by removing 5-10 of the most threatening multi-ton objects per year.[33] Doing this with rockets lifting single-use grasp-and-deorbit or grasp-and-rehabilitate vehicles would likely be economically unfeasible and would need to be continued indefinitely.

Fortunately, there may be another way. From 2012 to 2014, NASA did preliminary work on developing an orbital debris removal vehicle called the ElectroDynamic Debris Eliminator (EDDE).[33] A project using EDDE vehicles could theoretically remove 2000 tons of upper stages within a 10-year period, reducing future collisional shrapnel by 97% at an estimated *total* cost of under $1 billion. Although this estimate will need to be verified, part of the cost savings would come from the fact that EDDEs are *non-propellant* vehicles that could be launched as *secondary* payloads.[32] [33] [51]

Ton-Class Objects in GEO

The space community does not currently know much about the debris situation in GEO, largely because it is too distant (35,786 km) to measure debris objects smaller than about 60 cm across.[52] We do know, however, that there are more than 1300 multi-ton objects in GEO, and about 70% are not operating and are tumbling and currently uncontrollable.[53]

Even though the impact velocity of such objects is much lower in GEO than in LEO (peaks at about 1.5 km/sec or 3,350 mph), they remain dangerous to working satellites and to potential remediating spacecraft because of their high mass. Moreover, uncontrollable objects in GEO are subject to gravitational perturbations that increase orbital eccentricity and relative inclination, leading to clustering at the relatively stable points and higher velocities of such mass-clusters as they cross the operational torus within which controlled satellites operate.[54]

In reaction to these dangers, the International Telecommunication Union (ITU) has placed increasingly strict requirements on the station-keeping ability of new satellites. The ITU demands that satellite owners guarantee their ability to safely move the satellites out of their orbital slots and into “graveyard” orbits, 300 km above GEO, at the end of their lifetime.[15] Unfortunately, evidence is mounting that these *new ITU requirements are insufficient to have a major effect on collision frequency*. In fact, an altitude increase of at least *2,000 km* would have to be used to reduce by one order of magnitude the long-term collision risk among geostationary satellites and explosion fragments.[55]

Rocket-Propelled “Catcher” or Service-Tender Spacecraft in LEO and GEO

Concerned aerospace engineers have proposed various grasping or manipulating spacecraft as catchers or service-tenders, including those utilizing balloons, nets, harpoons, and robotic grapplers.[22 56 57 58 59 60] In some concepts, the spacecraft would attach a deorbiting mechanism or simply grab and plunge to deorbit. In other concepts, the spacecraft would refuel or otherwise rehabilitate a defunct satellite. To be useful in LEO, however, rocket-propelled spacecraft would have to carry enough fuel to match repeatedly and precisely the speed and direction of target debris moving at different speeds, orbits, and altitudes. *The cost of designing, developing, testing, and launching such rocket-propelled spacecraft does not appear to be economically feasible*.[61] This situation again militates for utilizing propellantless or solar electric propulsion as much as possible for these spacecraft.

On the other hand, because relatively fewer satellites operate in GEO and because of their high commercial or military value, even rocket-propelled service-tender spacecraft at that altitude may be economically feasible in some cases.[22] It is perhaps for this reason that the Defense Advanced Research Projects Agency (DARPA), under a demonstration project called Phoenix, is teaming up with the private sector to harvest and “repurpose” still functional components of nonworking satellites in GEO to create new space systems at hoped-for greatly reduced cost.[21 22]

Beginning in 2016, the Phoenix Project proposes to attach nano-satellites to parts of retired U.S. Government and commercial satellites, making the debris a resource. In a process called “cellularization,” nanospacecraft separately carrying out functions such as power, communications, and attitude control would be launched into orbit as secondary payloads. A service-tender spacecraft would then be telerobotically directed to attach such miniature devices to large antennas or other large parts of dead satellites to produce working satellites at an estimated fraction of the cost of new ones launched from Earth.

DARPA’s cellularization concept is not the only approach to rehabilitating spacecraft in GEO. Vivisat, a joint venture of Orbital ATK and U.S. Space LLC, is proposing a Mission Extension Vehicle (MEV), which would attach to a satellite and take over the satellite’s stationkeeping activity, thus extending its useful life. the Space Infrastructure Servicing (SIS) vehicle, made by Canadian aerospace company MacDonald, Dettweiler and Associates (MDA), would use its manipulators to refuel or repair a spacecraft.[22]

"Touchless" Electrostatic and Electrostatic-Electromagnetic Disposal of Debris

Another potentially affordable way to clean up LEO and GEO, and perhaps other orbits as well, is by using a space-based electron gun or beam emitter to either deflect debris, or tug debris objects to deorbit.[61 62 63] *Electron beam technology is very mature, and the energy needed to generate the electron beam is orders of magnitude lower than what is needed for high power lasers.* For these reasons, *this technology offers a low-cost path for debris removal*. The exact size range of debris amenable to this treatment is unknown at this time, but will likely include kg-class to ton-class objects, at least for towing with electrostatic tethers (described below).

To deorbit a small to medium-sized debris object in LEO or low middle Earth orbit (MEO) by electromagnetic deflection, a spacecraft would direct a beam of electrons to a debris object. The beam would remotely impart an electrostatic charge to the object. Earth's magnetic field would thereupon exert a force on the electric charge of the debris as it crossed the field lines at high speed. Over time, the orbit would become highly elliptical and would intersect the Earth's atmosphere more and more deeply until the increasing friction brings the debris object down.[61]

On the other hand, to *collect* an object for deorbit from LEO or for reorbit into a GEO "graveyard" orbit by electrostatic "tether," a beam-emitter spacecraft would generate an electron beam at a debris object, thus remotely imparting an electrically negative potential on the object, while the emitting spacecraft remains relatively positive. The attraction between the negative and positive objects acts like a tether. The spacecraft could then remotely collect small or large debris, whether metal or non-metal.[56 63 64]

The big advantage of electrostatic "touchless" technology is that the deflector or tug spacecraft can operate with a separation distance of multiple craft radii, thus greatly reducing the risk of collision, even if the target object is tumbling. In addition, the cost is likely to be much lower than the cost of propellant-using catcher spacecraft. The disadvantage in GEO, however, is that the higher "graveyard" or "disposal" orbits envisioned would not in fact remove the debris from the cislunar econosphere, and such tumbling debris could therefore create a danger to future highly eccentric/elliptical Earth orbiting spacecraft.

The International Space Station (ISS) has a large power-generation capacity and is already in LEO. An electron beam device could therefore be integrated there for testing and deployment as an add-on module, avoiding the need to develop and launch a new spacecraft. A transparent, international program, involving space agencies of several countries, could implement projects using touchless or other debris-remediation technologies. Here again, testing and deployment on the ISS would facilitate international cooperation. For all these reasons, **NSS recommends utilizing the ISS to spur international cooperation for testing and deploying orbital debris management technologies.**

Toward the Future: Establishing Responsibilities and Rights in Space

Besides the Article VI requirement for "continuing supervision," Article VIII of the Outer Space Treaty (OST), calls on the Launching State to retain "jurisdiction and control" over any object it launches, whether that object, or even pieces of that object, cease to function or not. Removing a debris object *or even its fragments* therefore requires the consent of the State Party on whose registry it was launched.[65] However, determining the State Party can be daunting for small fragments in popular orbits. Most tracked fragments change inclination by less than one degree from their source object, and most are traceable to not just a source owner, but a source object. However, sun-synch orbit (roughly 97-99 deg.) is the second most popular inclination (after 81-83 deg.), and many countries use sun-synch. Therefore, if an object is not detected and tracked soon after it is launched, its owner or Launching State may not be identified.[31]

Complicating this picture is the fact that Article VI and VIII of the OST pertain to "Launching States," which are *not necessarily the owners* of launched spacecraft. After all, the "Launching States" for a rocket and its payload can include the country owning the satellite at the time of launch, the country owning the rocket at that time, and the country from which the rocket was launched. Moreover, selling and re-registering an object does not transfer Launching State liabilities to the new owner or registrant. Yet, no matter the owner, Articles VI and VIII place full responsibility for supervision, jurisdiction, and control of space objects (including fragments) on the Launching State(s). How, then, can this responsibility and its concurrent liability be transferred to a company attempting to remove or otherwise remediate orbital debris?

Under the long tradition of Maritime Salvage Law dating back to the time of the ancient Greeks and Romans, a person who voluntarily preserves at sea any vessel, cargo, freight, or other recognized salvage from danger has traditionally been able to collect a reward proportionate to the value of the object salvaged and taking into account other factors, such as the degree of danger to salvors and time used and expenses of salvors. Maritime nations have most recently codified such custom and law in the International Convention on Salvage 1989.[66] Article 14 of the Convention even considers protection of the environment as part of salvage, awarding a salvor who prevents oil pollution, for example, special compensation termed *liability salvage* instead of *property salvage*.

Unfortunately, there is no space equivalent to Maritime Salvage Law, which gives a private party the right to salvage an abandoned or imperiled vessel at sea *no matter the owner or country of vessel registration*. Nor is there a space equivalent of the 1972 London Dumping Convention, which prohibits the disposal at sea of vessels, aircraft, platforms, and other debris. An International Orbital Debris Convention, however, could promulgate rules analogous to some in maritime law for anti-dumping and for the removal, reuse, recycling, or rehabilitation of orbiting objects by salvors, who would collect rewards through the reward system described above.

Such salvage rules could even address removing orbiting shrapnel clusters from the Earth-orbit environment by compensating salvors with *liability* salvage. Key to making such rules work, however, would be the formulation of legal mechanisms for voluntary *and involuntary* loss of ownership of and responsibility for the objects to be salvaged. There would also have to be special salvage exemptions or other provisions for sensitive military satellites. Yet a motivated space community, by means of an International Orbital Debris Convention, could *enlist space-appropriate provisions from these maritime legal systems into an international legal codification to deal with orbital debris*, while resolving the legal uncertainties surrounding Articles VI and VIII of the OST.

Article IX of the OST, *inter alia*, calls on the State Parties to avoid "harmful interference with the activities of other State Parties in the…use of outer space" and to "*undertake appropriate international consultations* before proceeding with any such activity or experiment" (emphasis added). Clearly orbital debris is interfering now with the space activities of State Parties to the OST. **NSS therefore recommends that spacefaring countries, along with public and private space-related entities within their borders, organize and participate cooperatively in an International Orbital Debris Convention, in compliance with OST Article IX, to clarify legal responsibilities and rights vis-à-vis orbital debris management, including those surrounding OST Articles VI and VIII.**

Such a Convention, while international, *need not be under the auspices of the United Nations*. Indeed, the International Code of Conduct, first formulated by European Union Member States to deal with orbital debris mitigation, came to languish in 2015 amid fractious negotiations sponsored by the United Nations.[67]

Summary

In the preceding pages the National Space Society has laid out both the non-technical and technical challenges dealing with orbital debris cleanup. To reiterate, the n*on-technical* challenges include 1) adverse economic factors, 2) policy and legal barriers, and 3) international/geopolitical sensitivities. The *technical* challenges include 1) inadequate Space Situational Awareness (debris detection, tracking, and conjunction predictions) and 2) lack of ready technology for removing or using orbital debris.

To overcome the non-technical challenges, we recommended three different funding sources for orbital debris cleanup to be established in consultation and collaboration with spacefaring governments worldwide and multilateral commercial entities, most notably the Satellite Industry Association (SIA); enhanced international cooperation in sharing Space Situational Awareness (SSA) data through the Inter-Agency Space Debris Coordination Committee and commercial entities; a strengthened and empowered DOT/FAA/AST, a public-private monetary reward system to carry out the cleanup; the establishment of a new Space Traffic Management entity within the Executive Branch of the U.S. Government with international reach and capacity to organize and supervise cleanup; orbital debris guidelines and agreements with Russia, China, and other countries; and an International Orbital Debris Convention to determine liabilities, ownership, and legal responsibilities to facilitate cleanup efforts.

To overcome the technical challenges, NSS reviewed the major emerging players in the SSA realm and recommended ways that public and private resources could be used to foment growth of these entities. Possibly effective strategies and technologies for orbital debris remediation were described. Finally, policies such as utilizing the ISS as a test bed to facilitate the international development of orbital debris remediation technologies were recommended.

In the face of plans by new space companies to put up thousands of new satellites into Earth orbits already threatened by orbital debris, the National Space Society urges the worldwide space community to tackle this threat to our spacecraft, our modern way of life, and our future plans for space—while it is still manageable and economically feasible.

<u>ANNEX A</u>: Emerging Providers for Space Situational Awareness

Examples of emerging SSA providers include the Commercial Space Operations Center (ComSpOC), run by Defense contractor Analytical Graphics, Inc. (AGI), currently using more than 28 optical sensors within eight optical sites, three radio frequency interferometry sites, and two radar installations to track 6,000 to 7,000 space objects so far.[68 69]

In 2015 defense contractor Lockheed Martin announced its own effort to develop an orbital debris tracking site in Western Australia.[68]

Another emerging SSA provider, ExoAnalyticSolutions, is offering a software suite called ExoAnalytic Space Operations Center (ESpOC™) that can process and interpret optical data from small telescopes in real-time. ExoAnalytic also has a web-based application called SpaceFront™ that enables rapid analysis of astrometric and radiometric data for resident space objects (RSOs) observed by the ExoAnalytic global sensor network. Using such data, SpaceFront™ provides orbital debris conjunction alerts, expected minimum miss distance, and expected time of closest approach.[70]

Some emerging free or minimal-fee providers of orbital debris and other SSA data include:

1) The USAF Academy Center for Space Situational Awareness, deploying its Falcon Telescope Network involving twelve universities around the world;[71]

2) The International Scientific Optical Network (ISON) started by Russian astronomers in 2005, which joins 35 observation facilities with 80 telescopes in 15 countries;[72]

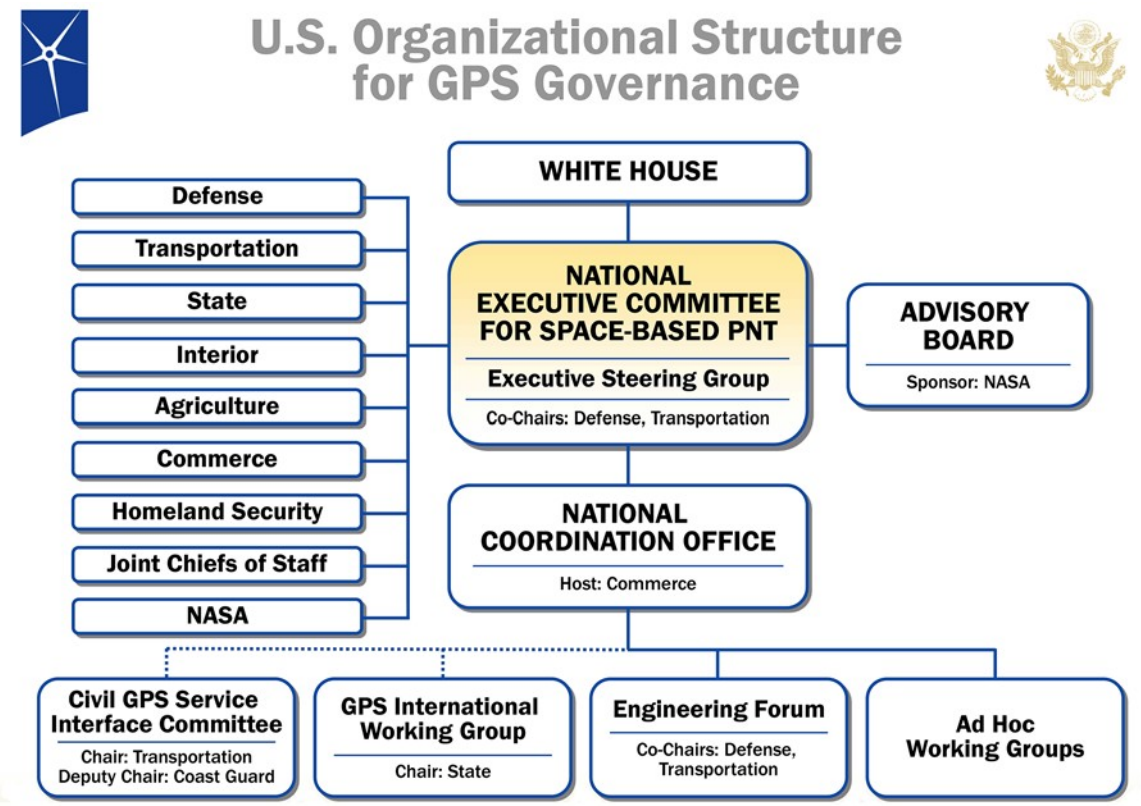
3) A consortium of Lawrence Livermore National Laboratory, Naval Postgraduate School, and Texas A&M University deploying its Space-based Telescopes for the Actionable Refinement of Ephemeris (STARE), with a goal to have 18 3U Cubesats in LEO, each with a small telescope to observe objects predicted to have close conjunctions with valuable assets;[25]

4) The Canadian Space Agency's Near Earth Object Surveillance Satellite (NEOSSat) launched in 2013 carrying a 6-inch aperture telescope in a sun-sync orbit to find and track debris in high Earth orbits as one of its missions;[73 74]

5) The Space Surveillance and Tracking (SST) Consortium Agreement signed by representatives of France, Germany, Italy, Spain and the United Kingdom in June 2015, which sees its members cooperating to provide an EU-wide Space Surveillance and Tracking Framework to help protect European space infrastructure, facilities and services.

ANNEX B: The PNT ExCom

As can be seen from the diagram below (see colored box), the National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT ExCom), the model for our proposed entity for Space Traffic Management (STM ExCom), has input from relevant U.S. Government agencies and international entities, as well as from private persons through an Advisory Board sponsored by NASA.[75]



Source: www.gps.gov [75]

The permanent staff for the PNT ExCom are in the GPS-PNT National Coordination Office. Connected to the GPS-PNT National Coordination Office is a GPS International Working Group and Ad Hoc Working Groups needed to do planning and solve problems nationally and internationally. Through the GPS International Working Group, the whole structure feeds into the International Committee on Global Navigation Satellite Systems (ICGNSS) from the U.S., Russia, China, Europe, India, and Japan. ICGNSS operates under the auspicious of the United Nations Office for Outer Space Affairs (UNOOSA).

Because the permanent staff of the GPS-PNT National Coordination Office plans and quickly solves GPS-PNT issues through national and international coordination and consensus, it has considerable flexibility, nimbleness, capacity, and reach.

The White House by executive action through the U.S. Space-Based Positioning, Navigation, and Timing Policy of December 15, 2004 established the above-described executive offices.[76] Funding and staffing for the entity largely comes from the U.S. agencies involved.

Although the purview of the (Space-Based) PNT ExCom and its offices could theoretically be expanded to include orbital debris, an analogous entity, focused specifically on orbital debris cleanup and coordinating with PNT ExCom, would likely do a much better job coordinating a national and international effort to clean up Earth's orbits.

ANNEX C: Glossary of Acronyms

ADR: Active Debris Removal

ASRA: American Space Renaissance Act ComSpOC:

Commercial Space Operations Center

COTS: Commercial Orbital Transportation Services

DARPA: Defense Advanced Research Projects Agency

DOT: Department of Transportation

DOT/FAA/AST: Office of Commercial Space Transportation in the FAA EOL:

End of life

FAA: Federal Aviation Administration

GEO: Geosynchronous Orbit

GPS: Global Positioning System

IADC: Inter-Agency Space Debris Coordination Committee ISS:

International Space Station

LEO: Low Earth orbit

NRL: U.S. Naval Research Lab

NSS: National Space Society

OOS: On-Orbit Servicing

OST: Outer Space Treaty (Full Title: International Convention on etc.)

PNT ExCom: National Executive Committee for Space-Based Positioning, Navigation, and Timing

SIA: Satellite Industry Association

SSA: Space Situational Awareness

STM ExCom: Space Traffic Management Executive Committee

USAF: United States Air Force

USG: United States Government

JICSpOC: USAF Joint Interagency Coalition Space Operations Center

JSpOC: USAF Joint Space Operations Center

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