A Proposal for Active Debris Remediation – Selecting Objects

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Abstract

Worldwide scientific consensus exists on a "short list" for selection of high mass derelict objects in LEO for ADR. The next collision involving those objects could happen at any time, after which the costs of operating in space will increase. Although several key questions remain unanswered and serious hurdles to ADR persist, it's time to start planning ADR missions. TCTB's public-private model for ADR planning among responsible nations could catalyze meaningful remediation as soon as possible.

Introduction

Today there are thousands of high mass derelict rocket bodies (R/Bs) or spacecraft (S/C) with large debris-generating potential in or passing through Low Earth Orbit (LEO), left by Russia, the U. S., China, France, the European Space Agency, Japan, India and a few others. Although Active Debris Remediation (ADR)[1] of all of those space objects has not been recommended, the need to begin ADR among them to reduce future risk to operating spacecraft has been clear since before 2006.[2]

A notional set of 500 potential ADR candidates was identified in 2011 by J.-C. Liou, NASA's Chief Scientist for Orbital Debris.[3] Since then, several authors have analyzed high mass derelict objects in LEO and identified smaller groups (generally 10-100 objects per group) that present the greatest risk to operating spacecraft.[4] Liou used a remediation criterion based on mass and collision probability over time (plus a

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[1] ADR includes deorbiting or orbital lowering of a space object where decay will ensue within a reasonable time, or "nudging" the object to reduce the probability of collision with other objects, which is known as Just-in-time Collision Avoidance (JCA).

[2] Liou, et al., "Risks in Space from Orbiting Debris", Science Magazine, Vol. 311, pp. 340-341 (2006). For general background regarding ADR, see Bonnal, McKnight (Eds.), "IAA Situation Report on Space Debris – 2016".

[3] Liou, "An Active Debris Removal Parametric Study for LEO Environmental Remediation", Advances in Space Research, Vol. 47, Issue 11, pp. 1865-1876, Figure 13 at p. 1874 (2011). Figure 13 identifies the "Top 500 Current R/Bs and S/C" potential ADR candidates by class and orbital characteristics (i. e., altitude, inclination, mass). NASA did not authorize public release of the 500 specific space object names.

[4] These include McKnight, "Pay Me Now or Pay Me More Later: Start the Development of Active Orbital Debris Removal Now" (2010); Utzmann, et al., "Ranking and Characterization of Heavy Debris for Active Removal" (2012); Kebschull, et al., "Deriving a Priority List Based on the Environmental Criticality" (2014); Rossi, et al., "The Criticality

few necessary assumptions) to identify categories of objects that present the greatest risk; each subsequent author used similar formulas and assumptions to identify specific objects, or types of objects, with the highest risk in terms of impact (of each object's collision and fragmentation) on the surrounding space environment over time. There is considerable overlap among the space objects identified by each author since Liou. Moreover, most of the objects identified by each subsequent author fall into the same categories of objects identified by Liou in 2011. Appendix 1 (Space Object Identification Compilation) lists the objects from the cited studies, including specific Space-Track SATCAT (NORAD ID) object numbers where the author provided it in his or her paper, organized by the categories contained in Liou's study. Appendix 1 contains 291 specific objects, identified by SATCAT number. **65 of the specific objects in Liou's categories were named by multiple authors.** An Abstract for a paper entitled "Identifying the 50 Statistically Most Concerning Derelict Objects in LEO", to be written by Dr. Darren McKnight and several of the authors noted above, has been accepted for presentation at the 71st International Astronautical Congress (Cyberspace Edition) in Dubai in October 2020.

Russian objects constitute the overwhelming majority among the larger group of 500, and they form an even higher percentage of most of the shorter lists.[5] There are at least two reasons for this: They are generally higher in mass than other derelict objects in LEO, and many of them are "clustered" together in the same relatively crowded circular orbital planes.[6] As a practical matter, ADR has to start somewhere, so identifying the most dangerous objects from a statistical viewpoint seems like the best course of action to begin a serious dialogue about ADR.[7]

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of Spacecraft Index" (2015); Pardini, et al., "Characterization of Abandoned Rocket Body Families for Active Removal" (2015); McKnight, et al., "Preliminary Analysis of Two Years of the Massive Collision Monitoring Activity" (2017); McKnight, et al., "The Cost of Not Doing Debris Remediation" (2017); Anselmo, et al., "An Index for Ranking Active Debris Removal Targets in LEO" (2017); Letizia, et al., "Extending the ECOB Space Debris Index with Fragmenting Risk Estimation" (2017); Letizia, et al., "Development of a Debris Index" (2017); Pardini, et al., "Evaluating the Environmental Criticality of Massive Objects in LEO for Debris Mitigation and Remediation" (2017); and McKnight, et al., "Assessing Potential for Cross-Contaminating Breakup Events from LEO to MEO/GEO", IAC-18-A6.2.9x41942, 69th Annual Astronautical Congress (IAC), Bremen, Germany, October 1-5, 2018. A few other papers not listed here, some of which pre-date the 2011 Liou study, focus on the same objects described in the studies listed above, although the objects listed in those other papers were not included in the Compilation in Appendix 1. A comparison of the various methodologies used in all these studies is found at Lidtke, "High Collision Probability Conjunctions and Space Debris Remediation" (2016).

[5] Judging by mass alone, at the beginning of 2015, Russian R/Bs in unclassified orbits in LEO accounted for 64% by number and 76% by mass. (Note 4, supra, Pardini, "Characterization of Abandoned Rocket Body Families for Active Removal")

[6] Besides altitude, mass and time in orbit, the greater frequency of "near misses" experienced within clusters is a significant factor in determining probabilities of collision. Once a class of objects is determined, there is generally little difference among individual objects within that group in terms of their orbital or physical characteristics. Many clusters consist of derelict R/Bs and their no longer functional companion S/C.

[7] Most studies have suggested at least 5 objects per year should be removed to stabilize the affected orbits in LEO. Economies of scale would flow from multi-target ADR missions among "clusters" of objects which are similar in size, shape and other characteristics such as tumbling. In addition, targeting similar objects would facilitate multiple removal missions utilizing the same hardware and procedures. Selecting one or more objects within each group should also be part of any ADR targeting plan. One or more of the 18 Russian SL-16s R/Bs still in orbit at 71 deg. inclination and 850 km altitude, each with a mass of 8300 kg, seem like good candidates for initial selections. See McKnight, et al., "Proposed Series of Orbital Debris Remediation Activities" (2017), for a summary of the recent conjunctions between these objects.

However, while countries are entirely responsible for the existing high mass debris in LEO, expecting Russia, or any other nation if the statistics were reversed, to shoulder the entire initial financial burden of ADR based on legal "ownership" considerations would be counterproductive, especially since leaving objects in space after they are no longer used has been a common practice among space-faring nations since the beginning of the space age.

The need for concerted international action now is based on forecasts suggesting the next high mass collision among derelicts could happen at any time, after which the costs of operating in space will greatly increase.[8]

Although several ADR object identification studies have been published, and numerous ADR technologies have emerged across the world since NASA highlighted the need for remediation in 2006, legal, political, national security, funding and economic impediments to ADR remain to be overcome. From a purely practical planning perspective, we are no closer to ADR than we were in 2006! **It's time to start planning ADR missions**! Armed with maturing object selection and technology baselines, we need to start confronting the issues that must be addressed before ADR can begin. Questions such as who will pay and how much, how to make choices among competing ADR technologies and companies, which objects will be first, and how to allocate mission risks among stake-holding countries and ADR mission participants, are just a few that need to be addressed. Given the broad nature of these questions and the diverse interests of the parties involved, answers (and progress towards actual ADR) will take several years.

Like the technical groundwork on target selection, much has also been written to date addressing the legal, political, national security, economic and funding hurdles which confront ADR. Possible solutions have been proposed for each of these impediments, but no one has actually started planning the real remediation missions which lay waiting near the end of whichever path is chosen. Stated another way, real ADR will only result from a combination of technical progress, legal risk mitigation, political will, economic resource commitments, **and a procurement plan that prepares for and then results in action**. Here's how we can get started.

Proposal

In May 2019 TCTB, LLC[9] proposed a private-public international partnership, based on a Red Cross or mediation model, designed to facilitate communication among two or more stake-holding nations complementary to (and parallel with) diplomatic channels. TCTB streamlines cooperation among those nations through separate but interdependent "consulting" contracts with each participating country.

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[8] Note 4, supra. See also, Adilov, et al., "An Economic "Kessler Syndrome": A Dynamic Model of Earth Orbit Debris", Economic Letters, Vol. 166, pp. 79-82 (2018). Statistical probabilities, by their very nature, are not always effective motivators for action.

[9] TCTB is an acronym for "Three Country Trusted Broker", which describes its business model in a few words. See TCTB's website, threecountrytrustedbroker.com, for details regarding its business model and ADR planning Phases. TCTB overcomes the legal, political, national security, economic and funding hurdles that have hindered ADR to date. TCTB submitted formal contracting Proposals to China, Russia and the U. S. in May 2019. Two papers addressing impediments to ADR, written in October 2019 and February 2020, along with references to articles by others, can be found at TCTB's website in the Library section.

TCTB's six planning Phases are designed to address the above-described questions and overcome hurdles to ADR.

Since providing formal contracting Proposals to China, Russia and the U. S. in May 2019, TCTB has begun working with a Russian partner, Mr. Valentin Uvarov, with a similar professional interest in ADR, to explore formation of a companion company, "TCTB II", in Moscow, Russia, in order to facilitate local contracting and planning efforts in Russia.[10] TCTB's principals in Russia and the U. S. possess broad experience in space law, procurement law and planning, mediation, management systems, governance structures, and public-private collaboration which, when coupled with TCTB's unique creative vision, can provide a bridge for countries to work together to accomplish real ADR while setting aside political disagreements on unrelated matters.

To further illustrate the need for **ADR planning**, as well as its inherent timeline regardless whether countries act directly together or with TCTB's assistance, TCTB's process involves six Phases leading to ADR in Phase 7.[11] In Phase 5, TCTB plans to conduct a worldwide competitive bidding process on behalf of participating countries, by asking bidders to prepare and submit self-funded, priced Proposals to accomplish ADR of specific objects or groups of objects from among a narrow subset of objects chosen for this purpose.[12] The object identification studies described above have sufficiently defined potential ADR candidates for this activity to proceed.[13] The kind of practical information that would be provided by bidders seeking to accomplish the work (e. g., technology and technical work plan, specific objects or groups of objects per mission, pricing, risk allocation plan), and which would have to be negotiated, approved and funded by the participating countries before beginning Phase 7, is a prerequisite for accomplishing ADR, yet no effort is underway today among stake-holding nations to develop it. The results of that process could also inform (and speed) future investments to close any technology gaps, since some have suggested ADR is not yet "ready for primetime". Likewise, legal and other impediments to ADR among nations are mitigated through a series of clauses to be included in TCTB's country contracts, to be negotiated in Phase 1. Drafts of those clauses are contained on TCTB's website.

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[10] TCTB II seeks to contract with Roscosmos, or its designee, in Russia. In the U. S., TCTB is pursuing a contract with the Commerce Department's Office of Space Commerce, but NASA also has the flexibility (and funding) to undertake **ADR planning**. TCTB is also working with the authors of the article referenced in Note 8, supra, to develop an economic formula for country cost sharing based on each country's share of future (lost) opportunities in space due to future debris collisions. Participating countries will negotiate pro forma ADR cost sharing in Phase 1 of TCTB's process, subject to individual country funding vetoes before beginning ADR in Phase 7.

[11] Note 9, supra. TCTB estimates planning Phases 1-6 will take more than three years to accomplish.

[12] Several private companies across the world, including Airbus, Altius (Voyager Space Holdings), Astroscale, Clearspace, Maxar, Northrop Grumman, and others, along with a number of governmental entities, have developed and/or are using or testing ADR-capable technologies today. ADR "subcontracts" issued by TCTB to industry (contingent on country provided funding), under "prime contract" terms and conditions negotiated between TCTB and participating countries, would ameliorate legal and national security impediments to ADR, and facilitate cost-sharing among nations, as further described on TCTB's website.

[13] TCTB's Phase 2 envisions working with participating countries to develop a list of ADR candidates for bidding purposes. This process could involve each country nominating their own objects, or ranking objects by internationally recognized experts ("Dream Team"), to determine the best procurement strategy. The previously identified lists of ADR candidates discussed in this paper will almost certainly become the baseline for Phase 2 object selection and Phase 5 bidding activity, whether or not TCTB is involved in the process.

Unfortunately, gridlock today among the leading nations in space who "own" most of the risk of high mass debris in LEO (as well as most of the opportunity that would flow from ADR) shows signs of worsening.[14] Because the work product developed by TCTB in **ADR planning** will become the property of participating nations, it's hard to argue against starting now through TCTB, even if only in one or two countries at first, while the diplomatic process plays out.

Conclusion

Donald Kessler's seminal warning in 1978 about growing instability in LEO due to accumulating debris was based on mathematical theories concerning the growth of the asteroid belt.[15] As Don has said, the "Kessler Syndrome" was a phrase coined by others, not him.[16] Notwithstanding the hyperbole, objects and debris continue to accumulate in LEO, at a faster rate than Don assumed for his forecast, while our use and dependence on space is increasing, jeopardizing our collective future in space. Consideration of the consequences of failing to protect our environment from a number of imminent dangers, including orbital debris, should motivate us to begin **planning now for ADR** to protect our shared orbital space around Earth.

TCTB's **ADR Plan** presents a clear and achievable, albeit novel, path to ADR.

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[14] In the wake of the impasse over PAROS ("Proposed Prevention of an Arms Race in Space Treaty"), Russia and the U. S. have recently agreed to talk about an agenda for space matters, possibly including the Artemis Accords. Meanwhile, Coronavirus and the Wolf Amendment are likely to intertwine and further chill relations between China and the U. S. for the foreseeable future. In short, politics will continue to dictate a slow pace for progress on single issues like ADR through formal diplomacy.

[15] D.J. Kessler and B.G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt", Journal of Geophysical Research, Volume 83, pp. 2637-2646 (1978). The concept of collisional cascading of objects in orbit can be traced to studies of the origin of the solar system, ring formation around planets, and the origin of meteoroids and meteorites from asteroids.

[16] The "Kessler Syndrome" was meant to describe the phenomenon that random collisions between objects large enough to catalog would produce a hazard to spacecraft from small debris that is greater than the natural meteoroid environment. In addition, because the random collision frequency is non-linear with debris accumulation rates, the phenomenon will eventually become the most important long-term source of debris, unless the accumulation rate of larger, non-operational objects (e.g., non-operational payloads and upper stage rocket bodies) in Earth orbit were significantly reduced. Based on past accumulation rates, the 1978 publication predicted that random collision would become an important debris source around the year 2000, with the rate of random collisions increasing rapidly after that, if the accumulation rate were not reduced to near zero.

Appendix 1 – Space Object Identification Compilation[17]

The Compilation below is organized by the categories listed in Figure 13 of Liou's 2011 study referenced in Footnote 3 of the paper, by country, and includes Space-Track SATCAT Numbers for individual unclassified objects as identified by the authors of the studies listed in Footnote 4 of the paper. Liou's categories are **shaded and underlined in bold font**.

Although not intended as establishing any ADR priority among objects, 65 specific objects were named in multiple studies and were also contained in Liou's categories; they are **underlined in bold font**. 242 specific objects within Liou's categories were named by one or more authors. 49 additional specific objects named by single authors but not contained in Liou's categories are listed at the end by SATCAT Number. The Targeting Compilation demonstrates a substantial degree of consensus within the scientific community on suitable candidates for ADR. Moreover, there is general agreement regarding categories of objects.[18]

-**SL-16 R/Bs at 71 deg. incl., alt. 850 km**: **22220**, **22566**, **22285**, **23088**, **23405**, **31793**, **25407**, **28353**, **16182**, **17590**, **17974**, **19120**, **19650**, **20625**, **22803**, **23705**, **24298**, **26070**

-**SL-8 R/Bs at 66 deg. incl., perigee above 650 km; at 74 deg. incl., perigee above 650 km; and at 83 deg. incl., perigee above 650 km**:[19] 22308, 15056, 32053, 9044, 8646, 10732, 6708, 5239, **12115**, 4071, 4784, 5555, 6061, 6683, 7009, 7443, 7831, 8597, 9023, 9638, 10142, 10537, 10777, 11136, 11379, 11681, 12088, 12508, 13003, 13168, 13649, 14085, 14625, 15598, 16494, 16953, 17526, 18710, 19827, 20509, 21090, 21797, 22208, 23180, 24306, 26819, 28421, 11511, 12443, 16682, 23432, 1575

-**SL-3 R/Bs at 81 deg. incl., alt. 850 km**:[20] 4420 , 5732, 5918, 6080, 6257, 6393, 6660, 7210, 7275, 7364, 7493, 7575, 7715, 8027, 8294, 8520, 8800, 8846, 9482, 9662, 9904, 10515, 11166, 11289, 11608, 11963, 12457, 12646, 13719, 14453, 4394

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[17] Unclassified data regarding all space objects addressed in this paper is found in Space-Track, the publicly available data base maintained by the U. S. government for tracking purposes. For TCTB's space object selection purpose in Phase 2 of its ADR planning process, all available data regarding derelict space objects, from all available sources, would need to be considered.

[18] An earlier study by Klinkrad, "Space Debris: Models and Risk Analysis", Springer (2006), contained a list of the "Top 200" space objects for ADR according to their criticality for catastrophic collisions. Most of them also appear in the Compilation. See Peters, "Innovative Approach for Effective and Safe Space Debris Removal", (2019), at Table B.1, for Klinkrad's "Top 200" list.

[19] According to Space-Track as of May 31, 2020, 288 SL-8s remain in orbit, many in clusters. Peters (note 18, supra) selected 11668, 22591, 13128, 17240 and 7350, five SL-8s not included by object number in the Compilation, but contained within Liou's categories of objects, for a hypothetical ADR mission, based on their similarities (83 deg. incl., 1000 km altitude, and similar Right Angle of Ascending Nodes (RAANs)), and on ADR economy considerations.

[20] According to Space-Track as of May 31, 2020, 51 SL-3s remain in orbit. 2 are at 98 deg. incl. and are likely included in Liou's category entitled "Various R/Bs and S/C (1000-8300 kg)".

-**Cosmos S/C at 65 deg. incl., perigee above 850 km; at 71 deg. incl., perigee above 750 km; at 81 deg. incl., perigee above 550 km; and at 83 deg. incl., with perigee above 500 km**:[21] **27470**, **12879**, **13589**, **15171**, **33272**, **36095**, **10531**, **11084**, **11165**, **17369**, **18187**, **23189**, **40358**, **40699**, **12149**, **13259**, **17973**, **19119**, **23087**, **3081**, **39177**

-**Meteor S/C at 81 deg. incl., alt. 850 km; and at 83 deg. incl., alt. 950 km**:[22] **27001**, **35865**, **40069**, 4419, 5731, 5917, 6079, 6256, 6392, 6659, 7209, 7274, 7363, 7490, 7574, 7714, 8293, 8519, 8799, 8845, 9481, 9903, 8026, 9661, 10514, 11288, 11605, 11962, 12456, 13113, 13718, 14452, 15099, 15516, 16408, 16735, 17290, 18312, 18820, 19851, 20670, 20826, 22782, 16191, 19336, 20305, 21232, 21655, 22969

-**Various R/Bs and S/C (1000-8300 kg), 98 deg. incl., above 500 km perigee)**:

Russian: **23343**, **25400**, **27006,** 28367, 33397, 35688, 36509, 36600, 37795, 28811, 40541, 39228, 36606, 33319, 40303, 40047, 31699, 31123, 27610, 36589, 28061, 29269, 37363, 36039, 25394

French: **20443**, **21610**, **22830**, **23561**, **25261**, **27387 (Envisat R/B)**, **22823**, 25260

Chinese: **31114**, **40336**

U. S.: **25634**, 13777, 25682, 39084, 25994, **20322**, 19531, 13923, 15427, 16969, 22739, 23455, 25338, 26536, **27453**, 28654, 33591, 24796, 24836, 24841, 24870, 24903, 24905, 24946, 24948, 24967, 25043

ESA: **27386 (Envisat S/C)**, **29499**, **38771**, **21574**

Japanese: 28931, **24277**, **27597**, **27601**

Indian: 25756

Miscellaneous Space Objects at other inclinations and altitudes listed only by a single author but not contained in Liou's categories:

Russian SL-14 R/Bs (10541, 12880, 13590, 15100, 15475, 15822, 16194, 16594, 17178, 17291, 17588, 18340, 18821, 19337, 19852, 20238, 20671, 20741, 21034, 21305, 21734, 22040, 22283, 22693, 22970, 23412, 23793 and 25369); Russian Sea Launch R/Bs (26762 and 28138); Russian Intercosmos 22 R/B (12465); U. S. Atlas Centaur R/Bs (694, 6797 and 10722); U. S. Titan R/Bs (19461 and 26474); U. S. S/C (25791, 10967, 22076 and 21701); Chinese Yaogan S/C (36121, 38354, 39011, 39012, 39013, 39410, 40275 and 40878); and Indian R/B (40270).

[21] According to Space-Track as of May 31, 2020, 2490 Cosmos S/C have been launched to date. A few of these may also be included in Liou's category entitled "Various R/Bs and S/C (1000-8300 kg)".

[22] According to Space-Track as of May 31, 2020, 51 Meteor S/C are still in orbit, mostly in high LEO orbits.