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Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space

A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing

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Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space

A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing

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The Report is written in such a format that it could be easily understood by technical and non-technical readers alike. It is intended to provide an overview of various important interdisciplinary issues, matters and questions relevant to active debris removal and on-orbit servicing of satellites, and to serve as a basis for detailed and precise enquiry into the matters identified.

The Report is not a technical report, neither is it intended as a technical study. As such, many of the data, ideas, concepts and means described in this Report have not been referenced, tested and/or validated. Readers interested in undertaking independent scientific analysis of the technical concepts and means described in this Report for purposes of validation are free (indeed encouraged) to do so.

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Executive Summary

As a direct result of mankind's exploration and use of outer space since the dawn of the space age, a massive amount of space debris (i.e., non-functional and/or uncontrolled man-made objects and component parts thereof) have been left in outer space, particularly in those orbits that are most used. Over the last few decades, the rate at which human activities in space have led to the creation of space debris has increased in a linear fashion. Although presently, the number of space objects being launched into orbit has decreased as compared to the height of the Cold War era, more objects are being launched into higher orbits (and are thus staying longer in space), and many more countries are also launching objects. In the absence of globally uniform and systematic procedures for manoeuvring space objects in orbit for collision avoidance purposes, the resulting environment has been one in which conjunctions between orbiting space objects have become commonplace. In addition, there have been a few recent events — both intentional and non-intentional — that resulted in the creation of large amounts of debris thereby eliminating the gains made by years of debris mitigation efforts. The proliferation of space debris poses major risks to the sustainability of mankind's exploration and use of outer space.

The Inter-Agency Space Debris Coordinating Committee (IADC) and the United Nations Committee on Peaceful Uses of Outer Space (UNCOPUOS) have adopted a series of guidelines that lay down specific recommended measures to be implemented by all space actors so as to mitigate or reduce the possibility of creating space debris during the conduct of space activities. The value of the guidelines and the means by which their universal implementation can be achieved were assessed at the first two international interdisciplinary space debris congresses held in Montreal and Cologne in 2009 and 2010 respectively.[1] The space debris mitigation guidelines focus on, and emphasize the mitigation (or reduction) of the rate at which *new* pieces of space debris are generated during the conduct of space activities. However, in view of the massive amount of debris already in existence in Earth orbit, growing consensus among experts suggests that an active process for the removal of *existing* debris from space and for on-orbit servicing of satellites is required in addition to the mitigation efforts in order to protect the space environment and guarantee its sustainability in the long-term.

Active debris removal (ADR) and on-orbit satellite servicing (OOS) require the development of advanced technologies and concepts. Their implementation also raises a number of difficult technical, economic, strategic, institutional, legal and regulatory challenges that must be addressed at the very outset. The issue of how to legally define what constitutes debris for purposes of removal, for instance, ought to be urgently revisited. It is significant to note in this regard that the existing regime of international space law consisting primarily of the provisions of the five space treaties adopted under the auspices of the United Nations does not specifically define space debris. According to the relevant provisions, any object that is launched into outer space is a "space object", and the appropriate State (being the

[1] UN Document no. A/AC.105/C.1/2011/CRP.14 of February 2011.

launching State or the State of registry of the object as the case may be) is obliged to maintain jurisdiction and control over the object as long as it remains in outer space.

In view of the foregoing, it appears that we are at the threshold of a new epoch in which environmental preservation of outer space has taken on a new meaning and sense of urgency not only for purposes of protecting valuable space assets in the short-term, but also to ensure the continued sustainability of space activities in the long-term.

The goal of this Report is to contribute to the international discourse on the subject by: assessing the current space debris situation and determining what can be achieved by active debris removal and on-orbit satellite servicing; examining various technical concepts and means, legal and economic aspects, as well as operational and organizational requirements for active debris removal and on-orbit satellite servicing; and, proffering specific and viable policy and regulatory steps (mechanisms) that may be considered and adopted by States and other stakeholders to facilitate the removal of space debris and the servicing of satellites in orbit.

The Report is divided into five sections. The first section assesses the seriousness of the current space debris situation and considers the extent to which the situation can be improved with the implementation of active debris removal and on-orbit satellite servicing. The Report finds that at present, active debris removal and on-orbit satellite servicing are necessary to ensure the continued sustainability of activities in LEO, MEO and GEO, and that they will become absolutely indispensable in a relatively short period of time. The second section of the Report examines various technical concepts and means for the conduct of active debris removal and on-orbit satellite servicing, as well as their legal and economic implications. Specifically, the Report describes some of the technologies and capabilities that are currently being developed or considered to support active debris removal and on-orbit satellite servicing activities and considers the legal and economic implications thereof. Although the Report focuses on a handful of technological concepts and means, this is by no means an expression of support or approval for those concepts and means so discussed. The underlying objective is simply to assess the level of maturity and readiness of such technological concepts and means.

Section three of the Report considers various legal, regulatory and strategic issues related to active debris removal and on-orbit satellite servicing. In this section, the Report finds that there are numerous international and domestic legal, regulatory and strategic challenges to the conduct of active debris removal and on-orbit satellite servicing. At the international level, these challenges range from the lack of a specific definition of what constitutes space debris under the five existing space law treaties to difficulties posed by concepts such as State jurisdiction and control over space objects as well as State liability for damage that may occur to third parties as a result of ADR and OOS activities. At the domestic level, the Report particularly identified the existence prohibitions and restrictions on the transfer of control over space objects to foreign entities as a major challenge to ADR and OOS activities.

Section four of the Report focuses on the organizational and operational requirements for the effective conduct of ADR and OOS operations. In this regard, the Report finds that the establishment of an international inter-governmental organization to foster the development of the technology for ADR and OOS, and ultimately to conduct ADR and OOS activities on a commercial basis is a potential way forward. Alongside the establishment of the inter-governmental organization, the Report also proposes that governments should undertake either to remove or procure the removal of space debris created as a result of their national space activities, and that governments should also amend their licensing rules to include an assured removal requirement. The Report further proposes the establishment of a Global Fund for Space Debris Removal to foster the development of the technology and also to compensate commercial entities that achieve such active removal.

Conclusions as well as several policy and regulatory steps recommended by the congress are reflected in section 5 of the Report. It is envisaged that if these policy and regulatory steps are actively pursued by States and other stakeholders either unilaterally or through multilateral fora, they will facilitate the conduct of active debris removal and on-orbit satellite servicing operations. The congress also considered the *McGill Declaration on Active Debris Removal and On-Orbit Satellite Servicing* attached as Appendix A to the Report, and although the congress did not formally adopt the Declaration, it is nevertheless presented as a compendium of recommended regulatory and policy steps to be considered by stakeholders.

Preface

Although the space age has brought about many technological, societal, and economic benefits for all humankind, these benefits have not been achieved without negative consequences. As a result of past activities in space, a massive amount of space debris — non-functional and uncontrolled objects — has been left in Earth orbit and this poses a serious challenge to the sustainability of outer space.

Presently, 21,000 human-made objects larger than ten centimetres in diameter orbiting the Earth are being actively tracked. It is further estimated that there are an additional 450,000 to 600,000 objects measuring between 1 and 10 centimetres diameter in Earth orbit, and many hundreds of millions measuring between 1 millimetre and 1 centimetre. A total of 16,000 objects larger than 10 centimetres have been catalogued by the US government, meaning that their respective origins have been possibly identified with a specific launch or release event. Of these, only 6 to 7 per cent are operational satellites; this means that, at a minimum, more than 90 per cent of all man-made objects in Earth orbit are uncontrolled and/or non-functional. As these objects orbit at speeds of between 3 km/sec and 7.7 km/sec, a collision between one uncontrolled object of any size and another space object can have serious consequences. Although they are spread out over a vast area, most of this space debris is concentrated in the most useful Earth orbits — LEO, MEO and GEO.

The risks posed by space debris are of global proportions, requiring both national and international solutions. This can be best achieved through a concerted effort by space technologists, policy and law makers, in concert with spacecraft manufacturers, operators, and insurers, to establish policy and regulatory solutions and assure a sustainable space environment for future generations. Recognizing the globally shared concern that space debris constitutes a mounting challenge to the sustainability of space activities, the Institute of Air and Space Law of McGill University, Montreal, Canada, in cooperation with the International Association for the Advancement of Space Safety (IAASS), has since 2009, organized a series of International Interdisciplinary Congresses on Space Debris aimed at developing specific and viable policy and regulatory options, as well as technical mechanisms, for consideration by States and other stakeholders in order to address the challenges posed by space debris.

The first two International Interdisciplinary Space Debris Congresses, held respectively in 2009 and 2010 focused almost exclusively on developments relating to space debris mitigation — efforts aimed at reducing the rate of creation of new pieces of debris. However, there is a massive amount of debris already in orbit around the Earth and, even if no new objects are launched into space forthwith, the amount of debris already in existence poses a serious challenge to the sustainability of space activities. Accordingly, the third International Interdisciplinary Space Debris Congress, held in Montreal on 11 and 12 November 2011, focussed exclusively on, and addressed, active debris removal and on-orbit servicing of satellites in the hope of garnering international attention to the issue. The specific objectives of the congress were:

- To assess the current space debris situation and to determine what can be achieved by space debris remediation and on-orbit servicing of satellites;
- To examine various technical concepts and means, legal and economic aspects, operational and organizational requirements for space debris remediation and on-orbit servicing of satellites; and,
- To put forward specific and viable policy and regulatory steps (mechanisms) that may be considered by States and other stakeholders to facilitate the removal of space debris and the servicing of satellites in orbit.

Following the *Chatham House Rule*, participants comprising a selection of international experts in the fields of natural sciences, engineering, physics, astrophysics, business, military operations, political science, international relations and law, drawn from Australia, Belgium, Canada, China, France, India, Italy, Japan, the Netherlands, Switzerland, UK, and USA were provided the opportunity to brainstorm over a period of two days to determine where we are in connection with active debris removal and on-orbit servicing of satellites and how to proceed with it. In conformity with the *Chatham House Rule*, this Report does not provide attribution or citation to any particular participant or to any particular paper and/or presentation. The limitations of adopting such a methodology without direct citation of attribution authority are recognized. Nonetheless, it is hoped that the reader will understand that significant effort has been made to maintain the highest standards of objectivity and accuracy. The authority of the Report is primarily derived from the expertise of the congressional body as a whole.

This Report presents the deliberations and findings of the 3rd International, Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing. The Report: (a) objectively describes the current space debris situation; (b) describes and assesses the status and feasibility of various technical concepts and means for the conduct of active debris removal and on-orbit satellite servicing; (c) discusses an appropriate organizational framework for the effective conduct of active debris removal and on-orbit servicing operations; and, (d) proffers various policy and regulatory recommendations for consideration by States and other stakeholders to facilitate the conduct of active debris removal and on-orbit satellite servicing. This Report also serves as the background and basis for the *McGill Declaration on Active Debris Removal and On-Orbit Satellite Servicing* (see Appendix A) that was considered at the Congress.

List of Acronyms

AAA	American Arbitration Association
ADR	Active Debris Removal
ASAT	Anti-Satellite Tests
CIS	Commonwealth of Independent States
CNES	Centre National d'Etudes Spatiales (France)
COSTIND	Commission of Science, Technology, and Industry for National Defense (China)
CSA	Canadian Space Agency
DARPA	Defense Advanced Research Projects Agency (US)
DELTA	Debris Environment Long Term Analysis
EDDE	ElectroDynamic Debris Eliminator
ESA	European Space Agency
GEO	Geosynchronous Earth Orbit
GSFC	Goddard Space Flight Center
HEOSS	High Earth Orbit Surveillance System
HTV	H-II Transfer Vehicle
IAASS	International Association for the Advancement of Space Safety
IADC	Inter-Agency Space Debris Coordinating Committee
IAEA	International Atomic Energy Agency
ICC	International Chamber of Commerce
IGO	Inter-Governmental Organization
ISS	International Space Station
ITARs	International Traffic in Arms Regulations (US)
LEO	Low Earth Orbit
MDA	MacDonald Detwiler Associates Ltd. (Canada)
MEV	Mission Extension Vehicle
MOST	Micro Oscillations of Stars Satellite Project
NASA	National Aeronautics and Space Administration (US)
NEOs	Near Earth Objects
NEOSSat	Near Earth Orbit Surveillance Satellite
NRL	Naval Research Laboratory (US)
OOS	On-Orbit Satellite Servicing
OPCW	Organisation for the Prohibition of Chemical Weapons

PCA	Permanent Court of Arbitration
PMD	Post-Mission Disposal
SASTIND	State Administration for Science, Technology and Industry for National Defense (China)
SIS	Satellite Infrastructure Servicer
SSN	Space Surveillance Network (US)
SSO	Sun Synchronous Orbit
TCBMs	Transparency and Confidence Building Measures
TT&C	Telemetry, Tracking and Control
UAV	Unmanned Aerial Vehicle
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNGA	United Nations General Assembly
UNOOSA	United Nations Office for Outer Space Affairs

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1. Current Space Debris Situation

The object of this section is to assess the current space debris situation and to determine the extent to which the situation can be improved by active debris removal and on-orbit satellite servicing. Accordingly, after describing the nature and scope of the space debris problem, this section discusses why active debris removal and on-orbit servicing is necessary, for which areas of near-Earth orbit, and the timeframe within which it will become absolutely indispensable. It also considers what the appropriate goal of active debris removal and on-orbit servicing should be — i.e., should active debris removal and on-orbit satellite servicing aim primarily at stabilizing the rate of growth of the debris population or at protecting operational satellites?

A. What is in space today?

The space environment currently contains approximately 950 operational satellites located in the LEO, MEO and GEO regions. The space environment also contains massive amounts of space debris. Debris is any man-made object in space that does not serve a useful purpose.

In describing space debris, there are some important distinctions that need to be made from the outset. *Total debris* must be distinguished from *tracked debris* and *catalogued debris*. The US tracks objects in space with radar and optical sensors in the Space Surveillance Network (SSN). The SSN can track objects in LEO that are larger than 5-10 cm in size and objects in GEO larger than 1 m in size. Debris tracked by the SSN is known as *tracked debris*. The US also keeps a Catalogue of space objects that, currently, contains approximately 16,000 objects. There are a large number of objects that are tracked. However, because they are of unknown origin, they are not catalogued. As such, the number of *tracked objects* is larger than the number of *catalogued objects*. Also, the *total amount of debris* is much larger than the number of tracked and catalogued objects.

Debris may also be classified according to size. In that regard, three size categories of debris are commonly used:

Physical Size	Comments	Potential Risk to Satellites
> 10 cm	-Can be tracked -No effective shielding	Complete destruction
1-10 cm	-Smaller objects in this range cannot be tracked consistently -No effective shielding	Severe damage or complete destruction
< 1cm	-Cannot be tracked -Effective shielding exists	Damage

Table 1 — Size categories of space debris

Currently, it is estimated that, the total amount of debris *in LEO* measuring between 1 and 10 cm is around 400,000, whereas total debris in LEO measuring more than

10 cm in size is around 14,000. By comparison, it is estimated that the total amount of debris measuring between 1 and 10 cm in orbit *at all altitudes* is around 750,000, whereas the total amount of debris measuring more than 10 cm in size is around 24,000. Thus, according to the estimates, roughly half of all debris measuring more than 1 cm in size is located in LEO.

Tracking capabilities may improve in the future. The Canadian Space Agency's (CSA) Near Earth Orbit Surveillance Satellite (NEOSSat) initiative is the first satellite project dedicated to tracking objects from space. It will search for asteroids and near earth objects (NEOs) and operate 24 hours a day 7 days a week. The initiative involves the deployment of a suitcase-sized microsatellite based on the technology utilized in the successful Micro Oscillations of STars (MOST) satellite project, which will be directed from the ground at the defense research group. The project is currently in the development phase and is scheduled for launch in June 2012. NEOSSat will monitor orbiting space objects keeping track of the positions of both satellites and "space junk" as part of the High Earth Orbit Surveillance System (HEOSS) project by Defence Research and Development Canada (DRDC). The information produced by NEOSSat will bolster Canada's contribution to international efforts to maintain the safety of Canadian and international assets, both civilian and military. The CSA has also recently completed feasibility studies for a system to perform space debris detection and tracking to address the needs of CSA's Satellite Operations. Key requirements of the system are: 5 cm debris detection up to LEO (800 km) and 5 m in-track x 50 m cross-track debris position accuracy at time of closest approach. The system's concept encompasses 24 receiving antenna and one transmitting antenna operating within the S-Band. Interferometric processing of received signals has also been built in so as to achieve high-accuracy tracking.

B. Where did these objects come from and who owns them?

As indicated above, items catalogued in the US Catalogue are of known origin. As depicted in Figure 1 below, 57 per cent of these catalogued objects originated from breakup debris, 33 per cent from payloads, 11 per cent from rocket bodies, and another 11 per cent from mission-related debris. Five years ago propulsion explosions were the dominant contributor to breakup debris. Recently, however, there has been a significant change in the composition of breakup debris. The 2007 Fengyun 1C breakup contributed 41 per cent of the catalogued total of breakup debris in orbit. Accidental collisions have also become a major source of breakup debris. Most notably, the Iridium 33-Cosmos 2251 crash, which occurred in 2009, accounts for 20 per cent of breakup debris currently in orbit.

By way of trends, it is significant to note that 18 of the 25 worst non-deliberate fragmentations have involved rocket bodies — due to the explosion of residual propellant left on board. It is also important to note that collisions and close conjunctions (based upon the number of objects that passed within 5 km of each other) have become more frequent in LEO, doubling between January 2006 and July 2009. Between 1957 and 1996, the US and the CIS (formerly the USSR) added an average of 100-120 objects per year to the Catalogue. Between 1996 and 2006, the US added an average of 16 objects per year to the Catalogue, whereas the CIS added an average of 44 objects per year. A comparison of debris growth trend lines from the period 1957-1996 to those from 1996-2006 leads to the following conclusions: 1) debris mitigation efforts have shown significant effect; and, 2) individual events have produced a great deal of debris.

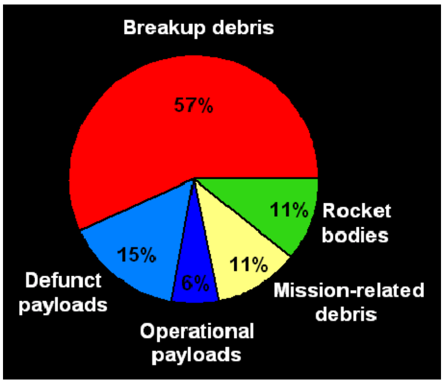


Figure 1: Current composition of objects catalogued in the US Catalogue of Space Objects.[2]

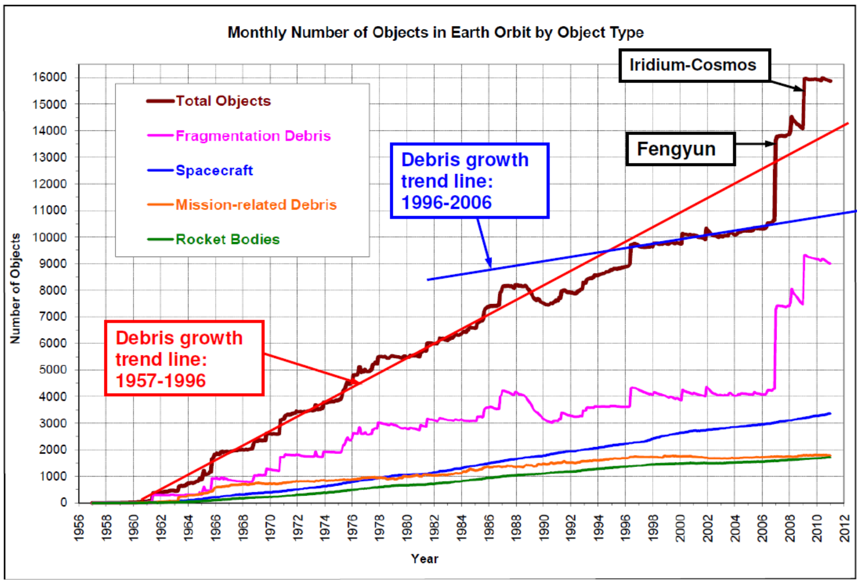
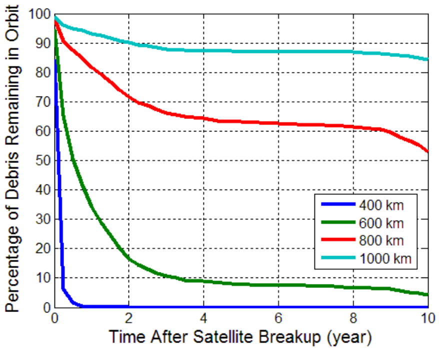


Figure 2: Historical debris growth trends through 2011 demonstrating the dominance of fragmentation debris as a source and the significance of recent individual events such as the Fengyun 1C breakup and the Iridium 33-Cosmos 2251 collision.[3]

2 Source: Chart prepared by Union of Concerned Scientists.
3 Source: Adapted from graph appearing in NASA's Orbital Debris Quarterly News, Volume 14, Issue 2 (April 2010) at page 4.

C. Where are they and how long will they stay in space?

The largest amount of mass is concentrated in the regions of space used for satellites especially LEO, at altitudes between 800 and 1200 km. As a result, the highest probability of a collision lies in this area.



Breakup at solar maximum   Breakup at solar minimum

Figure 3: Educated guesses of debris lifetime at different altitudes (based upon a 10-ton object breaking up at different altitudes under solar maximum and solar minimum conditions). In general, the graphs show that the higher the altitude, the longer the object will remain in orbit if the occurrence of a solar cycle about once every 11 years is accepted.

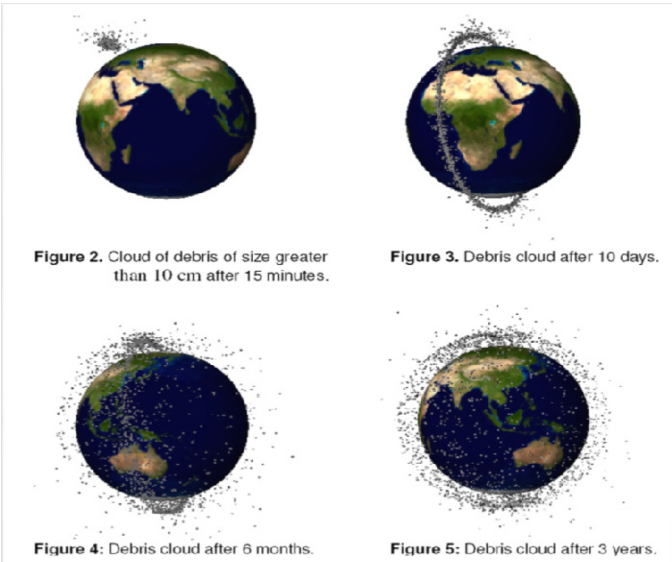
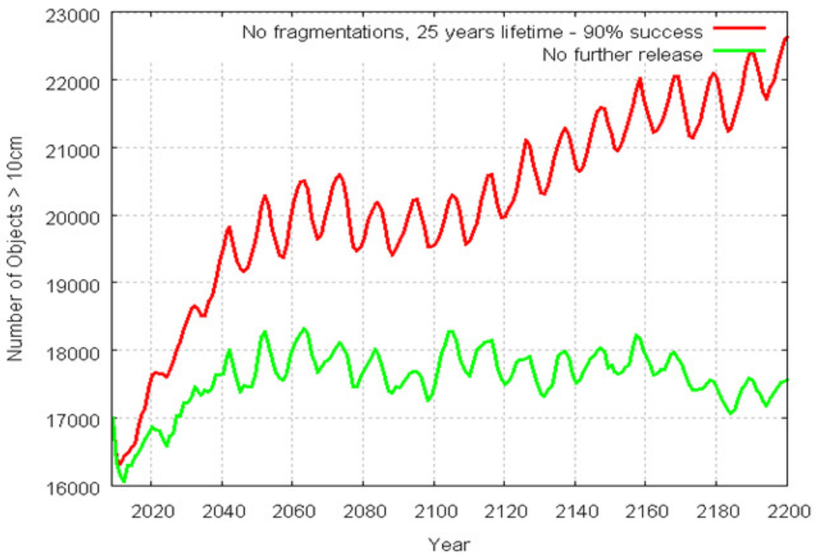


Figure 4: A pictorial demonstration of the evolution of debris following breakup showing how debris spreads around the orbit of the original breakup to form a "debris shell".

The breakup of a large 10-ton satellite might double or triple the amount of debris greater than 1 cm in LEO. Debris tends to stay around the original orbits of the objects but over time, it spreads out around the orbit to create a "debris shell".

D. How will the debris situation evolve in the future and what should be the role of active debris removal?

Currently, it is estimated that the rate of natural decay of objects larger than 10 cm in LEO is 0.15 per cent per year.[4] At this rate of decay, the Debris Environment Long Term Analysis (DELTA) model suggests, on the basis of the 2009 population of such objects in LEO that, natural decay results in the removal of approximately 5 intact objects per year from LEO. On the other hand, the current global rate of launches into LEO averages 36 launches per annum. Assuming that each launch injects 2 objects into LEO — i.e., 1 payload and 1 rocket body — at least 72 new objects are being injected into LEO each year. Taking the natural decay rate of 5 objects per year into consideration, the DELTA model estimates that at the current launch rate, 67 new objects remain in orbit in LEO each year. Even if we do nothing, taking into account the number of objects already in orbit, the space environment (at least in the most used Earth orbits) might not be sustainable on a business as usual basis if no mitigation or remediation efforts are undertaken.



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[4] This estimate is derived from the Debris Environment Long Term Analysis (DELTA) model. This is a 3-dimensional, time dependent, semi-deterministic model that provides a 200 year forecast by simulating the environmental response to active debris removal over a 200 year period (2009-2209). DELTA takes into account the launch cycle over the past 8 years, debris mitigation measures and is limited to the debris population above 10 cm. The results of the simulation are collated from several Monte Carlo runs.

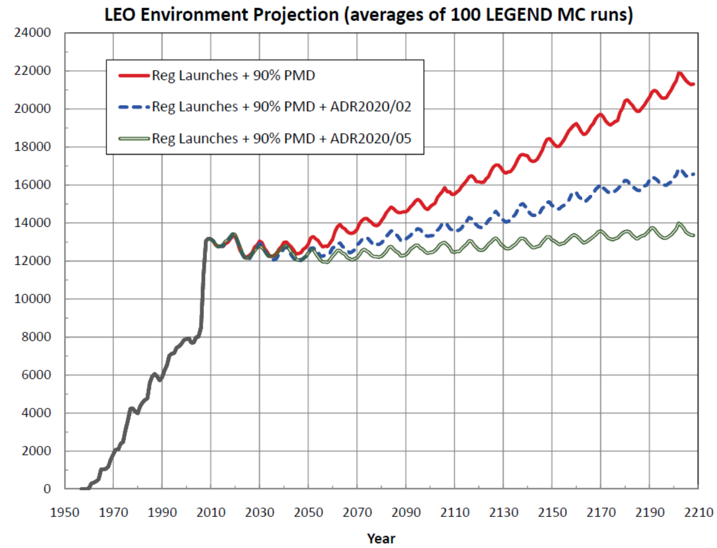

Figure 5: Environment projection graphs showing how the debris situation in LEO will likely evolve in the next 200 years under different scenarios. Both graphs demonstrate that even under the most optimistic assumptions (i.e., regular number of launches at 90 per cent compliance with the 25-year rule or, alternatively, with 90 per cent post mission disposal and without any new on-orbit explosions that cause further fragmentation), the situation will only get worse by the end of the 200-year timeframe.

A population of about 2500 intact objects in LEO may be considered the threshold of stability beyond which the amount of debris in LEO will continue to increase by itself. Estimates show that this threshold of stability has already been surpassed with the current number of intact objects in LEO reaching 2683. Presently, there are 3 major mechanisms for returning the LEO population of intact objects to a sustainable level below the 2500 threshold of stability: (1) lifetime limitation; (2) launch rate reduction; and, (3) active debris removal. Lifetime limitation involves limiting the lifetime of objects launched into LEO. It is premised on the idea that the number of objects in orbit is a function of the number of objects launched each year and the length of the lifetime of each object. Thus, as depicted in Table 2 below, a longer lifetime implies that there will be many more objects in orbit at any point in time.

Lifetime (years)	**Satellites**	**Rocket bodies**	**Total**
5	468	180	648
15	828	540	1368
25	1188	900	2088

Table 2: Total number of intact objects in orbit in LEO as a function of the lifetime of objects. These projections assume that, given the current launch rate of 36 launches per year, a constant number of intact objects will be added to the total number of objects in orbit in LEO at any point in time. The projections do not take into account the fact that

some of the launches may fail or that the total number of intact objects may be reduced as a result of natural decay.

Launch rate reduction involves a reduction in the current rate of launches into LEO. As indicated above, it is estimated that currently, an average of 72 new objects are injected into LEO each year. Active debris removal involves the removal of intact but non-functional and/or uncontrolled objects (i.e., defunct satellites and rocket bodies) from LEO. In essence, a lifetime limitation requirement must be established and applied before active debris removal can be effectively carried out. This would provide a preliminary criterion for determining which objects are potential candidates for removal. Although active debris removal is an expensive option, making judicious choices as to what is (or will be) removed from orbit can make a significant difference to the risk of collisions. Small objects cannot trigger catastrophic collisions. The focus should therefore be on removal of larger objects capable of causing catastrophic collisions and massive fragmentations in space. There are different removal strategies: i.e., removal by mass, by area, by altitude or inclination, or a combination of all three. Furthermore it should be considered that the uncontrolled re-entry of objects of large mass constitutes a safety[5] risk for the public on Earth, and that the overall re-entry risk is increasing on an annual basis due to the 25-year rule. Therefore, the technique selected for removal of large debris must also take into account the need to minimize the public safety risk.

The LEO population can be returned to a stable level below the threshold of 2500 intact objects using a combination of the 3 different mechanisms described above. However, given that current trends in the use of space are not expected to change drastically, a more realistic scenario will be one under which (1) the lifetime limitation is kept at 25 years with a 90 per cent success rate in complying with this limitation; (2) the total number of launches is kept at 36 per year; and, (2) the number of years to reach the threshold of stability is set at 200 years. Under such a scenario, there will be the need to remove 9.1 objects per year from LEO by means of active debris removal in order to achieve the threshold of stability within the 200 year timeframe. Ideally, only one type of removal vehicle would be used in the implementation of this concept (requiring targets to have similar characteristics).

In view of the foregoing, when should active debris removal operations commence in LEO? What happens if we start late? It is obvious that active debris removal can be a more efficient alternative as compared to launch rate and lifetime reduction, because the targets can be selected and optimized. It is important to understand the timeframe in which the LEO environment will be stabilized. As such, delays in commencing ADR activities will make ADR less effective. This can be optimized by selecting density hot-spots (in high altitudes). Criteria for removal may be set using the following parameters: collision probability (area, object density); altitude of the density hot spot (lifetime of fragments); and, mass of the object.

[5] Safety of space missions refers to the risk for the general public, launch range personnel, and humans on board. Space safety, in a wider sense, encompasses the safeguarding of critical space infrastructure and assets, the protection of the space environment (orbital and planetary), and the protection of the Earth atmospheric and ground environment (chemical, radioactive and biological hazards). The main source of risk for the general public are falling debris and toxic materials which are produced, nominally or due to malfunction / failures, by launch operations or by low Earth orbit operations.

2. Emerging Technical Means and Concepts for Active Debris Removal and On-Orbit Satellite Servicing

The object of this section of the Report is to examine various technical concepts and means for active debris removal and on-orbit satellite servicing, as well as their legal and economic implications. Specifically, this section describes the fundamental technologies and capabilities that are needed (or are currently being developed or considered) to support active debris removal and on-orbit satellite servicing activities and discusses their advantages and disadvantages as well as their legal and economic implications. Although a handful of technological concepts and means are discussed in detail in this section of the Report, this should not be considered in any way as an endorsement or approval by the congress or participants thereof of the concepts and means so discussed. It is important to recall in this regard that, the primary object of discussing these technological concepts and means is to address the level of maturity and readiness of such technologies for the conduct of active debris removal and on-orbit satellite servicing.

Concern about future near-Earth space debris environment is increasing due to the "Kessler Effect". Debris mitigation (i.e., disposal at end of mission, passivation, etc.) has also become increasingly important in recent times. However, NASA predicts that, in order to stabilize the LEO population, an approach that combines effective Post-Mission Disposal (PMD) with removal of at least 5 large objects per year will be required. As such, there is the need to reinforce PMD requirements and also to move forward with active debris removal and on-orbit satellite servicing. The models are optimistic and, in reality, it is quite likely that we will be confronted with this problem sooner than fifty years from now. We need to revisit already published studies/opinions that advocate the lack of need to do anything about space debris at the present time. In this connection, there is an ESA sponsored study by Hugh Lewis and two other studies (DARPA and Rand) that bear review.

In identifying and prioritizing threats for removal, it is important to identify dense debris regimes, and to determine the cumulative probability that a satellite will survive. The way to do this is: (1) to conduct close approach statistical analyses; (2) to assess the cumulative probabilities of collision; and, (3) to estimate the consequences of conjunctions. Two regions of space are of particular concern for active debris removal and on-orbit satellite servicing: (1) LEO — the region of greatest concern for uncontrolled growth of debris;[6] and, (2) GEO, with 1000 tracked debris objects larger than 1 meter and an unknown number of untracked debris objects passing through the protected region.[7] Satellites operating in GEO can avoid collision with other operating satellites and tracked objects given

[6] LEO has the highest population of small, untracked objects; the highest energy at collision; the greatest potential for creating lots of debris; approximately 500 operating satellites; approximately 12,000 tracked debris objects larger than 10 cm; and 400,000 to 600,000 untracked debris larger than 1 cm. LEO satellites have a design lifetime of approximately 5-10 years and an average cost (including launch) of between $130-$330 million for commercial satellites.

[7] Collisions occurring in GEO are less energetic than those occurring in LEO. With an average lifetime of approximately 10-15 years and an average satellite cost (including launch) of approximately $200-$400 million, GEO satellites are typically large, tracked, maneuverable objects operating in assigned "boxes".

accurate and timely notifications. Satellites operating in GEO may also be removed from service to comply with PMD requirements. This may be a potential market for a towing service.

The following are some of the essential prerequisites for the conduct of active debris removal and on-orbit satellite servicing:

- A “cost effective” technique;
- A proper legal and policy framework to protect the parties involved and to deal with “alternative use” concerns;
- Available and willing target for removal or customer for servicing;
- Someone to pay;
- Accurate tracking and necessary assistance during operations; and,
- Capability to locate, approach, connect deorbit/servicing device, control orientation and to move the target object to desired destination.
- Safety of the public on ground, at sea and travelling by air.

Thus, to execute an active debris removal or on-orbit satellite servicing mission, it is important to first identify the threat(s), determine the time available to react, plan the access for minimum energy, rendezvous and establish the orbit modification device, plan the orbit modification to ensure that the risk is less than that of the original circumstance, and execute the mission with extreme vigilance. Although the removal of derelict objects from heavily populated, high inclination orbits may have relatively low cost per unit of debris mass, several discriminants are necessary to determine which objects pose the highest level of threat. Mission planning and execution are therefore potentially more difficult than the actual implementation of the mechanism(s) physically employed to modify the orbits of debris objects. This is primarily due to the difficulty associated with determining the mass properties of debris objects in order to decide how to safely apply forces and to achieve the desired effect. Also, it is difficult to ensure that, once forces have been applied to debris objects, they will descend or move to the desired orbit with the least risk of colliding with other space objects and that their re-entry into the Earth’s atmosphere will be safe. Although the technology for active debris removal and on-orbit satellite servicing may be ready, the relevant operational procedures are lagging behind.

A. Emerging technological concepts for the removal of small debris objects

A number of technological concepts have been developed and advanced (or are being considered) for active debris removal. For untracked objects smaller than 10cm in diameter in LEO, such concepts include the use of thin film or other methods such as ground-based or space based lasers to remove or reduce the momentum of small objects thereby lowering their orbit in order to facilitate their decay by re-entry into the Earth’s atmosphere. For lower altitudes, atmospheric drag provides a natural cleansing mechanism. In view of the impact frequency in LEO, the thin film concept will require the use of a very large device (e.g., a plate or a balloon) for short term effect.[8] Use of a large device, however, poses a threat to other (i.e., functional) objects and would also require active control in order to maintain it in orbit for an extended period of time. The effectiveness of such a concept can be difficult to measure. As such, removal of small untracked objects in LEO may not be cost effective or practical. Instead, it may be a better idea to remove potential sources of small debris by implementing debris mitigation techniques like end of mission disposal and by removing large debris objects that are susceptible to collision and fragmentation.

B. Emerging technological concepts for the removal of large debris objects

With regard to the removal of large debris objects in LEO and GEO, it is important to recall that only large objects (i.e., objects larger than 10 cm in LEO and those larger than 1 m in GEO) are tracked although satellites are susceptible to serious damage by objects larger than 1 cm in LEO and 10 cm in GEO. It is also important to note that large debris objects may not be capable of avoiding collisions with other large debris objects, and this could be a potential source for the creation of massive amounts of additional debris. Concepts being developed for the removal of large objects include:

- Momentum exchange or electrodynamic (LEO only) tether;
- Attaching a deboost motor;
- Inflating a balloon (LEO only) or adding a device to the object to increase drag;
- Deploying a reusable tug that grapples and moves; and,
- Retrieval (return to earth, recycling in space) of the object.

Notwithstanding the foregoing, the removal of large objects faces numerous challenges. These include the fact that there might be the need to rendezvous with, and control, the target debris object which may be tumbling and may possess unknown mass properties. Another challenge lies in the fact that there may not be a convenient place to grab the object or attach a deorbit device to it. Finally, the removal effort itself may result in the creation of more debris.

Another debris removal concept is for a mission to remove, according to one analysis, five large intact objects per year, residing in the same orbital slot. Ideally, this would involve the same capture interface and the same de-orbit strategy. Initial reviews have shown that there are sufficient target object candidates in the same orbital slot to make this mission feasible. The potential mission concept is to locate the debris object, rendezvous with it after close range monitoring and tracking, capture it, and then dispose of it by way of boosting it to a graveyard orbit or by deorbiting the object. These different stages require different technologies, all of which have been designed and developed, but are yet to be deployed in orbit.

[8] For instance, at an altitude of 850 km and at a flux of approximately 1E-2 with 1 mm particles passing through an area of 1 square meter per year, a plate of about 100-200 square meters in size will be required in order to intercept one 1-mm particle per year. At the same altitude and at a flux of approximately 5E-4 with 1 cm particles passing through 1 square meter per year, a plate of about 2500-5000 square meters in size will be required to intercept one 1-cm particle per year

The underlying technology has been developed and demonstrated over the last thirty years. For instance, Canada's McDonald Dettwiler and Associates Ltd. (MDA) has developed autonomous robotic capability and believes that the fundamentals for conducting such a mission are presently available. In addition, it should be noted that both SpaceX and JAXA have similar capabilities.

The foundation of the technology is the International Space Station (ISS) and the US Space Shuttle program, encompassing twenty-five years of robotic operations with 91 Shuttle Missions and 9 years of ISS robotic assembly and support operations including numerous instances of HTV capture and docking using the Canadarm. The major advantage of these robotic technologies is that they involve pre-planned and well-rehearsed operations. Much has therefore been learnt about what works for robots and operators, how to recover from unexpected events, and what are considered to be realistic expectations for the future. As a result, it is believed that, at present, robotic technologies are sufficiently mature and ready for prime time space missions involving removal of large debris objects by way of capture and disposal in GEO and/or LEO. Canada's Special Purpose Dexterous Manipulator on the ISS — Dextre — provides a valuable test bed to test out risky parts of a capture mission involving robotics.

Thus, using existing robotic technologies, a large or small tumbling object in SSO, LEO or GEO can be autonomously captured and berthed by a grapple arm, then moved to a graveyard orbit or deorbited. This task will employ the same capabilities used for assembly and servicing on the ISS. Autonomous capture and berthing capability has been demonstrated with the DARPA Orbital Express 2007. Guided deorbit capability, on the other hand, has been demonstrated with the Compton Gamma Ray Observatory and Mir space station.

With roughly 2600 dead satellites and spent stages already spread all over LEO (approximately 2000 tons in total), statistical estimates suggest that the next catastrophic collision is likely to yield as many fragments ("shrapnel") as the Iridium-Cosmos collision and Fengyun 1C breakup combined, and that collisions of such magnitude might occur every 12 years on average. To radically reduce the frequency of catastrophic collisions and the future growth of the number of fragments in LEO, debris removal on a small scale will not be sufficient, but will have to be carried out on a wholesale basis. And, in order to be commercially viable, it is envisaged that active debris removal should cost much less than typical launch costs. In view of the high costs associated with the use of rockets as launch vehicles, implementing the concept of wholesale debris removal using rocket technology is the most expensive option, as shown in Figure 6 below.

Figure 6: Comparative analysis of the cost of debris removal via different mechanisms.

The ElectroDynamic Debris Eliminator (EDDE) is a debris removal concept that involves the use of electrodynamic propulsion requiring no fuel to propel an electrodynamic "garbage truck" in space. It derives propulsion from solar electrical power and interaction with the geomagnetic field and plasma, thereby "sailing in the ionosphere". The ionosphere circuit closing that enables electrodynamic propulsion was demonstrated in orbit by Plasma Motor Generator in 1993 and Tethered Satellite System in 1996. The EDDE vehicle consists of nanosatellites "taped" together. The tapes serve as electron collectors and conductors. Although the system weighs only 100 kg and two of them will fit into one ESPA secondary payload slot, it may nevertheless be capable of removing tons of debris. The electrodynamic tether technology will be tested in space by the US Naval Research Laboratory (NRL).

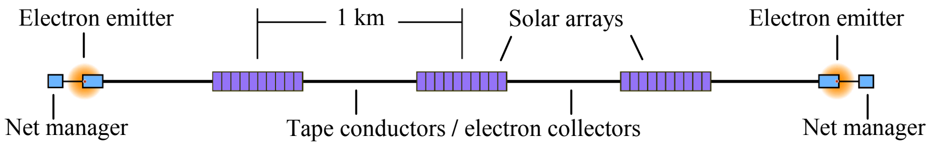

Figure 7: Pictorial representation of the ElectroDynamic Debris Eliminator (EDDE) concept.

Funding needed for the development and deployment of an electrodynamic system for debris removal remains a major outstanding challenge. However, this investment may be justified: it is estimated that within a period of 12 years and at a total cost of less than $1 billion, all the existing intact legacy debris from past space operations could be removed by implementing the wholesale removal concept using electrodynamic vehicles. Unfortunately, such a concept relies on uncontrolled re-entries and would therefore substantially raise the risk of accidents occurring to victims on the ground or aboard aircraft in flight.

Given that statistical projections suggest that there will be one major collision in LEO approximately every 12 years, there are three options for dealing with the situation. The first option involves doing nothing, in which case the space environment will continue to deteriorate, endangering LEO assets.

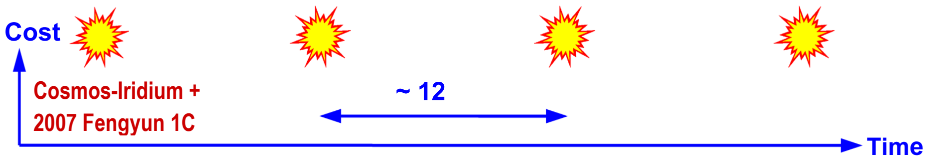

Figure 8: Doing nothing about the debris situation in LEO.

The second option involves selective removal of debris with rocket technology — it would require governments to spend on the order of $1 billion every 12 years to stabilize the population of large debris at the current levels. There would be no exit for the governments, as the expenditure will recur indefinitely, while collisions will continue, adding new fragments of all sizes to the LEO debris population. On the other hand, this technology would allow safe controlled re-entries for large mass objects.

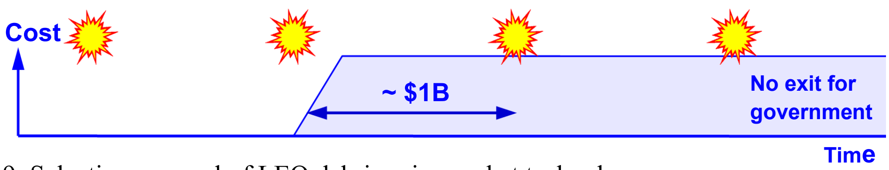

Figure 9: Selective removal of LEO debris using rocket technology.

The third option involves wholesale removal of debris with electrodynamic vehicles. As described above, this option will require governments to make a one-time expenditure under $1 billion over a 12-year period in order to remove all the existing intact legacy debris. Along with the establishment of new rules for the disposal of new debris, the definition of a new fault standard under existing rules and, strict enforcement, this option may pave the way for governments to exit after the first 12 years. Although this option is much cheaper, it is unsafe for the re-entry of large objects that would not be totally burnt up during re-entry.

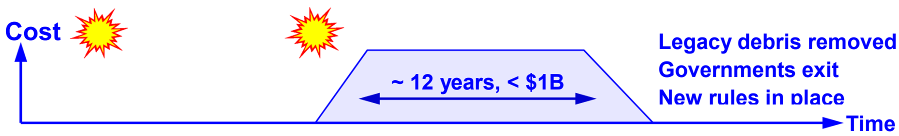

Figure 10: Wholesale debris removal using electrodynamic vehicles.

A way potential forward would be to use the second and third techniques synergistically, such that EDDE would be used to lower the orbits of large debris objects, while robots based on chemical rocket technology would then capture the debris objects and make them perform a safe controlled re-entry.

C. Emerging technological concepts for on-orbit satellite servicing

In connection with on-orbit satellite servicing, the technology for autonomous servicing of prepared clients has been demonstrated with the DARPA Orbital Express 2007. Strategies have also been demonstrated for clients designed to Non-Robotic Standards using Remote Operator Supervision. These include a Goddard Space Flight Center (GSFC) and MDA demonstration of dexterous robotics with the Hubble Space Telescope HiFi mock-up in 2004-2005 which combined the best of automation with human cognitive skill and judgment. Another good example is the robotic rescue of the Hubble Telescope, including service, undoing small connectors, removing latches and opening doors. Planned robotic compatibility can be non-invasive to a client. Key servicing functions have also been demonstrated in LEO for remote servicing missions such as:

- Autonomous vehicle capture
- Autonomous computer and battery exchange
- Autonomous fluid transfer
- Streamlined operations approach
- Candidate servicing interface standard

DARPA's Phoenix Program brings to light another (albeit slightly different) concept for on-orbit satellite servicing. The goal is to provide satellite broadband capability from dead satellites in space for airplanes at UAV prices by recycling economically useful components of space objects (such as antennae) that are still intact. The concept involves fractionating many sub-systems into nanosatellites or satlets as hosted payloads on commercial satellites. Once these hosted payloads reach their intended orbits, robotic spacecraft launched into GEO will grab the nanosatellites, proceed to the graveyard zone, locate a dead communications satellite with the proper antenna, rendezvous and snip off the antennae, and then attach them to the nanosatellites to form a fully functional satellite. The satellites will communicate with each other using a wireless network and will be powered through solar panels or batteries. These are rendezvous and proximity operations**.** To accomplish this, a request proposal would be put out to private companies. The robotic arm must be provided, as well as design and manufacture of satlets and the rendezvous and docking systems. DARPA will award contracts and development will flow from these. Challenges arise from the audacious design, as well as the significant legal, technological, and political issues.

D. Analysis of the cost-effectiveness of active debris removal and on-orbit satellite servicing

In the short term (i.e., over the next 20-30 years), active debris removal will have minimal apparent benefit to operating satellites. This is because the principal effect of debris is degradation of satellite lifetime due to small debris impacts on solar panels — effects that can be fairly easily minimized through improvements in solar panel design. Also, as collision avoidance services mature, there have only been a few collisions involving operating satellites and large debris. Projections show no major cost increase for satellite operations in the short term. The primary benefit of active debris removal will be realized only in the long term as it will reduce the possibility of uncontrolled debris growth and future limitations on space operations. Active debris removal must therefore be performed in conjunction with adherence to debris mitigation guidelines for maximum long term benefit. The incentive to pursue active debris removal at this time must come from the long term perspective. Presently, funding is needed to cover the development and testing of removal techniques. In the future, long term funding will be required for a removal service. An important consideration that must be addressed at this stage before moving any further is whether a full-fledged removal service would be less expensive than the option of adding removal capability into new satellites.

On the other hand, on-orbit satellite servicing offers short-term benefits by way of mission life extension through fuel replenishment, disposal services at end of life; and, assurance that the operator can meet PMD requirements. Life extension directly affects income for commercial systems and extends capabilities for government satellites. On-orbit satellite servicing may be of particular interest for the GEO region due to minimal delta-V requirements to reach multiple satellites. In view of the foregoing, there may be a business case for implementing on-orbit satellite servicing which would include removal to a graveyard orbit to free up an operational slot in GEO. Debris removal services may be added as the techniques mature.

E. Who should pay for active debris removal and on-orbit satellite servicing?

Active debris removal and on-orbit satellite servicing involve considerable expense and new technology still needs to be developed. There are multiple solutions. One proposed during the congress envisages the creation of a Global Economic Fund for Space Debris Removal partially borrowing from the X-prize model, to which all launch operators and space systems would contribute equitably —

government and private — in proportion to their current share of the global launch and operations activities. It is the most "future oriented" way to proceed and has many potential benefits. The "looking back" approach that requires nations considered responsible for deploying or creating debris to pay for a proportional share of the cost of its removal is more equitable but probably less viable. The primary benefits of a Global Economic Fund for Space Debris Removal are that: (i) it would stimulate a diversity of "international licensed entities" to compete in developing the needed technology; (ii) these entities would be compensated only after they have successfully developed needed technology and removed debris from orbit; (iii) the fund could be shut down when the mission is accomplished; (iv) this would be the most economically effective approach; (v) this approach would be able to model the payment of launch insurance — a process that is well known to the space community of States and businesses. The removal entities would be licensed to perform such service by their countries on the basis of international (non-binding) guidelines. Such a scheme would, in any case, most likely require a new international convention or protocol to amend the current Liability Convention. Compensation would be paid for the amount of kilograms of debris brought down.

In sum, a possible approach for moving forward with active debris removal and on-orbit satellite servicing may include the following elements:

- Development of a legal framework and details to enable and/or facilitate the removal of objects (e.g., liability once object is touched by another entity, etc.);
- Development of international agreements that address concerns about "alternative uses" of servicing and removal technology and resources;
- Creation of a **Debris Removal Prize** with reward for successful removal of identified object(s);
- Identification and conclusion of necessary agreements with owners for small number (1 to 3) of debris objects (e.g., stage, small spacecraft, large spacecraft) to serve as targets for removal;
- Development of "standard" fixtures and approaches to be required on new spacecraft and stages to facilitate servicing and removal;
- Setting and publicizing of goals for yearly removal beginning in ~2025 (incentive for near term private investment); and,
- Creation of a Global Economic Fund for Space Debris Removal to pay for removal service in the long term (to cover the cost of removal of existing debris plus spacecraft that fail in orbit).

3. Legal, Regulatory and Strategic Issues Related to Active Debris Removal and On-Orbit Satellite Servicing

The object of this section of the Report is to consider various legal, regulatory and strategic issues related to active debris removal and on-orbit satellite servicing in an effort to answer the following questions:

- Who defines whether an object is space debris and a candidate for removal?
- What is the process for determining who is allowed to remove a particular piece of debris?
- What legal constraints will hinder the implementation of active debris removal and how should they be resolved?

- What is the legal status of the 'debris' with regards to jurisdiction, control and salvage?
- What are the liability considerations for accidents stemming from removal and servicing activities? What are the intellectual property constraints? Does "shutter control" apply to spacecraft looking at other spacecraft?
- Do ITARs apply to active debris removal and on-orbit servicing?
- What are the prospects for developing economic incentives for debris removal?
- What are the strategic (military) implications of on-orbit servicing and active debris removal?
- What form of international cooperation and organizational framework would be required to implement active debris removal and on-orbit servicing?

A. Defining space debris for purposes of removal

None of the existing space law treaties specifically defines what constitutes "space debris". "Space objects" is the broader term that commonly appears in all the treaties and, by necessary implication, space objects include space debris. The need to define space debris becomes even more important when considering what, how, and by whom something should or may be removed from space. Any object that is launched into outer space (or component parts thereof) will, sooner or later, become space debris. It is apparent that, subject to the consent of the State of registry, a party can only remove objects that are already or about to become without value or function and which pose a serious risk of damage or destruction to other functioning space objects by way of collision or further fragmentation. Non-functional and non-manoeuvrable space objects pose a risk of harm to functional space objects. However, what remains unclear is the question as to who must determine (and by what process) the value and utility of an object launched into outer space in order for that object to be deemed a proper candidate for removal.

Legally speaking, the term "space object" connotes legal liability for a certain class of States associated with the object. Thus, if space debris is a constituent category of space objects, then certain liability implications will arise for certain States if damage is caused during the active removal of debris from space. Also, many complex questions relating to State jurisdiction and control over space objects will have to be resolved before any removal or servicing activities can commence. As such, from a legal point of view, there is an overriding need to establish a standard and legally acceptable definition of what constitutes space debris in order to permit the conduct of active debris removal and on-orbit satellite servicing activities.

Article 4(1) of the Registration Convention lists all the information that a State of registry must furnish to the Secretary General of the United Nations (in practice, through the United Nations Office for Outer Space Affairs (UNOOSA)) in connection with any space object carried on its registry. This includes, *inter alia*, information concerning the general function of the space object. Pursuant to this provision, the technical definition of space debris endorsed by the Inter-Agency Space Debris Coordination Committee (IADC), UNCOPUOS and in the European Union in its Code of Conduct for Outer Space Activities (EU Code of Conduct) focuses on the functionality or otherwise of space objects as the relevant criteria for distinguishing between space objects and space debris. Thus, according to the technical definition, if a space object is functional, it is not space debris and *vice* *versa*. However, the technical definition of space debris does not suffice for purposes of active debris removal because space objects that are outwardly non-functional may still have a legal value. In other words, space debris does not always qualify as "space waste". Legally speaking the concept of "waste" connotes an intention on the part of the owner to abandon the object in question.

Another qualification of space debris is that it is uncontrolled. According to the provisions of the 1967 Outer Space Treaty, the 1972 Liability Convention and the 1975 Registration Convention, the State that must exercise jurisdiction and control over a space object is the "appropriate state" and/or the State of registry. If the State of registry of the object (which by necessary implication is a launching State) is no longer in a position to exercise jurisdiction and control over the object, should the object be considered to have been abandoned? In general, property is deemed to have been abandoned if the owner thereof is in no position to, or has no intention to recover it. Whoever finds such property may then lay claim to it. However, this is not the case in connection with space objects because by law, ownership therein continues irrespective of where the object may be or where it is found. Consequently, abandonment does not apply to space objects since, under the existing international legal regime, a space object continues to be owned by its owner(s) even if outwardly it appears to be uncontrolled and/or non-functional. This is underlined, for instance, by article 5 of the 1968 Rescue and Return Agreement, which provides that a space object that has returned to Earth must be returned to the launching State. Such a space object is therefore not "lost" or "abandoned" property under the law.

Further, it is difficult to draw an analogy between the legal status of space debris and the international treaties governing the removal of wrecks from exclusive economic zones of the sea. It is clear in the law of the sea conventions that the State of registry of the wrecked vessel must agree with the State in whose jurisdiction the wreck exists (i.e., the State that has been damaged) to remove the wreck. In the space context, it is not clear with whom such an agreement should be made — should it be with the international community at large or with another State's entity that conducts the salvage operation? Article 6 of the Registration Convention is important because it encourages States to share information in circumstances where application of the provisions of the treaty does not enable a State Party to identify a space object that has caused damage to it or which may be of a hazardous or deleterious nature.

Another issue of relevance to the definition of space debris is that each of the 5 existing space law treaties is a separate instrument, telling only part of the story, and each with different sets of States Parties. Also, unlike what pertains under the climate change instruments, there is no institutional support for the implementation and enforcement of the 5 space law treaties — there is no body enforcing and/or coordinating the provisions of the treaties. The space law treaties are aging and there are various lacunae present therein. In spite of the foregoing, the provisions of the existing UN space treaties, must, as a matter of necessity, be interpreted and applied in the most useful way in order to achieve optimal results. Thus, in line with the provisions of article 4(2) of the 1975 Registration Convention which urges States to provide additional information about space objects carried on their registries, the UN Secretary General (acting through UNOOSA) could proactively trace uncontrolled and non-functional space objects and/or component parts thereof back to their respective States of registry for purposes of obtaining consent for their removal. Perhaps the best solution to the definitional problem of space debris would be to have a new treaty that comprehensively addresses the issue. However, for various obvious reasons, this is a very difficult approach.

B. Liability, jurisdiction and control aspects of active debris removal and on-orbit satellite servicing

Under the Liability Convention, proof of 'fault' is required in order for a State to maintain a claim against another State for damage occurring in space. Although, leaving a non-functional satellite in a congested (dangerous) orbit could be considered to be a manifestly wrongful act, it is difficult to establish what constitutes fault in such cases. Also, in the absence of a systematic space traffic management system, it is difficult to prove fault when damage occurs in space. In a satellite collision, both objects are moving, so the real question that arises is: which of the two objects would be deemed to be at fault? For damage caused by a space object on the surface of the Earth or to an aircraft in flight, liability attaches to the launching State on the basis of strict liability. Article 4 of the Liability Convention is the relevant provision when it comes to removal of space objects. If a removal operation causes damage to a third party, the launching States of both space objects (i.e., the removal mechanism and the target object) that caused damage to the third party will be jointly and severally liable under the provisions of the Liability Convention. Ownership does not factor into the equation as it is not connected with liability. It may be possible for a State to recover damages from the owner of the space object that caused the damage through domestic law, but the Liability Convention ascribes liability for damage primarily to launching States.

In removing a satellite, there might be the need to cross orbits on the way up or down. This might increase the risk of the entity conducting the removal operation in terms of liability which, in turn, creates an incentive to leave satellites in their orbits even after they are no longer functional. It may be useful to make the point perhaps in a protocol to the Liability Convention that, if someone does the right thing (e.g., by removing a non-functional object from orbit), then fault could be mitigated in some way. In other words, active debris removal and on-orbit satellite servicing will likely occur if the global space faring community could come to an agreement not to apply the fault standard to such operations. Considering that States may be defensive of their space objects in an effort to avoid divulgence of the proprietary technology carried thereon, if international agreement is achieved to exempt active debris removal from the scope of application of the Liability Convention's fault standard, a further decision has to be made concerning which State's space objects would be removed and in what order.

The State that holds jurisdiction and control over a space object is the State on whose registry an object launched into outer space is carried. If a State, or a State-licensed actor, remediates a space object, it can only legally do so if it has legal jurisdiction and control over that space object *or* permission from the State of registry. The rules establishing State jurisdiction and control over space objects provide certainty in a situation where States may not exercise sovereignty in outer space. There is no legal recognition of a temporal termination of a State of registry's jurisdiction and control over a space object. There is no precedent of State practice for:

- Transfer of jurisdiction and control for the purposes of removal or on-orbit servicing of a space object.
- Removal without the permission of the State of registry.
- Removal of a space object of unknown registry.

In view of the general rule that a State (or its private entities) cannot remove or service another State's space object without permission, the fundamental questions which arise are as follows: whether States should be allowed to remove or service a space object without obtaining permission from the State(s) on whose registry the space object is carried? On what basis should it be decided when remediation is allowed without permission from the State of registry? What are the national security concerns of allowing jurisdiction and control to terminate or to be transferred without the explicit permission of the State of registry? It is important to note that the space security nexus to jurisdiction and control over space objects continues *ad infinitum*. As such, circumventing the provisions of the existing regime that establish jurisdiction and control in the State of registry may have negative consequences for space security. The legal regime was not constructed to deal with this issue and discourse is only just beginning. The international community needs to think about what mechanisms will facilitate the seeking and granting of permission and establish rules respecting both the jurisdiction and control issue and consent.

C. National legal and regulatory provisions that may facilitate or inhibit conduct of active debris removal and on-orbit satellite servicing

There are different ways of achieving the objectives of active debris removal and on-orbit satellite servicing while addressing the various legal and regulatory challenges. Each State can implement as part of its licensing process a provision that enables it to order remediation as a possible solution in an appropriate situation. In the UK for instance, licensing power flows from section 5(2) of the Outer Space Act of 1986, which provides the basis for remediation measures by giving the Secretary of State the power to license outer space activity and to prescribe certain types of conditions. Thus, a licensee must conduct operations so as to: prevent contamination of space; avoid interference with the outer space activities of others (including frequency interference and physical interference), ensure compliance with the terms of ISO 24113; and, avoid a violation of the UK's international obligations. If a breach of conditions occurs, the Secretary of State may order the disposal of any space object. An argument can be made that leaving a non-functioning satellite in orbit can amount to appropriation of space, a violation of the non-appropriation and due regard provisions — fundamental principles — of the Outer Space Treaty.

The United States' International Traffic in Arms Regulations (ITARs) are extremely relevant when it comes to the conduct of active debris removal and on-orbit servicing activities. ITARs basically govern the export of defense articles, services, and technical data for items on US Munitions List; the US Department of State's

Directorate of Defense Trade Controls administers them. Spacecraft and associated systems are included in Category XV of the US Munitions List. By definition, "export" includes: transferring control or ownership of a satellite to a non-US person; disclosing or transferring technical data; and/or performing defense services on behalf of, or for the benefit of, non-US persons. Countries for which ITAR controlled exports are absolutely prohibited include several countries that have satellites in space such as: Belarus, Iran, North Korea, Venezuela, and China. For other countries, it may be possible to obtain a license, but this may be subject to onerous conditions and can be costly.

Thus, performing active debris removal and on-orbit servicing of a US satellite or a satellite of another country that has US components or technology on board falls squarely within the definition of "export" under the ITARs since transfer of jurisdiction and control over the space object will likely occur, even if only for a limited time. If a US company wanted to contract with a foreign country for removal, this would be considered a defense service. If a US entity is doing the work, there will be the need to share technical data and that qualifies as an export. It is also likely that satellite refuelling will raise ITAR issues: docking implicates control and necessitates data sharing. ITAR reform is currently ongoing, but satellites are an exception requiring US Congressional action. As such, for the foreseeable future, it is reasonable to assume that ITARs will continue to be a major hindrance to the conduct of active debris removal and on-orbit satellite servicing operations. Possible solutions exist. For instance, when there is some question as to whether the activity will be subject to ITARs or not, a commodity jurisdiction request may be tendered to seek clarification. This was the approach used in successfully exempting space tourism suborbital flights from ITAR application, despite the fact that some information had to be shared with non-US entities. It is also possible to request that certain articles should be removed from the US Munitions List, subjecting them instead to the less restrictive US Commerce Control List. However, this would require Congressional action. Another solution is to seek a license for the exports created by space debris remediation and satellite refuelling activities. This could be expensive at least with regard to US satellites. Thus, in sum, ITARs matter when it comes to active debris removal and on-orbit satellite servicing.

China does not have dedicated comprehensive space legislation.[9] However, two departmental rules that were adopted before 2010 are of some relevance to debris remediation. These are: the *Procedure of Space Objects Registration and Management* (Order No. 6 of the Commission of Science, Technology, and Industry for National Defense (COSTIND) and the Ministry of Foreign Affairs, 8 February 2001) and the *Interim Procedure of Licensing Civil Space Launch Programs* (Order No. 12 of the Commission of Science, Technology, and Industry for National Defense, 21 November 2002). In 2008 COSTIND merged into the State Administration for Science, Technology and Industry for National Defense (SASTIND). In 2010, SASTIND promulgated the *Interim Instrument of Space*

[9] The legislative hierarchy in China includes the Constitution, Basic Laws, and other laws (enacted by the standing committee of the National People's Congress, (NPC)), Administrative Regulations (enacted by the State Council), Department Rules (adopted by Ministries or Commissions, as well as the State Council), Local Regulations (promulgated by Local People's Congress) and Local Rules (adopted by Bureaus or Commissions, Local Administration).

Debris Mitigation and Management which aims to implement China's international obligations to control and mitigate space debris. It defines debris almost the same way as debris is defined in the IADC and UNCOPUOS Guidelines. SASTIND is the organizational entity in charge of implementing the Interim Instrument. It revises the interim procedure of space debris management. The idea of remediation will be included in the next Chinese White Paper on space activities.

Canada's *Remote Sensing Space Systems Act* contains provisions regarding systems disposal. It was enacted in 2007 partly on the heels of IADC Space Debris Mitigation Guidelines. Disposal means more than just debris mitigation. Under the Act, the Minister of Foreign Affairs and International Trade may not issue a licence without having approved: (a) a system disposal plan for the licensed system satisfactory to the Minister that, among other things, provides for the protection of the environment, public health and the safety of persons and property; and, (b) arrangements satisfactory to the Minister relating to the guarantee of the performance of the licensee's obligations under the system disposal plan. A licensee and, in the case of a licence that has terminated, the former licensee, shall ensure that the following things are disposed of in accordance with the system disposal plan approved by the Minister:

a) Every system satellite,
b) The things used in connection with the cryptography and information assurance measures of the system,
c) Any raw data and remote sensing products from the system that are under the control of the licensee or former licensee, and
d) Anything else prescribed.

The licensee is also required to put into effect guarantee arrangements approved by the Minister and to keep them in effect until the system disposal plan has been carried out.

Building upon the Space Debris Mitigation Guidelines (a set of voluntary and non-binding technical guidelines developed by the IADC and approved by UNCOPUOS and the UNGA), the EU is drafting a new comprehensive set of rules in connection with space debris remediation. The different actors include national space agencies (such as CNES) and coordinating bodies (ESA) as well as the EU and third parties. Europe is involved in international debris mitigation (Code of Conduct, IADC, UN COPUOS, and ISO), and there is also implementation at the national level (France, Germany, Austria and Belgium). The EU Code of Conduct for space activities is evolving into an ad hoc conference to be likely held in early 2012. This could form the basis for the adoption of an international code on space debris remediation although its primary focus is on space debris mitigation. Limited EU competencies do not preclude an active remediation role for the EU. Measures evolve through best practices, rules originating from national space agencies and industry, and coordinated by agencies. The EU is the middle level broker that facilitates voluntary implementation of international measures by its Member States. The EU Code of Conduct shows that parallel paths with different actors will likely continue to be pursued. So far, economic reasons have dictated a focus on mitigation. However, there is no legal bar to the EU pursuing remediation through existing channels. As such, once economic and political objections are dealt with, there will be the need to strengthen the existing legal rules to include remediation.

D. Mechanisms for the settlement of disputes that may arise during the conduct of active debris removal and on-orbit satellite servicing

In trying to establish the way we balance the risks and opportunities associated with remediation activities, it is important to recognize that treaties and contracts are the instruments that will spell out the issues and allocate the risks and opportunities between private entities and States because some stakeholders do not have the capacity to enter into treaties. In that connection, articles III, IX and XIII of the Outer Space Treaty are extremely relevant. In general, there are several different means of settling international disputes. These include negotiation (consultation), inquiry, mediation, conciliation, arbitration (Permanent Court of Arbitration — Optional Rules for Arbitration of Disputes Relating to Outer Space Activities), judicial settlement (adjudication), resort to regional arrangements of agencies, and other peaceful means of the parties' own choice. These mechanisms derive from: article 33(1) of the Charter of the United Nations; the UNGA Declaration of Principles of International Law Concerning Friendly Relations and Co-operation among States, 1970; as well as the UNGA Declaration on the Peaceful Settlement of International Disputes (Manila Declaration), 1982 among others.

Although it can be argued that there is no clear mechanism for space dispute resolution, article IX of the Outer Space Treaty refers to the obligation to undertake consultations where a State has reason to believe that the activity it intends to conduct will cause harmful interference or where a State is of the view that the activity of some other State will cause harmful interference to itself. The obligation to consult has its genesis in paragraph 6 of the 1963 Declaration of Legal Principles and is arguably customary international law. The treaty framework governing space activities was designed with the intention that activities in outer space would be carried out primarily by States. As such, article III of the Outer Space Treaty makes international law applicable to the conduct of activities in outer space. However, there are many private actors presently engaged in space activities. Regarding practical matters, article XIV of the Outer Space Treaty gives States the opportunity to liaise with each other, with international organizations or through agreements and this could be interpreted as a means for the settlement of disputes. Articles 11, 12, and 19(2) of the Liability Convention are also relevant to dispute resolution in the context of active debris removal and on-orbit servicing.

However, having identified that disputes flowing from remediation activities can be settled, we must keep in mind the need for applicable laws and procedures. Arbitration has become the preferred method of dispute resolution in many fields of international endeavour. In arbitration, there is party autonomy in choosing the applicable substantive law. As such, international law on its own, or used in conjunction with a national system of law may be specified as the "substantive law" of a contract, particularly where that contract is with a State or a State agency. For rules of procedure of arbitral panels, resort may be had to the International Chamber of Commerce (ICC), the American Arbitration Association (AAA), the Optional Rules recently developed under the auspices of the Permanent Court of Arbitration (PCA), as well as the non-binding Space Debris Guidelines. The private sector is participating proactively because of the introduction of insurance and municipal laws to limit liability should space activities cause harm. Therefore, trade practices need also to be considered.

In view of the increasing involvement of private sector entities in space activities, States, inter-governmental organizations, non-governmental organizations, corporations and private parties may all become parties to disputes revolving around active debris removal and on-orbit satellite servicing. Recently, a UK High Court held in the case of *Republic of Serbia v. Imagesat International NV* [2010] 1 Lloyd's Rep 324 that "it would be wrong to allow a State to escape liability under a commercial contract merely by pronouncing that it was not an original party to the contract, and then sheltering behind a cloak of non-justiciability in order to prevent an arbitration or adjudication based on the true legal position".

E. Strategic (military) implications of active debris removal and on-orbit satellite servicing

National space policies adopted by governments of space faring and non-space faring nations alike may have significant implications for the conduct of active debris removal and on-orbit satellite servicing. In the US, for instance, the relevant aspects of national space policy that may have an impact on active debris removal and on-orbit satellite servicing are set out in the following 3 policy documents.

(1) **The Transportation Policy of 2005** states that "the United States shall … pursue research and development of in-space transportation capabilities … including but not limited to: automated rendezvous and docking, and the ability to deploy, service, and retrieve payloads or spacecraft in orbit".

(2) **The National Space Policy of 2010** provides in material part that, "for purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall pursue research and development of technologies and techniques, through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment".

(3) **The National Security Space Strategy of 2011** aspires to improve shared awareness of spaceflight activity in order to foster global spaceflight safety and to help prevent mishaps, misperceptions, and mistrust. It provides that the "United States will support development of data standards, best practices, transparency and confidence building measures, and norms of behaviour for responsible space operations". The US will also "consider proposals and concepts for arms control measures if they are equitable, verifiable, and enhance the security of the United States and its allies".

By their very nature as well as their dual use attributes, ADR and OOS technology (such as lasers, robotics, space sails, solar concentrators, electrodynamic tethers, drag augmentation devices, orbital transfer vehicles, and ultra short optical pulse) come with very significant strategic and military implications. Both ADR and OOS technology can be used for Anti-Satellite Tests (ASAT) and what matters the most in this connection is the capability of the technology, not the intent behind it. OOS technology, especially technology that will allow replenishment of fuel supplies in space, makes it possible to increase the flexibility of space systems and to respond effectively to changing circumstances in space. Autonomous rendezvous and proximity operations capability enables intelligence gathering, surveillance, reconnaissance, and docking, and produces little or no spin off debris. Satellites can be parked in orbit until needed.

All of these capabilities are extremely important from a strategic and military perspective. However, at present, these implications are only theoretical since there are no mature systems in existence today and there are also no significant attempts to develop these technologies — there is no political will on the part of States to fund the development of the technology. In a setting where there are numerous competing priorities in a constrained fiscal environment, the challenge now is how to develop a cost-effective means of active debris removal and on-orbit satellite servicing. Educating the policymakers is the key to making progress at this stage — the space community needs to do a better job of educating the decision makers. If big space faring nations invest in the development of ADR and OOS technology, chances are that emerging space players will be put under pressure to follow suit. There is a potential spin off of positive as well as negative benefits — development of these technologies could have an impact on robotics and other areas.

In view of the foregoing, Transparency and Confidence Building Measures (TCBMs) will have a significant role in reducing mistrust and misperceptions in the conduct of ADR and OOS operations. As such, initial ADR missions should focus on non-controversial debris. For attributed debris, the State that created the debris would be responsible for removing it either by way of its own ADR operations or by authorizing others to remove it. For unattributed debris, only those that are tracked and which pose significant safety hazards would be removed, subject of course to the prior consent of the State of registry. This approach would minimize military, diplomatic, and political concerns; enable success and the development of best practices, as well as the attainment of the goal of reduced orbital debris. We are better off using TCBMs rather than treaties. Some may not like this because TCBMs are not binding and because one of the 3 big producer States (US, Russia, China) could drop out. Nonetheless, this proposed solution is noteworthy as a first step. The extension of warfare to the space domain represents a threat to the proliferation of space debris and is unwise in a strategic sense. Clarifying the application of the Law of Armed Conflict to space warfare would, for instance, be a significant TCBM.

In a nutshell, there is a lack of policy direction at both the national and international levels. Validation of ASAT capability on the ground through simulation is possible. There is an overriding need to establish collision avoidance mechanisms and to improve space surveillance capabilities. Proactive engagement of non-State actors operating in space is important. Any legal regime on active debris removal and on-orbit satellite servicing should be supported by an organizational framework (akin to IAEA, OPCW) for purposes of implementation and enforcement.

4. Organizational and Operational Aspects of Active Debris Removal and On-Orbit Servicing of Satellites

This section of the Report discusses the organizational and operational requirements for the effective conduct of active debris removal and on-orbit satellite servicing operations. In this connection, the following questions are addressed:

- Who should undertake active debris removal and on-orbit satellite servicing?
- What is needed to reduce the risk of mishaps, misperceptions, and mistrust?
- What are some specific transparency and confidence building measures, norms of behaviour, and best practices for active debris removal and on-orbit satellite servicing?
- How do we handle the costs and funding?

A. Who should undertake active debris removal and on-orbit satellite servicing?

The efforts and best practices of space actors in the realm of space debris mitigation have reached their limit and it is now time to seriously consider active debris removal and on-orbit satellite servicing. Space sustainability implies that space must be kept open for terrestrial benefits. We know what needs to be done but we are not quite sure how to do it. Doing nothing is not an option and the longer we fail to address the problem in a meaningful way, the worse the situation will get. As a general rule, the State or entity (i.e., principal space system procurers, developers and operators) responsible for creating space debris should bear primary responsibility for its proper disposal. However, under current circumstances, cleaning up the useful Earth orbits is a technologically challenging and costly activity. Also, satellite constellations such as the US's Global Positioning System (GPS), weather satellites and other spacecraft constitute significant global "social infrastructure" that provide immense benefits to the world at large, not only to the space faring nations that are responsible for their launching. In light of the foregoing, it is only fair and equitable that all who are involved in space development — either directly by way of utilization or indirectly by way of deriving benefits therefrom cooperate internationally in an effort to find an appropriate mechanism for the conduct of active debris removal and on-orbit satellite servicing.

To this end, public-private partnerships with activities monitored and coordinated at both the national and international levels will be conducive to the conduct of active debris removal and on-orbit satellite servicing operations. The UN is a powerful organization for eventually arriving at consensus but this takes several years. The UN mechanism is good for addressing overarching legal questions, but it is not a suitable vehicle for undertaking operational tasks. Instead, it stimulates nations to take individual or bilateral actions and it is good for that purpose. An Operational and Regulatory Framework for Space Debris Remediation worthy of consideration and adoption encompasses the following three elements:

1. Establishment of an **inter-governmental organization** (IGO) based on the early INTELSAT model to foster the development of the technology(ies) for active debris removal and on-orbit satellite servicing, and subsequently to perform removal and servicing operations on a commercial basis.

2. Subscription of governments to concurrently sign an agreement to procure on a commercial basis the removal of **space debris created by their own national space activities** (e.g., 1 per cent per year). Each subscribing country would then be allowed to impose a national space "garbage" collection tax on final users of space-based commercial services available in the country.

3. Amendment of national licensing rules to include an **assured removal clause** that would apply to satellite and relevant launcher upper stage(s). Under the clause, the operator shall be required to demonstrate either that the systems have the capability (and plans) to perform a safe controlled re-entry (or transfer to graveyard orbits) at the end of mission or that the operator has contracted a commercial removal service to carry out the said removal operation at the end of the mission. In addition, the operator should be required to take out an insurance policy to cover the costs of removal or disposal in the event that a failure or malfunction prevents performance of the planned disposal.

B. What is needed to reduce the risk of mishaps, misperceptions, and mistrust during the conduct of ADR and OOS operations?

Intelsat and MDA (as well as some other entities) are exploring OOS ideas particularly in connection with how the concept may be used to assist commercial space operators. Two ideas in particular are being considered: the first one built by MDA is a Satellite Infrastructure Servicer (SIS) — a huge set of tanks and robot arms designed for refuelling missions. ATK is the manufacturer of the second OOS mechanism — the Vivisat Mission Extension Vehicle (MEV). The idea involves launching a spacecraft to operate another spacecraft. The tug docks with the other spacecraft and remains attached to it. It replaces the attitude control subsystem of the client and thereby becomes the control element of the spacecraft. Both can move objects out of GEO into graveyard orbits, but they cannot grasp tumbling objects.

The two ideas have strengths and weaknesses. Neither of them fits into a category on a license application as they exist now. For instance, one question that needs to be answered before a license will be granted for any of these concepts is where the satellite/space object will operate? For these mechanisms, the answer is "all over space". It should be kept in mind that national law is essential because that is where any such operation will be licensed. Another problem is the radio frequency band within which these mechanisms will operate. Preferably, they should use commercial frequencies. But these mechanisms are more likely to be categorized as space operations (thereby falling within the S band). Yet, since they remain essentially commercial operations, questions will arise as to whether they are permitted to operate within those S band frequencies. A more precise understanding of where the space objects are is needed. Regulators are, as yet, not sure of how to proceed. Further, these mechanisms must have "eyes", and the question that arises is whether or not they will be sensing. If they will be sensing, would it be considered space sensing or remote sensing? Another issue is how to deal with data transmission i.e., enhanced telemetry, tracking and control (TT&C). This requires the establishment of a ground network of terrestrial services around the globe. Space systems are complicated and there is always the possibility for things to go wrong. These are regulatory challenges that must be addressed — we must work together to solve them.

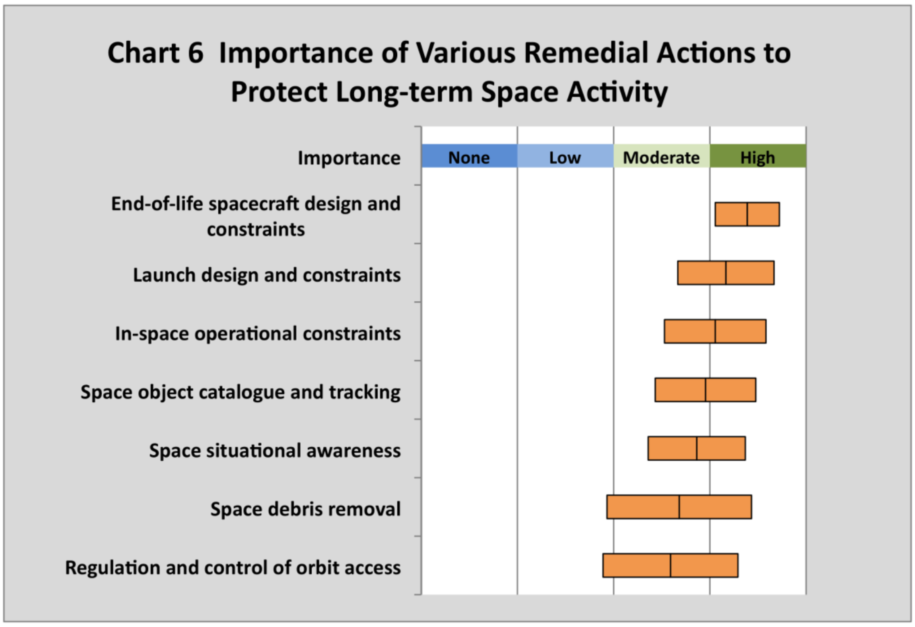

Figure 11: The importance of various remedial actions in protecting long-term space activity

Figure 11depicts the results of a study conducted within the Canadian space sector on the most important things to do right now to enhance the long-term sustainability of space activities. These are (in order of importance):

- End of life (EOL) design and constraints;
- Launch design and constraints;
- In-space operational constraints;
- Space object catalogue and tracking;
- Space situational awareness (SSA);
- Debris removal; and,
- Regulation and control of orbit access.

As next steps, the study proposes the following measures:

- Support UNCOPUOS and national efforts on long-term sustainability of space activity
- Establish, report, collect and implement national and international best practices
- Establish need for, and technical and economic feasibility of space debris removal
- Once feasibility of various technical approaches is confirmed for achieving or improving the long-term sustainability of space activity, establish whether national or international guidelines, regulations and treaties need to be strengthened for implementation.

With regard to best practices, the basic requirements are: international standardization (consensus); confirmation of implementation; information sharing; decision-making, and negotiation with State of registry of the object to be removed or serviced. For TCBMs and norms of behaviour, there needs to be assessment by an independent party. There is also the need to establish a quantitative mechanism for evaluating the debris creation potential of objects in space in order to determine which objects are prime candidates for removal. In other words, a quantitative indicator of an orbiting object's potential influence on the orbital environment is required. This indicator will be important for evaluating remediation.

C. If active debris removal and on-orbit satellite servicing become feasible, how will the costs be shared and under what conditions?

The problem of space debris is a serious emergency that needs to be tackled by States. Remediation (curative) is no substitute for mitigation (preventive). Both should be undertaken together and must complement each other from political, economic (and sometimes technical) points of view. ADR and OOS activities should be effective at the lowest cost: remediation/mitigation modes should remain proportionate to the project/mission. There should be no disruption of competition — no impact on competitiveness: and solutions must be globally applicable. If remediation takes the form of a political recommendation with reference to technical standards, the issue will be how to ensure they will be applied by all operators or in all missions. If remediation takes the form of a legal obligation (possibly through articles VI, VII or VIII of the Outer Space Treaty), solutions must be fairly and equitably available to all operators or projects. If remediation takes the form of commercial services, they must be fairly and equitably available to all operators or projects. Competition between such services would be welcome but there would be the need to make sure that all service providers consistently apply basic standards. Perhaps this is wishful thinking, but replacing fault-based liability under article IV of the Liability Convention with either an objective strict liability standard (with limited liability amount) or a waiver of liability between States participating in space debris mitigation and/or remediation compliance programs may facilitate the achievement of these goals.

D. What are some specific transparency and confidence building measures, norms or behaviour, and best practices for active debris removal and on-orbit satellite servicing?

To jumpstart active debris removal and on-orbit satellite servicing, we must first deal with complex governance issues. Various stakeholders are involved (e.g., bureaucrats, politicians, military, industry, etc.), each with different interests and agenda. Politicians understand the problem of debris but do not want to do anything about it because it costs money. Multilateral challenges must first be addressed nationally. Perhaps multilateral institutions should facilitate and encourage rather than create solutions (like the IADC guidelines). Also, limitations may not work in some areas (due to negative economic implications/national security), but could work in others.

The Nike slogan: "Just Do It" is an important indicator of what needs to be done to kick start ADR and OOS activities. States and their governments do not need to wait to attain consensus or agreement among themselves before any action is taken. Instead, we need to encourage unilateral action on the part of States. Countries should be encouraged to make unilateral declarations of what they will agree to, and take responsibility for (e.g., a declaration not to conduct high altitude impact tests, to provide access to data on non-operational space objects, and/or to conduct one ADR mission by 2014). As consensus forms, a multilateral forum for more formal agreement will emerge.

5. Conclusions and Recommended Policy and Regulatory Steps

This section draws conclusions from the various aspects of active debris removal and on-orbit satellite servicing discussed in the previous sections of the Report. It also identifies and recommends a number of policy and regulatory steps that will facilitate the conduct of active debris removal and on-orbit satellite servicing operations if actively pursued by States and other stakeholders either unilaterally or through multilateral fora.

The problem of space debris is of growing concern for the long-term sustainability of space. Useful Earth orbits have become crowded with debris, and scientific estimates suggest that, even if no new space objects are launched, the amount of debris in orbit around the Earth will continue to grow. The implementation of debris mitigation measures has had a significant impact in curtailing the rate of creation of new debris during the conduct of space activities. However, taking into consideration that there is a massive amount of space debris in orbit as a result of past space activities, it is clear that the time has come for active debris removal and on-orbit satellites servicing activities to commence in order to meet the long-term need to protect the space environment as well as a short-term need to protect operating space assets from damage or destruction by debris.

Various technical concepts, means and capabilities have been developed (are currently being developed or considered) to support active debris removal and on-orbit satellite servicing activities. These include: the use of thin film or other methods such as ground- or space-based lasers to remove or reduce the momentum of small debris objects in order to facilitate their re-entry into the Earth's atmosphere; the removal of large objects from LEO using electrodynamic tethers or robotic technologies; and, the servicing of satellites using robotic concepts such as that exemplified by the DARPA Orbital Express 2007. While the implementation of each of these technological concepts and means poses significant legal, regulatory and economic challenges, it is obvious that their primary benefits will only be realized in the long term. Most importantly, the availability of funding and "alternative use" concerns appear to be the most significant obstacles to the development of ADR and OOS technologies. As such, there is the need to inform and convince policymakers about the urgency of taking appropriate steps to facilitate the development and maturity of the technologies and concepts needed to achieve the goals of ADR and OOS.

In addition to the foregoing, there are other legal, regulatory and strategic challenges that may inhibit the conduct of active debris removal and on-orbit satellite servicing activities if not properly addressed. The existing regime of international law that governs the conduct of space activities does not specifically define what constitutes "space debris". Under international law, space debris is a constituent category of “space objects”, a term which connotes legal liability for all States who qualify as launching States with respect to the object in question. A technical definition of space debris provided by the IADC/UNCOPUOS Space Debris Mitigation Guidelines relies upon the functional status of a space object as the relevant criteria for determining whether or not a space object may be classified as space debris. For purposes of removal, however, this technical definition may not suffice since jurisdiction and control over a space object continues to attach to the State of registry of the object irrespective of whether it is functional or not. Also, ownership of space objects is not affected by the functionality and controllability of the space object.

Closely related to the issue of jurisdiction and control over space objects is the issue of national policies, laws and regulations that either facilitate or hinder the conduct of active debris removal and on-orbit satellite servicing activities. Pursuant to their jurisdiction and control obligations and also in furtherance of national security and economic interests, several countries have established domestic legal and regulatory regimes that either completely prohibit or at times place onerous restrictions on the transfer of jurisdiction and control over their space objects to third parties in foreign countries. The US regime of ITARs best exemplifies such legal and regulatory restrictions. From a strategic and military point of view, ADR and OOS activities are of significant concern to States primarily because they involve autonomous proximity and rendezvous capabilities that may either compromise or facilitate intelligence gathering, surveillance and reconnaissance in space. In reducing mistrust and misperceptions, TCBMs will be indispensable to the successful implementation of ADR and OOS activities as and when the technology matures.

With respect to the operational and organizational aspects of ADR and OOS activities, it is clear that the lack of a streamlined organizational framework for the implementation and enforcement of the five existing space law treaties has not augured well for the international community. Although the UN is a powerful (albeit slow) mechanism for eventually achieving consensus on broad overarching legal questions, it may not be a suitable mechanism for undertaking operational tasks such as those envisaged in ADR and OOS operations. Accordingly, it is proposed that an operational and regulatory framework that would facilitate the conduct of ADR and OOS activities should encompass the following three elements:

1. Establishment of an **inter-governmental organization** (IGO) based on the early INTELSAT model to foster the development of the technology(ies) for active debris removal and on-orbit satellite servicing, and subsequently to perform removal and servicing operations on a commercial basis.

2. Subscription of governments to concurrently sign an agreement to procure on a commercial basis the removal of **space debris created by their own national space activities** (e.g., 1 per cent per year). Each subscribing country would then be allowed to impose a national space “garbage” collection tax on final users of space-based commercial services available in the country.

3. Amendment of national licensing rules to include an **assured removal clause** that would apply to satellite and relevant launcher upper stage(s). Under the clause, the operator shall be required to demonstrate either that the systems have the capability (and plans) to perform a safe controlled re-entry (or transfer to graveyard orbits) at the end of mission or that the operator has contracted a commercial

removal service to carry out the said removal operation at the end of the mission. In addition, the operator should be required to take out an insurance policy to cover the costs of removal or disposal in the event that a failure or malfunction prevents performance of the planned disposal.

With respect to funding of ADR and OOS activities, although the customary rule that applies under general international law is that the polluter must pay for the clean-up costs, the "looking back" approach that requires countries considered responsible for deploying or creating space debris to pay for their removal is not a viable approach for ADR and OOS. This is because, among other things, satellite constellations such as global satellite positioning and navigational systems, weather satellites and telecommunication spacecraft constitute significant global "social infrastructure" that provide immense benefits to the world at large, not only to the space faring nations that are responsible for their launching. In light of the foregoing, it is only fair that all who are involved in space development — either directly by way of utilization or indirectly by way of deriving benefits therefrom — cooperate internationally in providing equitable funding for the conduct of active debris removal and on-orbit satellite servicing. Accordingly, borrowing partially from the X-Prize model, it is proposed that a Global Economic Fund for Space Debris Removal should be established to foster the development of the technology to remove space debris from orbit and to compensate commercial entities that achieve such active removal. It is envisaged that all launch operators as well as space systems owners and operators — whether governmental or non-governmental — will make financial contributions to the Fund on an equitable basis. The Fund would be particularly designed to incentivize the active participation of entities that could develop and implement suitable technology that is able to remove the maximum amount of orbital debris at the most rapid pace and at the lowest net cost, consistent with agreed upon international regulations, or consistent with national regulations covering the removal of orbital debris associated with past programs of that country's launch operations. This could be the form of prize awards or other types of incentives provided after capabilities are actually demonstrated.

Given the lack of political will both at the national and international levels in relation to the conduct of active debris removal and on-orbit satellite servicing, there is a need to encourage unilateral action on the part of individual States. Governments should therefore be encouraged to make unilateral declarations of what they will agree to, and take responsibility for, within the realm of space debris mitigation and remediation. Proactive engagement of non-State actors operating in space is also important. Finally, any legal regime on active debris removal and on-orbit satellite servicing should be supported by an organizational framework (akin to IAEA, OPCW) for purposes of implementation and enforcement. Other equally important policy and regulatory steps that are recommended for consideration and adoption by the international community of both State and non-State stakeholders are outlined in the McGill Declaration on Active Debris Removal and On-orbit Satellite Servicing appearing in Appendix A to this report. In spite of the fact that the Declaration was not formally adopted by the congress, it is nonetheless presented for consideration by stakeholders.

Appendix A

McGill Declaration on Active Space Debris Removal and On-Orbit Satellite Servicing

November 2011

The third International Interdisciplinary Congress on Space Debris Remediation held at McGill University's Institute of Air and Space Law in November 2011 and attended by a selection of international experts in the fields of natural sciences, engineering, physics, astrophysics, business, military operations, political science, international relations and law from Australia, Belgium, Canada, China, France, India, Italy, Japan, the Netherlands, Switzerland, UK and USA:

Recalling the first and second Space Debris Congresses held respectively at McGill University's Institute of Air and Space Law in May 2009 and the University of Cologne's Institute of Air and Space Law in April 2010;

Noting that orbital debris poses a growing and serious hazard to the sustainability of space activities and a threat to vital multi-billion dollar space operations that include space meteorology, space navigation, space communications, remote sensing, space science and exploration on which the world now depends;

Noting that presently, the problem of space debris is very pressing given that:

i) The amount of catalogued trackable space debris objects has increased from 5600 objects in 1980 to over 16000 in 2011 and is continuing to increase at an alarming rate, and that there are many more pieces of debris in orbit that are not catalogued or tracked;

ii) Space debris, particularly in LEO and Polar Orbits, are a mounting hazard to all future space launch operations; and

iii) There is increasing evidence that we are near the "tipping point" whereby the "cascade effect" would make the problem progressively worse and this would not only be a problem for LEO operations but for *all* space activities;

Encouraged by the development of the Space Debris Mitigation Guidelines adopted by the Inter-Agency Space Debris Coordination Committee as well as the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space, as endorsed by the General Assembly of the United Nations in its Resolution 62/217 of 22 December 2007, as an important international cooperative step towards reducing space debris risks;

Recalling the Treaty on Principles Governing Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Rescue and Return Agreement), the Convention on International Liability for Damage Caused by Space Objects (Liability Convention), and the Convention on Registration of Objects Launched into Outer Space (Registration Convention);

Recognizing that according to Article I of the Outer Space Treaty, the exploration and use of outer space is the province of all mankind and outer space is free for exploration and use by all States without discrimination of any kind, and that according to Article VI of the Outer Space Treaty, States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the activities of their non-governmental entities;

Recognizing that Article VI of the Outer Space Treaty and the Liability Convention sets out the principles for ascribing liability to the launching State for damage caused by its space object, including that of its non-governmental entities, to the space object of another State in outer space and for damage occurring on the surface of the Earth or to an aircraft in flight;

Recognizing that Article IX of the Outer Space Treaty obliges States to avoid harmful contamination of outer space during the conduct of studies and exploratory activities in outer space, and to have due regard to the corresponding interests of all other States;

Recognizing that the United Nations General Assembly in its Resolution 1721 B (XVI) of 20th December 1961 calls upon States launching objects into Earth orbit or beyond to furnish information promptly to the Secretary General, for the registration of launchings, and that this obligation is codified in the provisions of the Registration Convention;

Noting that Transparency and Confidence Building Measures are essential to the success of active debris removal and on-orbit satellite servicing efforts;

Noting that actions so far taken by international and national actors and institutions to address the problem of space debris have focused mainly on mitigating the creation of *new* pieces of debris;

Noting that active removal of space debris is essential to assure the sustainability of the space environment for productive and peaceful purposes as a critical element of a comprehensive process that includes judicious and collaborative mission architectures, diligent and cooperative space situational awareness, coordinated launch operations, and space system design practices that emphasize debris minimization and mitigation

Noting the development and maturity of several concepts and technologies that will enable the active removal of *existing* pieces of debris from orbit and the servicing of satellites in orbit;

Hereby Declares That:

1. States are encouraged to increase compliance of existing and planned space systems with space debris mitigation guidelines, requirements and standards;

2. Active removal of space debris and on-orbit satellite servicing should be undertaken by all stakeholders as soon as possible;

3. The United Nations and other international agencies should work diligently to complement international conventions, particularly those dealing with the liability of space activities as well as State jurisdiction and control over space objects, in order to facilitate the conduct of active debris removal and on-orbit satellite servicing;

4. Governments and commercial operators should work actively and diligently to develop and demonstrate debris removal and on-orbit satellite servicing technology and missions;

5. States and satellite operators should cooperate in sharing Space Situational Awareness (SSA) information on a transparent basis;

6. Efforts should be made to collect data from, and to provide SSA services to, as many space operators as possible in order to prevent collisions involving controllable objects;

7. National governments and competent international bodies should examine legal and regulatory mechanisms and processes to advance and facilitate the removal of space debris from orbit and the servicing of satellites in orbit. These mechanisms and processes should seek to encourage or commend the following types of actions:

a. Active removal by launching State(s) of space debris attributable to them;

b. Establishment of national or international funds to support the removal of space debris from orbit and the servicing of satellites in orbit;

c. Promulgation of national legislation and regulations to promote active debris removal and on-orbit satellite servicing; and

d. Other appropriate actions to advance the expeditious disposal of space debris and the servicing of satellites in orbit;

8. States are encouraged to improve upon their levels of compliance with international obligations for the registration of space objects so as to allow the identification of space objects that are suitable candidates for removal and so as to confirm their jurisdiction over, and commit to their obligation to control, space objects;

9. Consideration should be given to the idea of establishing national, bilateral and/or international/intergovernmental entities (preferably on Public-Private Partnership basis) whose mandate will be to conduct active debris removal and on-orbit satellite servicing activities on a commercial basis;

10. Consideration should be given to the creation of a Global Economic Fund for Space Debris Removal to pay for removal service in the long term (to cover the cost of removal of existing debris plus spacecraft that fail in orbit);

11. Debris producing nations should unilaterally take the lead in voluntarily removing their own debris and servicing their own satellites in orbit;

12. Debris removal shall be performed without increasing the safety risk to the public on ground, at sea, and travelling by air.

Done at Montreal on the Twelfth Day of November of the Year Two Thousand and Eleven

Ram S. Jakhu
Chair

Appendix B

List of Participants[10]

1. Ajey Lele (IDSA, India)
2. Armel Kerrest (Faculté de Droit de Bretagne Occidentale, France)
3. Brian Weeden (Secure World Foundation, U.S.A)
4. Catherine Doldirina (IASL, McGill, Canada)
5. Daniel Jutras (Faculty of Law, McGill, Canada)
6. David Finkleman (Center for Space Standards and Innovation, U.S.A)
7. David Kendall (CSA, Canada)
8. David Wright (UCS, U.S.A.)
9. Diane Howard (IASL, McGill, Canada)
10. Duncan Blake (DoD, Australia)
11. Eugene Levin (STAR, Inc. U.S.A.)
12. Frank Teti (MDA, Canada)
13. Holger Krag (ESOC, Space Debris Office, Germany)
14. Jean-Francois Mayence (Federal Office for Science Policy, Belgium)
15. Joan Johnson-Freese (Naval War College, U.S.A.)
16. Joseph N. Pelton (former Dean of ISU, U.S.A.)
17. Karl Doetsch (Doetsch International Space Consultants, Canada)
18. Li Bin (Beihang University, PRC)
19. Matthew Schaefer (University of Nebraska, U.S.A.)
20. Michael Mineiro (NOAA, U.S.A.)
21. Paul Dempsey (IASL, McGill, Canada)
22. Phil Meek (Retired, USAF, USA)
23. Philip De Man (Leuven Centre for Global Governance, Belgium)
24. Ram Jakhu (IASL, McGill, Canada)
25. Ray Williamson (Secure World Foundation, U.S.A.)
26. Richard H. Buenneke (State Department, U.S.A.)
27. Richard DalBello (INTELSAT, U.S.A.)

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[10] Although the affiliations of participants are listed in this Appendix, it is important to point out that each participant attended and participated in the congress in his/her personal capacity. Views and opinions expressed in the Report may therefore not be attributed to any participant or the organization with which he/she is affiliated.

28. Richard Tremayne-Smith (OoS, U.K.)
29. Sa’id Mosteshar (London Institute of Space Policy and Law, U.K.)
30. Sergio Marchisio (University of Rome, Italy)
31. Tare Brisibe (OnAir, Switzerland)
32. Thomas Gillon (Foreign Affairs, Canada)
33. Timiebi Aganaba (IASL, McGill, Canada)
34. Tommaso Sgobba (Independent Safety Office, ESA, the Netherlands)
35. William H Ailor (Center for Debris Studies, U.S.A.)
36. Yaw Nyampong (IASL, McGill, Canada)
37. Yukihito Kitazawa (IHI, JAXA, Japan)
38. Anne Marie Hébert (Department of Justice, Canada) — observer
39. Arun K. Misra (Mechanical Engineering, McGill, Canada) — observer
40. Ashlyn Milligan (Department of National Defense, Canada) — observer
41. Daniel Rey (Canadian Space Agency, Canada) — observer
42. David S. Kang (ATK Space, U.S.A.) — observer
43. Dennis Woodfork (Office of the Deputy Secretary of Defence, U.S.A.) — observer
44. Geoffrey Languedoc (Canadian Aeronautics & Space Institute, Canada) — observer
45. Giovanna de Marco (European Space Agency, the Netherlands) — observer
46. Jaisha J. Wray (State Department, U.S.A.) — observer
47. Kenneth Rodzinyak (Department of National Defense, Canada) — observer
48. Maxime Puteaux (IASL, McGill, Canada) — observer
49. Michel Doyon (Canadian Space Agency, Canada) — observer
50. Michelle Ancona Reynolds (IASL, McGill, Canada) — observer
51. Samuel Vaillancourt (Mechanical Engineering, McGill, Canada) — observer