Orbital Debris: Drafting, Negotiating, Implementing a Convention

by

Thierry Senechal
M.P.A. Harvard University, 2002
M.Sc. London Business School, 1995
B.A. Columbia University (Phi Beta Kappa), 1992

Submitted to the MIT Sloan School of Management
in Partial Fulfillment of the Requirements for the Degree of

Master of Business Administration

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Signature of
Author……………………………………………………………………………………………

Thierry J. Senechal
Sloan Fellows Program in Innovation and Global Leadership
May 11, 2007

Certified
by………………………………………………………………………………………………

Lawrence E. Susskind
Ford Professor of Urban and Environmental Planning
Thesis Supervisor

Certified
by………………………………………………………………………………………………

John Van Maanen
Erwin H. Schell Professor of Management
Thesis Supervisor

Certified
by………………………………………………………………………………………………

Geoffrey E. Forden, Research Associate, Program in Science, Technology and the Society
Reader

Accepted
by………………………………………………………………………………………………

Stephen J. Sacca
Director, MIT Sloan Fellows Program in Innovation and Global Leadership

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Abstract

It is time to recognize that while space may be infinite, Earth orbital space is a finite natural resource that must be managed properly. The problem we face with space pollution is complex and serious. The space treaties and conventions are not sufficient. They were drafted at the time of space exploration in the 1960s and 1970s. Today, they fail to account for rapid changes in the field, especially the increasing commercial activity. Moreover, the existing mitigation guidelines remain voluntary and are not legally binding under international law. As a result, space debris tends to accumulate and remains in orbit for a long period of time.

A space debris convention is thus warranted. The proposed international convention would have the following objectives: 1) Implement an international and independent tracking and cataloguing system for space debris; 2) Adopt enforceable space debris mitigation and disposal guidelines; 3) Enforce a space preservation provision for protecting the most vulnerable outer space regions and; 4) Define a space debris compensation and dispute settlement mechanism. The convention must bring all together policy-makers and the civil society for addressing this problem; it is also time for the space industry to play its corporate social responsibility and to actively seek to participate to the drafting and implementing of the convention.

More than ever, the space debris problem is hindering space commerce, space tourism, the scientific exploration of space, the use of raw materials from space, and even distant plans for the future settlement of space. The possibility of great harm posed by debris should bring all nations and stakeholders together to find the most appropriate solutions.

Thesis Supervisor: Lawrence E. Susskind
Title: Ford Professor of Urban and Environmental Planning

Thesis Supervisor: John Van Maanen
Title: Erwin H. Schell Professor of Management

A hundred times every day I remind myself that my inner and outer life depend on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving.

Albert Einstein

No one should be ashamed to admit they are wrong, which is but saying, in other words, that they are wiser today than they were yesterday.

Alexander Pope

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I would like to thank a number of people who have made much appreciated contributions, including my former colleagues from the United Nations, students and faculty from the MIT Department of Aeronautics and Astronautics. This group constituted a friendly and intellectually stimulating environment and provided key information regarding the technical aspects of the thesis. Professors Jeffrey Hoffman, Annalisa Weigel, Manuel Martinez-Sanchez from MIT also repeatedly and cheerfully illuminated the caverns of my scientific ignorance. I would also like to thank the Aero-Astro Library for making its databases available for use in many of our examples and case studies.

I cannot possibly thank everyone who provided assistance with this thesis.

In hope that this work may in some ways contribute to a more sustainable exploration of space.

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Figures and Tables

Abbreviations

AECB	Canada's Atomic Energy Control Board
ASAT	Anti-satellite weapon
Cm	Centimeter
CNES	Centre National d'Etudes Spatiales (French Space Agency)
CNSA	China National Space Administration
COSPAR	Committee on Space Research
CRS	Corporate Social Responsibility
DoD	Department of Defense (USA)
ESA	European Space Agency
FAA	Federal Aviation Administration (USA)
FKA	Federal Space Agency of Russia
GEO	Geosynchronous Orbit
GTO	Geostationary Transfer Orbit
HTO	High Earth Transfer Orbit
IAA	International Academy of Astronautics
IAC	International Astronautical Congress
IADC	Inter-Agency Space Debris Coordination Committee
IAF	International Astronautical Federation
ISRO	Indian Space Research Organization
ISS	International Space Station
Km	Kilometer
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NGO	Non-Governmental Organization
NORAD	North American Aerospace Defense Command
MEO	Medium Earth Orbit
MOU	Memorandum of Understanding
SDAG	Space Debris Advisory Group (Europe)
SSN	Space Surveillance Network (USA)
STSC	Scientific and Technical Subcommittee (UNCOPUOS)
UN	United Nations
UNCOPUOS	United Nations on the Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office for Outer Space Affairs
UNPSA	United Nations Programme on Space Applications
USA	United States of America
WSDC	World Space Debris Congress

CHAPTER 1 – INTRODUCTION AND CONTEXT

1.1 Space Debris: The Problem

On 11 January 2007 a Chinese ground-based missile was used to destroy the Fengyun-1C spacecraft, an aging satellite orbiting more than 500 miles in space since May 1999. Although the test was hugely successful from a military point of view, demonstrating China's ability to use very sophisticated weapons to target regions of space that are home to various satellites and space-based systems, it caused great concerns to both the military and scientific communities. Indeed, the event is a real danger in the sense it may fuel an arms race and weaponization of space, with some countries being tempted to show they can easily have a control of space as well. From the scientific perspective, the Chinese destruction of Fengyun-1C gave a new dimension to the space debris issue.

In shattering the old weather-watching satellite into hundreds of large fragments, the Chinese created a large "debris cloud". The debris are now spreading all around the earth, the majority of the them residing in very long-lived orbits. As such, they can seriously damage other satellites in nearby orbit and possibly even spacecraft on their way to the moon or beyond. As of 27 February 2007, the U.S. military's Space Surveillance Network had tracked and cataloged 900 debris fragments greater 5 centimeters in size, large enough to create potentially serious problems. The total count of objects could go even higher based upon the mass of Fengyun-1C and the conditions of the breakup, which could have created millions of smaller pieces. The debris cloud extends from less than 125 miles (200 kilometers) to more than 2,292 miles (3,850 kilometers), encompassing all of low Earth orbit.

The Chinese test has demonstrated that the actual system for preventing the creation of space debris is still weak, a single test threatening to put in shamble the efforts made by other countries in many years. In particular, questions are now raised as to the extent to which the existing bodies working on space debris could take measures to protect the orbital space from pollution. The test also shows that the various existing treaties and conventions regulating outer space activities do not play a significant role in preventing such an incident because they lack coverage on such issues or are impossible to enforce.

Again, the Chinese test of January 2007 made it clear that a sovereign and military logic still prevails on efforts made to mitigate the hazard posed by space debris and coordinate international response to such a global challenge. It is time to realize that the debris created may have significantly adverse consequences for national security, global commerce, and scientific endeavor.

1.2 Space Debris: Managing the Future

It is time to recognize that while space may be infinite, Earth orbital space is a finite natural resource that must be managed properly. The outer space environment should be preserved to enable countries to explore outer space for peaceful purposes, without any constraints. It has become obvious that space debris poses a danger to human life as well as to the environment and the economic activities of all nations in space.

The problem we face is complex and serious; the danger posed by the human-made debris to operational spacecraft (pilotless or piloted) is a growing concern. Because debris remains in orbit for long period of time, they tend to accumulate, particularly in the low earth orbit. What is certain today is that the current debris population in the Low Earth Orbit (LEO) region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future. The tremendous increase in the probability of collision exists in the near future (about 10 to 50 years). Some collisions will lead to breakups and will sow fragments all over the geosynchronous area, making it simply uninhabitable and unreliable for scientific and commercial purposes.

In the early years of the space era, mankind was concerned primarily with conquering space. The process of placing an aircraft in Earth orbit and targeting the moon was such a challenge that little thought was given to the consequences that might arise from these actions. Space debris has thus been created at the time of the cold war, when the military and space race between the two great powers of the time was at its peak. Not much can be done to change what has been done during the last decades of the 20th Century.

As with many aspects of Earth-bound pollution, it is taking time to recognize the damaging effects of what we call now "space junk" or space pollution. Space debris is a source of increasing concern. The scientific and engineering community has studied the problem of space debris for decades and have warned the community of the dangers. Large space debris has been tracked and catalogued. The increase pace of small debris has also been studied using sophisticated models. Although space debris has been extensively studied by public and research institutions around the world since the 1980s, its implications have only been discussed in narrow circles of specialists at international conferences.

1.3 Advocating for a Global Space Debris Convention

The time is right for addressing the problem posed by orbital debris and realizing that, if we fail to do so, there will be an increasing risk to continued reliable use of space-based services and operations as well as to the safety of persons and property in space. We have reached a critical threshold at which the density of debris at certain altitudes is high enough to guarantee collisions resulting in many more debris fragments. In a scenario in which space launches are more frequent, it is likely that we will create a self-sustaining, semi-permanent cloud of orbital "pollution" that threatens all future commercial and exploration activities within certain altitude ranges. Debris in space are likely to exponentially increase hazards to satellites and other space missions, manned or unmanned. The debris and the liability it may cause, may also poison relations between major powers.

Because space debris is a global challenge that may impact any country deciding to develop space activities, the issue cannot be resolved among a few countries. This is why I am advocating that a global convention on space debris is a requirement for preserving the space environment for future generations. Following the logic of the Brundland Report, we need development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[1]

A global convention is needed for the simple reason that the successful approval of voluntary guidelines has not been consistent over the last years. For instance, the Chinese test is an example of failure to enforce mitigation standards for space debris. If rightly discussed and implemented, an international convention would increase mutual understanding on acceptable activities in space and thus enhance stability in space and decrease the likelihood of friction and conflict. It would also provide the mechanisms to study, mitigate and remediate the consequences posed by space debris. More importantly, the convention would serve as an agreement between the different countries and would be legally binding to the contracting States. Other important issues would also need to be addressed. For instance, the destruction of spacecraft is not covered right now. The liability and dispute mechanism and compensation of a damage resulting from "tracked" debris are non-existent at present. This is why a specific international convention on space debris is much needed.

1.4 Methodology Outline and Organization of the Thesis

For writing this thesis, I adopted a systematic approach organized in three phases. Each phase represents a block of work enabling subsequent tasks to be carried out efficiently. First, the inception phase consisted of preliminary consultations in order to compile a bibliography of documents for review and analysis. Second, during the analysis phase, I reviewed key documentation and collected various technical and scientific data through semi-structured interviews, discussions, and correspondence. The final phase consisted of summarizing the data and drafting a Space Debris Convention (see Appendix 1).

This thesis employs four methodological tools: 1) an extensive desk review of space debris documentation as provide by various organizations, including NASA and ESA, 2) approximately ten consultations with experts in the field of space debris and experts in the convention making process, 3) participation in a seminar at Harvard Law School in the Fall 2006 on Environmental International Negotiations, with the opportunity to lay down the principles for drafting and implementing a convention, and 4) an analysis of various guidelines and documents from the United Nations (UNOOSA) that have proposed a Space Debris Convention.

Certainly, this methodology has limitations. First, the number of interviews and consultations has been limited due to the time constraints. Second, the participatory approach necessary to arrive at a consensus for adopting a convention has not been completed in full. In a short time frame, it is impossible to organize a forum for stakeholder ownership on a space debris convention. The essence of ownership is that the stakeholders drive the process. That is, they drive the planning, the design, the implementation of the convention. However, we highlight that considerable amount of documentation has been reviewed to account for the differences in opinion regarding a space debris convention. Having done so, I have drafted a proposal for the space debris convention (See Appendix 1). The main tenet of the participative approach to be now implemented is that the space-faring community and stakeholders would need to be drawn into the drafting of the convention at every stage of project development in order to generate a sense of ownership of decisions and actions. Thus, the proposed convention for space debris has been drafted without any large consultations and the drafting relies on a purely observational design. Lastly, the time frame for conducting this research was short, most of the work having been conducted from October 2007 to May 2008.

The remainder of this report provides a comprehensive assessment of the space debris problem. Chapter 2 provides a detailed description scope of the space debris pollution problem and the inherent risks associated to such debris. It also reviews the major efforts made by space-faring nations and international organizations to regulate and mitigate space debris. Chapter 3 presents the political and legal framework governing space issues and points out the weaknesses of space laws. Chapter 4 sets out a proposal for international convention governing space debris. First, I present the objective of the convention and then I discuss the implementing strategies, from the timing and coordination efforts to the negotiation and ratification process. There is also an analysis on how the success of the convention can be measured and a proposal for a liability and dispute resolution mechanism. The conclusions derived from each of the preceding sections are presented in Chapter 5 that offers both conclusions and recommendations. Finally, readers are encouraged to review the comprehensive set of materials provided in the Appendix. It includes a draft convention that can serve as a basis for future negotiations.

CHAPTER 2 – SPACE POLLUTION, A REALITY

2.1 Space Debris: Definition

Since the launch of Sputnik I in 1957, space activities have created an orbital debris environment that poses increasing risks to existing space systems, including human space flight and robotic missions. It is crucial to understand what is meant by debris in the context of the space environment. Before analyzing where orbital debris comes from, it would be useful to know what the accepted definition of orbital debris is. There is however no universally accepted definition. The primary concern with orbital debris is that it pollutes the outer space environment by making satellites more susceptible to damage from collision. Thus, as pointed out by Taylor,[2] "everything orbiting around Earth poses some level of risk to every other object in orbit. The issue is which of those objects should be classified as orbital debris. At the outset, objects and particles that occur naturally in space, even though they do pose some risk to satellites, should be excluded from the definition of orbital debris because humans have no way to control the creation, movement, or removal of those types of objects in space."

In this thesis, I am only concerned with man-made debris and not the natural fast-moving rocky particles called meteoroids. It is true that meteoroids can also be a source of great concern, some of them being very large with a mass of several thousand metric tons. Every day Earth's atmosphere is struck by millions of small meteoroids but most never reach the surface because they are vaporized by the intense heat generated when they rub against the atmosphere. Non man-made debris is beyond the scope of this thesis.

2.2 Source of Debris

2.2.1 Categories of Space Debris

In his article "Space Debris: Legal and Policy Implications,"[3] Howard Baker divides space debris into four classes: inactive payloads, operational debris, fragmentation debris and microparticulate matter. I have been referring to these categories in my thesis as follows:

(1) **Inactive payloads or inoperative objects:** Inactive payloads are primarily made up of satellites which have run out of fuel for station-keeping operations or have malfunctioned and are no longer able to maneuver. However, the use of the term "inactive payloads" requires clarification. Because satellites can be deactivated for periods of time and then later reactivated, and because debris may include objects manufactured in outer space and not just payloads, the term "inoperative objects" may be more correct when referring to objects which entities can no longer control.

(2) **Operational debris:** Operational debris includes any intact object or component part that was launched or released into space during normal operations. The largest single category of this type of debris is intact rocket bodies that remain in orbit after launching a satellite.

(3) **Fragmentation debris:** Fragmentation debris is created when a space object breaks apart. This type of debris can be created through explosions, collisions, deterioration, or any other means. Some debris have been caused intentionally. The Chinese test is an example but it is not a unique event. For instance, the USSR has intentionally destroyed several reconnaissance satellites to prevent their recovery by other States. In 1985, the US also tested an air launched anti-

satellite weapon that produced 230 pieces of trackable debris, and in 1986, intentionally caused two US satellites to collide, producing hundreds more pieces of detectable debris.[4] Collisions are another source of fragmentation debris. Debris of this type may result from collisions between space object and either natural or artificial orbital debris.

(4) **Microparticulate matter:** Surface degradation is also a cause of space debris. Surfaces of spacecraft are exposed to the deleterious space environment of ultraviolet radiation, atomic oxygen, thermal cycling, micro-particulates, and micrometeoroids. This can lead to degradation in the optical, thermal and structural integrity of surfaces and coatings with subsequent shedding of materials into the space environment. Indeed, debris can be created as the result of the gradual disintegration of the surfaces on a satellite due to exposure to the space environment.

2.2.2 Examples of How Debris is Created

Debris in space is composed of various elements from various space missions. From 1957 through 2006, the total number of space missions to reach Earth orbit or beyond was 4477.

The types of debris are manifold. One source is discarded hardware. For example, many upper stages from launch vehicles have been left in orbit after they are spent. Many satellites are also abandoned after the end of their useful life. Another source of debris is spacecraft and mission operations, such as deployments and separations. A major contributor to the orbital debris background has been object breakup. Breakups generally are caused by explosions and collisions.

The majority of breakups have been due to explosions. According to a recent paper by the IAA,[5] it is noted that, as of 2005, more than 180 in-orbit explosions have occurred, generating about 40% of the orbital debris population. For instance, on 29 June 1961, the Able Star upper stage used to launch the Transit 4A satellite exploded and produced 296 catalogued pieces of debris, 181 of which were still in orbit in 1 January 2007. Explosions can occur when propellant and oxidizer inadvertently mix, residual propellant becomes over-pressurized due to heating or batteries become over-pressurized. Some satellites have been deliberately detonated. Explosions can also be indirectly triggered by collisions with debris. With proper mitigation guidelines in place and implemented by space-faring nations, debris creation of this sort can easily be easily avoided. This is why many experts have argued that any spacecraft or upper stage left in orbit should be "passivated", i.e. its internal energy eliminated. In doing so, owners of spacecrafts would ensure the following: residual propellants be dumped, pressurants be depleted, batteries safed, etc..

A large amount of debris may also be produced as an unexpected outcome of normal operations. For example, the nuclear reactor core disposal procedure adopted after the accidental re-entry of the RORSAT satellite Cosmos 954 resulted in many liquid metal (sodium potassium) droplets escaping from the primary cooling system encircling the expelled reactor core. The diameter of these liquid metal spheres, located at 850-1000 km with an inclination of about 65 degrees, can reach 5 cm or more.[6] Unfortunately, such debris can remain a hazard for years, the orbital lifetime of a 1 cm droplet is about 100 years.

In 2006, in February, the 45-year-old Vanguard 3 (1959-007A) released a single piece of debris with very low velocity while in an orbit of 510 km by 3310 km.[7] The release velocity was very small, and the likely cause was the impact of a small (untracked) particle or surface degradation of the spacecraft. In November of the same year, shortly after reaching an orbit of approximately 850 km circular on 4 November 2006, a Delta IV second stage unexpectedly released more than 60 debris in a retrograde direction with velocities mostly in the range of 0-50 m/s. In December, a 17-year-old Delta second stage

(1989-089B) released as many as 36 tracked debris from an orbit of 685 km by 790 km. The debris exhibited orbital decay rates higher than normal and all but three have already reentered.

The weaponization of space has also created space debris which is still in orbit. The January 2007 Chinese destruction of a satellite has, as noted, also been a source of debris.[8] According to Geoff Forden,[9] within a single 100 minute orbit, an equatorial satellite passed closer than 100 km to 18 catalogued space objects, including two functioning satellites. Of the 16 pieces of debris, six are from the destroyed Chinese satellite. Debris from this collision has been observed at altitudes as great as 3,600 km, four times as high as the original target satellite.

One of the worst cases in history is the so-called US "Westford Needles Experiment".[10] The Westford needles project was an experiment to allow long distance communications by bouncing radio waves off of a band of small wires (passive dipoles) cut to a specific length. Over 300 million dipoles about 2 cm were to be released from a spinning canister at around 3,900 km altitude. A belt of dipoles 8 km wide and 40 km thick was expected. Luckily, the first attempt was unsuccessful, but the second, in May 1963, encountered payload separation problems, resulting in clumps of dipoles. Of the 100 clumps cataloged by the US–Canadian North American Aerospace Defense Command (NORAD), 60 are still in orbit.

There is also unusual debris. Galaxy 3R, a US geosynchronous satellite launched in 1995, suffered a failure of its spacecraft control processor in January 2006. Attempts to recover control of the spacecraft were unsuccessful and the spacecraft operator was unable to boost the vehicle into a disposal orbit above the geostationary arc, Galaxy 3R remaining a debris in its orbit. There also exists celebrated space debris such as Ed White's spacesuit glove that drifted out of Gemini during the first US spacewalk in 1965, and the loss of a powered screwdriver during the repair of the Solar Max in 1984.

In summary, space debris finds its origin in:

Table 2-1 - Main Sources of Space Debris

Transfer and Early-Orbit Operations (Solid Rocket Motors represent the main source of debris created during this phase in a mission)
Deployment and Operational Debris (for instance, deployment phase of satellite operations, several items are deliberately released in-orbit)
Equipment breakups
Collision risks
End of mission and disposal

The questions thus becomes: What to do to prevent the further increase of space debris? How to reconcile the military and public policy dimensions and especially avoid a new weapons race in the space? How to negotiate a convention leading to the implementation of appropriate orbital debris mitigation policies and guidelines?

2.3 Tracking and Cataloguing Space Debris

More than 30,000 objects had been officially cataloged by the US Space Surveillance Network[11] (SSN) by the end of January 2007. SSN is the main comprehensive debris monitoring system for space debris. It has been tracking space objects since 1957 when the Soviet Union opened the space age with the launch of Sputnik I. The system was originally designed to detect objects of military significance, but it is capable of performing the task of monitoring many other types of space objects. The SSN is operating ground-based radars and optical sensors at 25 sites worldwide. Originally, the SSN tracked space objects which were ten centimeters in diameter or larger. Since March 2003, the sensitivity of the SSN has improved so that objects as small as five centimeters in LEO in medium to high inclinations can now be tracked.

Approximately, 8% of the cataloged population is operational spacecraft, while 50% can be attributed to decommissioned satellites, spent upper stages, and mission related objects. The remainder of 43% originates from 160 on-orbit fragmentations which have been recorded since 1961 (The bigger debris are well-tracked as shown in the below images).[12] The total number of identified satellite breakups by 1 January 2007 was 189.

Figure 2-1 - Space Debris Pollution Models

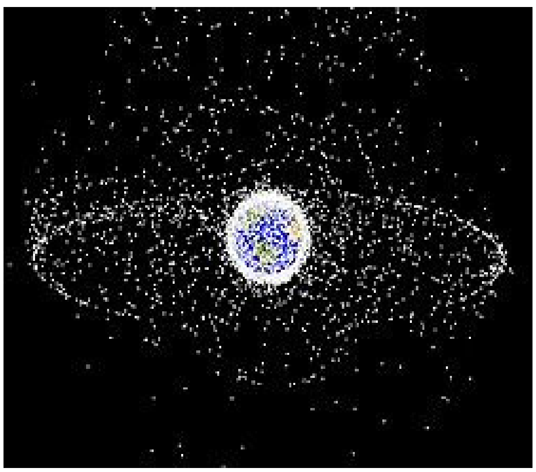


Image generated from a distant oblique vantage point to provide a good view of the object population in the geosynchronous region (around 35,785 km altitude). Note the larger population of objects over the northern hemisphere.

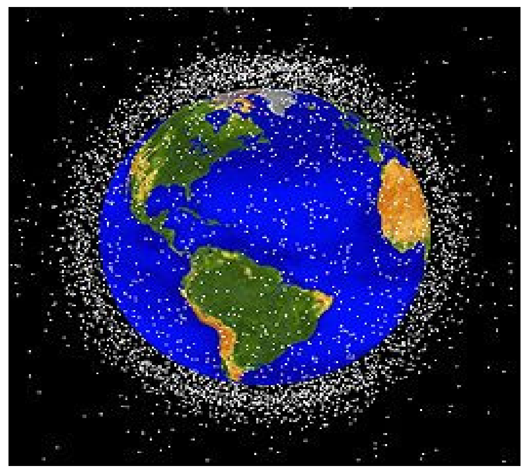


Image of the low Earth orbit, the region of space within 2,000 km of the Earth's surface. It is the most concentrated area for orbital debris.

Source: NASA orbital Debris Program Office

Most of space debris has a mean altitudes of 528 miles (850 kilometers) or greater. This means most will be long-lived.[13] Most space debris will not fall to earth for thousands or even millions of years, and the vast majority of what does fall to earth will incinerate itself when it hits the upper atmosphere.

The situation at some specific orbits can be described as a crowding problem. At altitudes between 700 and 1,000 km, around 1,400 km, and in geostationary orbit, this is the case. These altitudes correspond to appropriate orbits for specific missions: Remote-sensing sun-synchronous missions are primarily between 700 and 1,000 km, communication satellites (and some of the main constellations) in low Earth orbits are typically above 700 and below 1,500 km, and geostationary orbit is around 36,000 km. Each year, new debris is created, then catalogued and tracked by various organizations. For instance, in 2006, more than 300 debris larger than 5 cm in diameter were detected with approximately half of this debris being in orbits with likely lifetimes of many years.

Table 2-2 - Debris Generated in 2006 (Above 5 cm)

Type	Common Name	International Designator	Orbit Type	Debris Detected	Debris Lifetime
Spacecraft	Vanguard 3	1959-007A	Low, eccentric	1	Long
	SARA	1991-050E	Low, circular	2	Moderate
	Cosmos 2423	2006-039A	Low, circular	>30	Short
Launch Vehicles	Tsyklon 3rd Stage	1985-108B	Low, circular	-50	Short
	Proton Ullage Motor	1989-039G	High, eccentric	>100	Long
	Delta 2 2nd Stage	1989-089B	Low, circular	>30	Short
	Proton Ullage Motor	2000-036E	High, eccentric	-10	Short
	H-2A 2nd Stage	2006-002B	Low, circular	20	Short
	H-2A 2nd Stage	2006-037B	Low, circular	-20	Short
	Delta 4 2nd Stage	2006-050B	Low, circular	>60	Moderate

Source: NASA, Space Debris Environment and Policy Updates, Presentation to the 44th Session of the Scientific and Technical Subcommittee Committee on the Peaceful Uses of Outer Space, United Nations, 12-23 February 2007

2.4 Assessing the Threats: A Scientific and Economic Perspective

2.4.1 The risk of Collision: A Scientific Problem

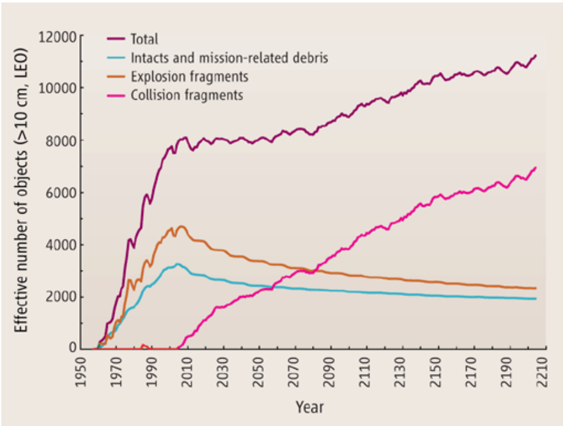
The Low Earth Orbit (LEO) is not a limitless resource and must be managed carefully. Collisions at orbital velocities can be highly damaging to functioning satellites and space manned missions. At orbital velocities of more than 28,000 km/h (17,500 mph), an object as small as 1 cm in diameter has enough kinetic energy to disable an average-size spacecraft. Objects as small as 1 mm can damage sensitive portions of spacecraft, but these particles are not tracked.[14] At a typical impact velocity of 10 km/s, a 1 cm liquid sodium-potassium droplet would have the destructive power of an exploding hand grenade. An aluminum sphere which is 1.3 mm in diameter has damage potential similar to that of a 0.22-caliber long rifle bullet. An aluminum sphere which is 1 cm in diameter is comparable to a 400-pound safe traveling at 60 mph. A fragment which is 10 cm in its long dimension is roughly comparable to 25 sticks of dynamite.

The chance of a collision and substantial damage is not insignificant. The Space Shuttle has maneuvered to avoid collisions with other objects on several occasions. Regarding satellite constellations, if a potential collision will lead to the creation of a debris cloud that may result in damage to other constellation members, it may be worthwhile to perform a collision avoidance maneuver more often. Large particles obviously cause serious damage when they hit something. Part of a defunct satellite or any large debris resulting from a space launch would almost certainly destroy a satellite or kill a space explorer on impact. For instance, on 24 July 1996, the French satellite Cerise was hit by debris from an Ariane rocket's third stage, which had exploded in 1986 generating 700 fist-sized debris.

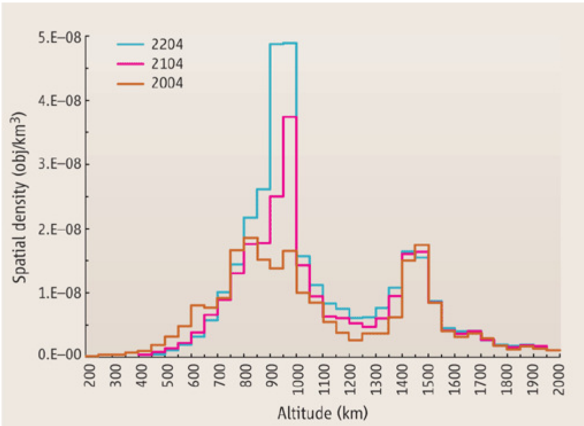
According to the United Nations Office for Outer Space Affairs (UNOOSA),[15] small particles are much more numerous and are nearly impossible to track because of their size. According to the NASA Orbital Debris Program Office[16], the estimated population of particles between 1 and 10 cm in diameter is greater than 100,000. The number of particles smaller than 1 cm probably exceeds tens of millions. According to Newman, a MIT scientist, a more subtle problem with space debris lies in the fact that the hazards are nondeterministic. That is, space junk often moves from its initial orbit, so the threat of danger is not clearly localized. As explained by Newman[17], this is due to the fact that “space debris is more the result of fragmentation or breakup of satellites than deterioration and out-phasing of satellites. Typically a single breakup can result in as many as 500 or more observed pieces. Each piece is free to settle in a new unpredictable orbit, creating a nonlocalized potential danger for operational satellites (i.e., an impact can come from anywhere).”

A source of risk is found in the likelihood of a chain of collisions among debris in the coming years. Under such scenario, space debris would grow exponentially as they start to collide, thus creating more debris. As a result, collisions would become the most dominant debris-generating mechanism in the future. Several studies demonstrated, with assumed future launch rates, the production rate of new debris due to collisions exceeds the loss of objects due to orbital decay.[18] As a result, in some low Earth orbit (LEO) altitude regimes, where the number density of objects is above a critical spatial density, more debris would be created. The Growth of future debris populations is shown in the above two graphs. They show the effective number of LEO objects, 10 cm and larger, from the LEGEND simulation.[19]

Figure 2-2 - Debris Simulations from LEGEND



Effective number of LEO objects, 10 cm and larger from the LEGEND simulation.



Spatial density distributions, for objects 10 cm and larger, for three different years.

Source: J.-C. Liou and N. L. Johnson

A detailed analysis conducted by NASA specialists J.-C. Liou and N. L. Johnson (2006) indicates that the predicted catastrophic collisions and the resulting population increase are nonuniform throughout LEO. They conclude that it is probable that about 60% of all catastrophic collisions will occur between 900 and 1000 km altitudes, the number of objects 10 cm and larger tripling in 200 years, leading to a factor of 10 increase in collisional probabilities among objects in this region. They argue: "Even without new launches, collisions will continue to occur in the LEO environment over the next 200 years, primarily driven by the high collision activities in the region between 900- and 1000-km altitudes, and will force the debris population to increase. In reality, the situation will undoubtedly be worse because spacecraft and their orbital stages will continue to be launched." [20]

2.4.2 An Increasing Space Market with Higher Risks of Economic Disruptions

The market for commercial space launchers has witnessed rapid growth over the past several years. If more space debris accumulates, the business is at risk. Today, more and more activities rely on the well-functioning of communication equipment in space. Any disruption can have major consequential losses. World geopolitics has dramatically changed since the 1960's race to the moon. At the time, the US and the Soviet Union competed with one another, both on Earth and in space.

Today, the two nations are partnering on common projects along with a number of other nations. The International Space Station is the most convincing example of international cooperation, not only between two space leaders, but also involving fourteen other nations: Belgium, Brazil, Canada, Denmark, France, Germany, Japan, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. As stated by Frost & Sullivan, [21] "international cooperation has greatly enhanced national efforts in space-based science, observation, telecommunication and manned exploration. Space research and development shifted from national confidential to government and industry collaborative programs to international cooperative projects."

Not surprisingly, the space market is again on the upward trend. By the end of last century, the world satellite market generated revenues of about $11 billion. In terms of satellite launches, the year 2002 has shown the highest number of launches with 289. Today, the world wide revenues for the market are around the $16 billion. The health of the global telecommunications market determines to a great extent the sustainability, and therefore the continuity, of space industry. For instance, of the 155 satellites successfully launched by Ariane-4 in the course of its operation, 139 are telecommunications satellites. Of the 39 satellites launched by Ariane-5 by mid-2005, 26 are telecommunication satellites. It is estimated that 90% of the value of satellite payloads launched by Ariane-5 will be telecommunications-related.[22] However, it is pointed out that the commercial space activities are not the only source of revenues as military and defense programs are also generating important revenues. For instance, the US commercial space activities have a relatively small role in the US space panorama. In recent years, they have averaged a total of about $4-5 billion as compared to NASA's budget which weights over US$15 billion.

Several trends are positively impacting on the commercial satellite market. First, new needs have appeared. Networks of Little LEOs, Big LEOs, LEO broadband systems, MEOs and GEOs are scheduled for launch within the next seven years. With improvements in satellite components, technologies and production processes, satellite systems are improving in function, as well as in production and operational costs. Second, the space market is also gaining prominence in many countries. For instance, Brazil and Mexico have become important operators of space system. Today, the Brazilian Instituto Nacional De Pesquisas Espaciais' (INPE) has an ambitious and visionary space program dating back to 1979. Since 1992, Argentina's space activities have been considerably developed. In 1994, a Space Plan for 1995-2006 was drawn and a

US$700 million budget allocated, for the launch of science and telecommunication satellites. South Korea, India, China and Japan all have strong space programs capable of integrating and launching satellites. As pointed by Frost and Sullivan, the “space systems market is encouraged by a new space race among Asian rocket and satellite builders vying for commercial customers on the global market”.[23]

In summary, several factors are positively impacting the satellite industry. These include:

1. Changing manufacturing approaches: greater standardization and mass production

2. Expansion and greater variety of satellite systems: More Little LEO, Big LEO, and MEO satellites

3. Movement to higher frequency bands: Ka- and V-bands

4. Industry consolidation: Major companies are merging (even across international lines) to expand industry resources

5. Global outsourcing of products and supply chain: As new entrants are getting access to the space market, main space-faring nations have started to delocalize supply chains and transfer technology

6. Movement from military and science satellite production to commercial production

7. Satellite component and subsystem changes: Satellites becoming more powerful and efficient units

As a result, the commercial satellite market is the most dynamic market sector within the satellite industry. Increasingly, commercial satellites compose a larger share of the market. From 1995 to 2005, a total of about 1,500 satellites have been launched, about 75% of them belong to the commercial segment. The total revenues for the launching market is about USD10 billion. However, the total satellite industry revenues (inclusive of satellite services, launch industry, satellite manufacturing, ground equipment) are about USD90 billion with an average annual growth of 6.7% over 2000-2005.[24] After a period of depression in the industry, the demand is now stronger, especially for new countries entering the market. For instance, as demand for satellites in China soars, the nation is projected to launch around 10 satellites a year during the 2006-2010 period, compared with an annual average of five launches between 2001 and 2005.[25]

Table 2-3 Total Commercial, Military, and Science Satellite Market (base year is 1998)

Year	Units	Revenues (US$ Billion)	Growth rate (%)
1995	70	7.56	
1996	69	7.29	(3.56)
1997	129	8.57	17.43
1998	145	9.56	11.62
1999	134	11.05	15.62
2000	94	11.06	0.04
2001	206	14.41	30.31
2002	289	14.92	3.53
2003	263	16.12	8.04
2004	189	13.69	(15.07)
2005	138	10.89	(20.45)
Compound Annual Growth Rate (1998-2005): 1.9%			

Source: Frost & Sullivan Market Research

Table 2-3 provides a breakdown of revenues and unit shipments for the world satellite launching market from 1995 to 2005. The commercial sector has, and should continue to account for, the highest revenues through the end of the forecast period. In 1998, 59 percent of revenues were generated from commercial satellite systems. Military satellites should continue to account for the second largest market in the industry. In terms of the total market, the military sector has been erratic from the 1995 to 1998 period. From 1999 to 2005, military satellites account for between 20 to 26 percent of the total market.

Finally, science satellites account for the smallest segment in terms of revenues, and are expected to remain so in the coming years.

At this pace, incidents are likely to occur. As a result, in case of damage and consequential business interruption for the commercial operators, there must be a compensation instrument put in place for recovering the cost of the loss. Typically, in the space industry, there are about 10-15 large insurers (called underwriters). There are about 13 international insurance underwriters that provide about 75% or so of the total annual capacity. However, none of them provides coverage for space debris damages.

We can find four implications of a disaster event:

1. It arrives suddenly and is unanticipated;

2. It poses new problems in which the community has little prior experience;

3. Failure to respond implies either a critical financial reversal or loss of a significant opportunity; and

4. The response must be urgent and cannot be handled promptly by normal business systems and procedure (i.e. a satellite breakdown caused by space debris could stop earth communication for a while).

Because damages and losses caused by space debris are difficult to cover from a traditional insurance perspective, it is important to draft an international convention that would define the extent of national jurisdiction in outer space. In the following pages, I discuss how a liability and compensation mechanism can be implemented (See Chapter 4).

2.5 Efforts Made by Space-faring Countries and International Organizations

Many space-faring nations have started to realize the problem posed by space debris and have adopted various measures to mitigate space debris. Today, there is a wide interest in the problem from the scientific community and various initiatives and organizations have been set up to debate and promote various guidelines or codes of conduct.

2.5.1 Space Debris Activities in a Global Context

Space debris activities started to display momentum in the 1960s with initial interest by the USA. In the mid-1970s, the problem was first raised at the international level when the IAF started to organize the Safety and Rescue Symposia congresses. But we have to wait until the early 1980s to bring space debris issues to the forefront of scientific agenda. In July 1982, NASA conducted the first dedicated conference on orbital debris. In September 1985, as a response to the decays of Skylab and Cosmos 1402, ESA organized a workshop on the re-entry of space debris. In April 1993, ESA also organized the first European conference on space debris with participants from the major space-faring nations. Since the mod-1990s, space debris research has gained considerable interest. According to Klinkrad,[26] regular NASA/ESA coordination meetings have taken place since 1987. Starting in 1989, NASA also created coordination initiatives with the Russians. At the same time, the International Academy of Astronautics (IAA) published it position paper on space debris, produced by an international ad-hoc group of experts.

We had to wait until 1993 for the seventh NASA/ESA coordination meeting to take place with the participation of NASDA to prepare the ground for the creation of the Inter-Agency Space Debris Coordination Committee (IADC). Now, the IADC meets annually and consists of four working groups to coordinate and disseminate the technical information exchange in the areas of debris measurements, modeling techniques, impact protection and debris mitigation. The space debris issue is also presented every year to the IAF conferences and every 2 years to the COSPAR congresses.

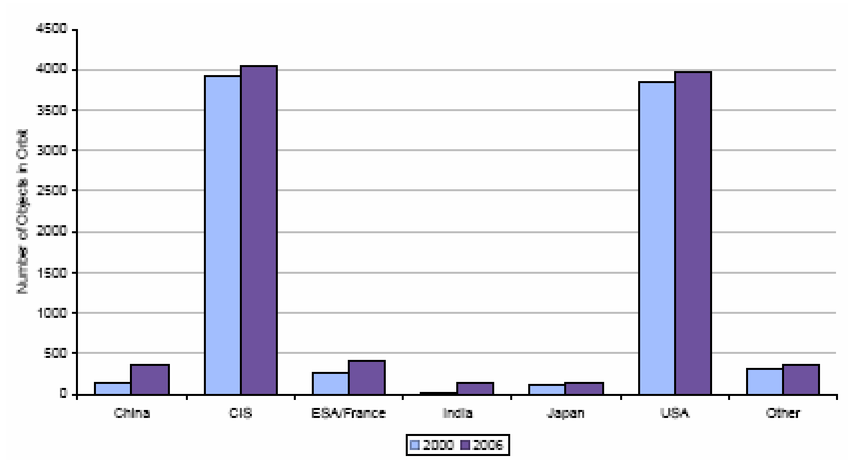
2.5.2 The Role of the US

Although at this time the US Government does not see the need or benefit for a new legal regime to address the topic of space debris, the US has played a crucial role in tracking, cataloguing, modeling space debris. NASA has been at the forefront of orbital debris mitigation efforts in the US government. With authority over all civil government space missions, the agency has developed a policy and specific procedural requirements for orbital debris mitigation.

A NASA Orbital Debris Program Office has been created and is located at the Johnson Space Center.[27] It is recognized world-wide for its leadership in addressing orbital debris issues. The NASA Orbital Debris Program Office has taken the international lead in conducting measurements of the environment and in developing the technical consensus for adopting mitigation measures to protect users of the orbital environment. Work at the center continues with developing an improved understanding of the orbital debris environment and measures that can be taken to control its growth. The Office plays a key role within the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space in promoting mitigation guidelines.

It is worth noting that the debris problem has its origin in the space competition between the former USSR and the US. Since 2000, the number of in-orbit objects larger than a bowling ball has increased by nearly 10 percent, with the United States and Russia each contributing approximately 40 percent of the total debris. The following graph illustrates the origin of space debris and clearly it becomes obvious that the role of the US in dealing with this problem cannot be marginal.

Figure 2-3: Growth in Number of Objects in Orbit, by Country/Organization, from 2000 to 2006[28]



Source: Futron Corporation, 2006

Space debris has been clearly identified in the new National Space Policy of the US signed on 31 August 2006 by President George W. Bush. The document flagged the progress made both nationally and internationally regarding proliferation of orbital debris over the past decade but also underscored the worrisome nature of space junk. The White House document stated: “Orbital debris poses a risk to continued reliable use of space-based services and operations and to the safety of persons and property in space and on Earth. The United States shall seek to minimize the creation of orbital debris by government and non-government operations in space in order to preserve the space environment for future generations”[29]. Toward that end the White House argued that American departments and agencies shall continue to follow the “United States Government Orbital Debris Mitigation Standard Practices, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the operation of tests and experiments in space.”

This is a major step but the intentions have to be followed by actions. It is also stated in the 2006 National Space Policy document that the USA shall take a "leadership role in international fora to encourage foreign nations and international organizations to adopt policies and practices aimed at debris minimization and shall cooperate in the exchange of information on debris research and the identification of improved debris mitigation practices." In regard to curbing space debris, the document encourages foreign nations and international organizations to also take steps toward debris minimization.

However, it is worth pointing to a major drawback. Although joint DoD/NASA guidelines known as the U.S. Government Orbital Debris Mitigation Standard Practices have been issued in 2000 for mitigating the growth of orbital debris, they are not considered binding regulations and responsibility and accountability is not legally enforceable. More importantly, national security and other government programs can be granted orbital debris waivers today, demonstrating that the current regulatory regime contains loopholes in terms of applicability of standards.[30]

2.5.3 The Role of Russia

The Federal Space Agency of Russia is active in the field of space debris problems. The Agency is mostly concerned with the safety of spacecraft and International Space Station (ISS). The activity on debris mitigation is presently being carried out within the framework of Russian National Legislation, taking into account the dynamics of similar measures and practices of other space-faring nations. Since 2000 designers and operators of spacecraft and orbital stages have been asked to follow the requirements of Federal Space Agency's standard entitled "Space Technology Items, General Requirements for Mitigation of Space Debris Population". According to the Federal Space Agency of Russia, no major accident has occurred in past years. In 2006, the agency reported that 194 events were detected with approaches of cataloged GEO objects to Russian operational spacecrafts up to distance less than 50 km. Furthermore, 10 events were detected with approaches up to distances less than 10 km that is comparable with errors of orbital parameters calculations.[31]

The Russian Federation is now working on a set of mitigation measures. A national standard called "General Requirements to Spacecraft and Orbital Stages on Space Debris Mitigation" is being developed and shall provide general space debris mitigation requirements to design and operation of spacecrafts and orbital stages. At this stage, the implementation of requirements would remain voluntary. In terms of international cooperation, and similar to the US position, the Russian Federation is convinced that development of space debris mitigation guidelines of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space is the essential input in developing an internationally approved set of measures to protect near-Earth space environment. For the disposal of satellite at geosynchronous altitude, Russia also proposes to base the standard on IADC Space Debris Mitigation Guidelines.

2.5.4 The Role of the European Union

ESA has a long history in tracking space debris.[32] In 1986, the Director General of ESA created a Space Debris Working Group with the mandate to assess the various issues of space debris. The findings and conclusions are contained in ESA's Report on Space Debris, issued in 1988. In 1989, the ESA Council passed a resolution on space debris where the Agency's objectives were formulated as follows: 1) Minimize the creation of space debris; 2) reduce the risk for manned space flight, 3) reduce the risk on ground due to reentry of space objects, 4) reduce the risk for geostationary satellites. ESA's Launcher Directorate at ESA Headquarters in Paris also coordinates the implementation of debris mitigation measures for the Arianespace launcher.

Over the last few years, ESA developed debris warning systems and mitigation guidelines. Following the publication of NASA mitigation guidelines for orbital debris in 1995, ESA published a Space Debris Mitigation Handbook, issued in 1999, in order to provide technical support to projects in the following areas: Description of the current space, debris and meteoroid environment, risk assessment due to debris and meteoroid impacts, future evolution of the space debris population, hyper-velocity impacts and shielding, cost-efficient debris mitigation measures. The Handbook has been updated.[33]

Space debris research is done at the European Space Research and Technology Centre (ESTEC) mainly focusing on the space segment. Activities include:

1. Development and deployment of impact detectors
2. Development of impact risk assessment tools
3. Development and testing of shielding designs
4. Support for shielding design verification
5. Impact analysis of retrieved hardware
6. Assessment of impact damage

In many cases, ESA actively proposed plans to shield its satellites, or at least critical areas such as using pressurized tanks to minimize the impact of a collision with debris. The Agency also advocates that this is a requirement for human space missions, including the ISS and all other critical areas used for human space flight.

2.5.5 The Role of the Inter-Agency Space Debris Coordination Committee (IADC)

The Inter-Agency Space Debris Coordination Committee (IADC) is one of the world's leading technical organizations dealing with space debris. ESA is a founding member of IADC, together with NASA, the Russian Aviation and Space Agency, and Japan. IADC is today an international forum of governmental bodies for the coordination of activities related to the issues of man-made and natural debris in space. It is composed of the following members: Italian Space Agency (ASI), British National Space Centre (BNSC), the Centre National d'Etudes Spatiales (CNES), China National Space Administration (CNSA), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), the European Space

Agency (ESA), the Indian Space Research Organisation (ISRO), Japan Aerospace Exploration Agency (JAXA), the National Aeronautics and Space Administration (NASA), the National Space Agency of the Ukraine (NSAU) and the Russian Federal Space Agency (ROSCOSMOS).

The primary purpose of the IADC is to exchange information on space debris research activities between member space agencies, to facilitate opportunities for co-operation in space debris research, to review the progress of ongoing co-operative activities and to identify debris mitigation options. The IADC comprises a Steering Group and four specialized working groups:

1. Measurements
2. Environment and database
3. Protection
4. Mitigation

Generally speaking a consensus has emerged on the adoption of mitigation guidelines in accordance with what has been proposed by the IADC. The "IADC Space Debris Mitigation Guidelines" was drafted in 2002 as the first international document that is specialized in field of space debris mitigation and based on a consensus among the IADC members. In February 2003 at the fortieth session of the Scientific and Technical Subcommittee of the UNCOPUOS, the IADC presented the "IADC Guidelines" as its proposals on debris mitigation. This document serves as the baseline for the debris mitigation in two directions: 1) toward a non-binding policy document, and 2) toward applicable implementation standards.[34]

Since the drafting of this document, IADC and its members have kept working on the mitigation guidelines as a way to solve the space debris issue. For instance, in 2004 the IADC Working Group 4 prepared the "Support to IADC Space Debris Mitigation Guidelines" with information on the rationale for the Guidelines, recommendations on how to cope with the Guidelines, applicable methods, and justification of the numerical values, a tailoring guide, and definition of parameters, technical information, applicable references, and examples. The IADC guidelines are based on these common principles and have been agreed to by the IADC member agencies. Mitigation guidelines have also been drafted by many national space organization but they vary widely in their requirements for the post-mission disposal of space systems in different orbital regimes, such as LEO, GTO, MEO, and GEO[35].

One criticism of the IADC Space Debris Mitigation Guidelines is found in the fact that they remain voluntary and not legally binding under international law. Still, IADC is an ideal forum on space debris due to its wide membership among the leading space agencies and provides a basis for further international cooperation when elaborating a space debris convention. Indeed, IADC standards have facilitated the discussion on space debris mitigation guidelines and opened the door to further research related to the cost of mitigation measures. Thus, recently, various studies have been conducted on the effectiveness and the costs of debris mitigation measures. These studies examine a number of important problems: prevention of on-orbit explosions and operational debris release, reduction of slag debris ejected from solid rocket motor firings, de-orbiting of space systems in LEO with various limitations on the post-mission lifetime, and re-orbiting of space systems to above the LEO & GEO protection zones (graveyard orbiting).

2.5.6 The Role of the United Nations

The United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)

Over the past years, UNCOPUOS and its Scientific and Technical Subcommittee (STSC) have played an important role in debating space debris issues over the past years. UNCOPUOS was set up by the General Assembly in 1959 in resolution 1472 (XIV). At that time, the Committee had 24 members. Since then it has grown to 67 members, one of the largest Committees in the United Nations. In addition to states, a number of international organizations, including both intergovernmental and non-governmental organizations, have observer status with UNCOPUOS and its Subcommittees. The Committee has the following goals: 1) review the scope of international cooperation in peaceful uses of outer space, 2) devise programs in this field to be undertaken under United Nations auspices, 3) encourage continued research and the dissemination of information on outer space matters, and 4) study legal problems arising from the exploration of outer space.

The resolution establishing UNCOPUOS also requested the UN Secretary-General to maintain a public registry of launchings based on the information supplied by states launching objects into orbit or beyond. Those terms of reference have since provided the general guidance for the activities of the Committee in promoting international cooperation in the peaceful uses and exploration of outer space. The Committee is divided in two standing subcommittees: the Scientific and Technical Subcommittee and the Legal Subcommittee. The Committee and its two Subcommittees meet annually to consider questions put before them by the General Assembly, reports submitted to them and issues raised by the Member States. The Committee and the subcommittees, working on the basis of consensus, make recommendations to the General Assembly.

The agenda of the Committee is quite large. For instance, the forty-fourth session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space was held from 12-23 February 2007 at the United Nation Office at Vienna. The session covered a wide array of issues, including space debris, matters relating to remote sensing of the Earth by satellite, including monitoring of the Earth's environment, use of nuclear power sources in outer space, near-Earth objects, space-system-based disaster management support, physical nature and technical attributes of the geostationary orbit, etc. The Committee has also been concerned with space objects with nuclear power sources on board and problems relating to their collision with space debris.

The Committee is unique in its ability to discuss issues related to space debris. Over the last few years, the Scientific and Technical Subcommittee has been actively promoting mitigation guidelines. It has been a common understanding since UNCOPUOS published its Technical Report on Space Debris in 1999 that man-made space debris poses risks because the amount of debris is growing and the probability of collisions that could lead to potential damage will consequently increase. The Subcommittee also advocated that member states, in particular, space-faring countries, should pay more attention to the problem of collisions of space objects, with space debris and to other aspects of space debris as well as its re-entry into the atmosphere. The Subcommittee agreed that research on space debris should continue and that member states should make available to all interested parties the results of that research, including information on practices that had proved effective in minimizing the creation of space debris.

United Nations Office for Outer Space Affairs (UNOOSA)

UNOOSA implements the decisions of the General Assembly and of UNCOPUOS. The office has the dual objective of supporting the intergovernmental discussions in UNCOPUOS and of assisting developing countries in using space technology for development. The Office is the focus of expertise within the United Nations Secretariat. It serves as the secretariat for the intergovernmental Committee (UNCOPUSOS), and implements the recommendations of the Committee and the United Nations General Assembly. The Office is also responsible for organization and implementation of the United Nations Programme on Space Applications (UNPSA).

In addition, the Office follows legal, scientific and technical developments relating to space activities, technology and applications in order to provide technical information and advice to member states, international organizations and other United Nations offices.[36] On behalf of the Secretary-General, the Office also maintains the Register of

Objects Launched into Outer Space and disseminates information transmitted by Member States and other parties to the Registration Convention.

The United Nations Programme on Space Applications (UNPSA)

UNPSA is part of the Office for Outer Space Affairs. Its mission is stated as follows: "Enhance the understanding and subsequent use of space technology for peaceful purposes in general, and for national development, in particular, in response to expressed needs in different geographic regions of the world".[37] Its primary function is the organization of a series of 8-10 annual seminars, workshops and conferences on particular aspects of space technology and applications. These activities are organized primarily for the benefit of the developing countries and emphasize the use of space technology and applications for economic and social development. In the past years, the space debris issues have not been part of the curriculum of the workshops and seminars. The Programme also provides technical assistance to Member States of the United Nations in organizing and developing space applications programs and projects.

2.6 The Corporate and Civil Society Perspective

2.6.1 The Corporate Responsibility

The role of space corporations is seen as important because commercial activity in space is increasing and thus potentially creating more debris. Until recently, space debris was a subject fraught with uncertainties, usually shunned by aerospace corporations around the world and inadequately addressed by many space agencies. As the issue gained prominence in the mid-1990s, the private sector has been seeking to find the most appropriate response to address the space debris problem. However, the space industry has been struggling to provide the required solutions. As competition has increased and profits have shrunk, many of the space corporations have adopted "lean" approaches, the "better, faster, cheaper" concept resting on the interconnection of decreased mission costs and increased risk. Most of the time, the prudent vehicle design and operations that may lead to decrease the level of debris is coming to a cost that is perceived too high by the industry.

At a time when there is so much talk about the commercialization of space and space tourism, it is important to raise the awareness of the space industry that it is in the interest of all parties to find the best and most acceptable solution to the problem Today, space corporations around the world are rightly considered the first line of defense for preventing debris to accumulate. As space activity increases, the accumulation of debris is also on an upward trend. Over the recent years, companies have been facing new demands to engage in public-private partnerships and are under growing pressure to be accountable not only to shareholders, but also to society-at-large.

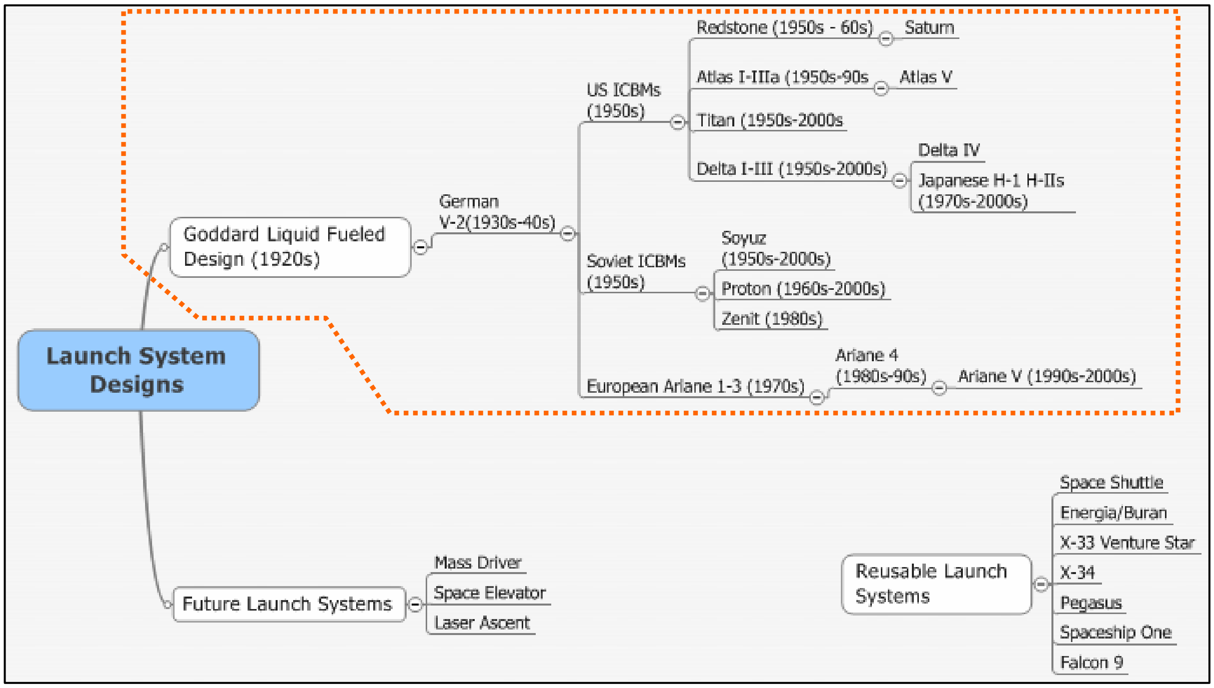
When addressing the problem posed by space debris, it is thus time to include the space industry in the international effort to tackle this pressing issue. The space industry does not bear the responsibility for leveling the playing field and ensuring that space free of pollution. However, government and the private sector must construct a new understanding of the balance of public and private responsibility and develop new governance for activity in space and thus creating social value.[38]

Many advances in the space industry have to be accounted for. First, due to the success of recent low cost launches, the projected scope of space tourism and NASA's new directive from President Bush to return to the Moon and then go to Mars, space transportation and exploration is again regaining considerable attention in the private sector. With new needs emerging for telecommunication (for instance GPS satellites at medium earth orbit, Sirius satellite radio at HEO, and commercial geostationary satellites) and other space activities, it is therefore believed that new firms will enter the space market. Unless they adhere to strict mitigation standards, these initiatives will continue to create more space debris and, at the same time, their business will be vulnerable to such debris. For that reason, it is vital for the space private sector to understand that the business is at risk if nothing is done to limit space debris. In the proposed international convention, the corporate view will be needed and the drafting of the legal regime will need to include the views expressed by the space industry at large.

Second, the pace of innovation in the space industry is high and it leads to major uncertainties on the rate of debris creation. For instance, in May 2006, Arianespace launched an Ariane 5 that delivered a record-setting dual-satellite payload of more than 8,200 kg. Atlas 5 and Delta 4 launchers are now strong competitors in this category. Payloads of above 15,000 kg can now be sent to space. At the same time, low cost initiatives are more numerous: Vega (Arianespace), SpaceX, SeaLauncher, and Kistler are a few of the big names. Russia, Ukraine, and China have also provided low cost rockets in the last few decades and have achieved a stable launch cost per payload weight of around $5-10K/kg. Other rockets may also emerge, such as variants off of the winning X-Prize design, Space Ship One. Sealaunch offers an ocean launch which also reduces the risks related to launching over populated areas, providing better safety to third parties. Reusable launchers are a promising technology. Falcon 9 of SpaceX is proposing launching above 9 tons to geo transfer orbits (GTO).

All these technologies however create space debris. Public data for launchers over all countries can be easily surveyed.[39,40,41,42] It includes 51 rockets, most of which are currently available. The following table provides an overview of space systems used to send payload in orbit and creating debris as they are launched and operated in space. The dashed line represents the dominant system design which has produced space debris since the first launch of rockets into space in the late 1950s–early 1960s.

Figure 2-4 - Dominant Space Design Creating Debris[43]



Source: MIT Disruptive Technology 15.365J – Space Launch Technology Group

2.6.2 Mitigation Rules and Costs of Compliance

In the USA, the Federal Aviation Administration (FAA) and its Office of Commercial Space Transportation, has licensing control over commercial space launch and reentry activities. As a result, commercial applicants for licenses must demonstrate various orbital debris mitigation characteristics for vehicle stages and components, such as having no unplanned contact with payloads after separation, and eliminating stored energy that could cause physical fragmentation.[44] For instance, the FAA in the US requires evidence of implementation of industry standard methods of passivation, for rendering spent upper stages remaining in orbit inert or otherwise ensuring that they will not explode or break up as a result of residual propellants, gases, or ordnance devices.

However, in many countries, the debris mitigation guidelines are not enforceable and/or are not expressed clearly for satellite operators and the space industry. Corporations have also expressed concern that the costs associated with the implementation of the package of mitigation measures could be too high. Risk and cost criteria are clearly important, but competing criteria. For instance, a relatively lower collision risk in the future will cost relatively more to achieve, and vice versa. Therefore, it is essential to analyze trade-offs and strike a balance between them in order to obtain the optimum set of mitigation measures. The costs imposed to the space corporations should therefore be carefully analyzed. A few studies have analyzed the mission costs due to space debris in a business as usual (no mitigation) scenario compared to the missions costs considering debris mitigation.[45] Clearly, mitigation strategies like the reduction of orbital lifetime and de- or re-orbit of non-operational satellites are promising methods to control the space debris environment. However, such practices increase costs. The key problem is who should bear the cost of such measures. It is important to conduct such empirical cost estimation and develop precise cost models under different mitigation scenarios.

The trend towards increased government enforcement in the orbital debris mitigation area will not necessarily motivate satellite system operators and spacecraft manufacturers to consider long-term approaches to space debris regulatory compliance unless the cost issue is debated. Clearly, manufacturers have to closely monitor orbital debris regulatory and policy developments around the globe because changing requirements will directly affect how operators approach satellite procurements. However, compliance with various national and international guidelines may result in higher system development and operations costs and may present increased technical complexity and risk failure.

New technology may constitute a promise for limiting space debris. For instance, new space technology based on tethers (or cables) is considered by many corporations for moving payload into space at lower cost with debris being limited. The promise of tethers in space revolves around their potential to provide low cost alternative for rocket propulsion. Tethers can be used to provide space propulsion without consuming propellant by slinging a payload from low earth orbit to a higher orbit.[46] Conductive space tethers can also generate electrical power or produce thrust forces through interactions with the Earth's magnetic field and therefore is an option for the space industry for de-orbiting a spacecraft after its mission to minimize space junk. As the same time, space tethers can be vulnerable to debris. This is why a Multi-Application Survivable Tether (MAST) experiment has been recently launched to study the dynamics of tethered spacecraft formations and survivability of a new tether technology in low Earth orbit. The experiment is needed to prove the survivability of the newest generation of multistrand tether technology in orbit where it will be exposed to impacts by orbital debris and erosion by atomic oxygen and ultra violet light.[47] Thus technology is not available yet and space corporations may be willing to invest in new technology if a more strict legal regime forces them to do so.

2.6.3 The Role of Civil Society

The number of non-profit organizations in the area of space is considerable. Many of them have gained prominence. I can mentioned the following: the American Astronautical Society which offers society overview, news, publications, schedule of events, member services and scholarship information; the British Interplanetary Society; the International Space Business Council; the Committee on Earth Observation Satellites (CEOS) which provides newsletters, events and publications related to space agencies responsible for earth observation. More scientific and professional associations are also very powerful, i.e. the Forum for Aerospace Engineers or the Foundation for International Development of Space. In the area of space debris, the Center for Orbital and Reentry Debris Studies contains information in the areas of space debris, collision avoidance, and reentry breakup. The Center is part of the Aerospace Corporation, a nonprofit corporation originally serving the US government in the scientific and technical planning and management of its space programs. Web-based organizations are also a source of diffusion of various space information, i.e. Space-Talk which provides message forums about space, astronomy and related topics.

However, these non-for-profit and non-governmental organizations (NGOs) have had a limited role to play in the field of space in the recent years. Unlike the representatives of citizen organizations which are increasingly active in policy making in the traditional field of expertise such as human rights, women's right, the environment, sustainable development, the space NGOs are not the most effective voices when it comes to space pollution. When we see many NGOs working closely with the United Nations departments and agencies, the civil society groups are not involved to the present work of UNCOPUOS related to space activity and debris mitigation.

I conclude this chapter by saying that the evolving spacecraft technologies, together with stricter enforcement of orbital debris mitigation regulations, present significant challenges but also opportunities for forward-looking satellite and launch vehicle operators and manufacturers. It is obvious that private sector corporations have everything to gain by equipping themselves with strong mitigation tools to prevent an accumulation of space debris. Together with the civil society organizations, they must participate vitally in the international system that will draft a space debris legal regime. They have the capacity to contribute valuable information and ideas, advocate effectively for positive change, provide essential technical capacity, and generally increase the accountability and legitimacy of the global governance process.

CHAPTER 3 – POLITICAL AND LEGAL FRAMEWORK GOVERNING SPACE ISSUES

3.1 Review of Existing Treaties, Conventions and Agreements Regulating Space Activities

3.1.1 Space Law Infancy

Before turning to the modalities of a space debris convention, I will review some of the existing conventions regulating space activities. One of the main problems of existing space law is that it does not address issues of controlling and limiting the proliferation of space debris. Furthermore, satellite and launch-vehicle manufacturers are not presently legally bound to employ mitigation measures.

It is important to note that the field of the space law is still in its infancy. The inception of this field began with the launching in October of 1957 of the world's first satellite by the Union of Soviet Socialist Republic. In 1958, United States and Soviet leaders each asked the United Nations to consider the legal issues associated with space activity. The United Nations subsequently created the previously discussed UNCOPUOS.

As noted in Chapter One, many conventions have been enacted but the main treaties and conventions have been drafted at the time of space exploration in the 1960s and 1970s and, today, they fail to account for the rapid changes in the field. As covered in Chapter 2, commercial space transportation is becoming widely available, with substantially lower launch costs and new countries are becoming active in space exploration. The market for commercial space launchers has witnessed rapid growth over the past several years. Firms in this market are competing and the commercial spaceports around the world are now quite numerous. The busiest spaceports at present are Cape Canaveral, Vandenberg, Baikonur, Plesetsk, Kourou, Tanegashima, Jiuquan, Xichang and Sriharikota.

The exiting treaties and conventions fail to account for this reality. They were drafted in time of political and military pressure when the US and the former Soviet Union were engaged in space race. It is now important to achieve a broader consensus with respect to commercial development and human settlement of outer space and, more importantly, to address the issue of space debris.

One must go back to 1967 to find the first key treaty and foundation of space rules, the Outer Space Treaty. The Treaty has 96 state parties signed on and contains a measure to not place in orbit around the Earth, install on the Moon or any other celestial body or otherwise station in outer space, any weapons of mass destruction, nuclear or otherwise. It limits activities on the Moon and other celestial bodies exclusively to those for peaceful purposes and forbids the development of military bases, installations, fortifications or weapons testing of any kind on any celestial body. In 1979, a similar treaty was published, and opened for signatures, which aims to achieve the same rules for celestial bodies. However, probably because of its provisions prohibiting the ownership of real estate in space, the treaty was virtually ignored by the world community. Only nine countries have ratified and just five others have signed it.

Other treaties have been presented and ratified, including treaties on the registering of objects launched into Outer Space, agreements on the rescuing of astronauts, and rules on international liability for damage caused by man-made space objects (See Table 3-3 summarizing the five most important space treaties and conventions). The treaties all elaborate on provisions of the Outer Space Treaty. The Treaty Banning Nuclear Weapon

Tests in the Atmosphere, in Outer Space and Under Water (5 August 1963) is targeted to control nuclear weapon proliferation. This treaty recognizes that space can be used for undesirable military projects. It bans the carrying out of any nuclear weapon test explosion or any other nuclear explosion in the atmosphere and beyond its limits, including outer space.

3.1.2 Failure to Recognize Space Debris in Legal Regimes

There is a critical weakness in the international law on space debris. Existing space law is related to the use of space and not to debris regulation. Most of existing treaties have been overtaken by technology advancement. While the rules system developed by the Outer Space Treaty or the Registration Convention is useful, it does not apply to the space debris issue. This means that commercial and government-sponsored space launches can still create more debris without limits. Today, any country or corporation can launch a rocket and/or place into orbit equipment without permit. The only constraint is that they are required to record the launching as stipulated under the Registration Convention.

Furthermore, nothing is said about the destruction of satellites in space and the creation of space debris resulting from it. In international law, nothing can prevent a nation from destroying one of its own satellites. In the end, China was free to target one of its old weather satellites with an ASAT weapon and blow the spacecraft apart because 1) it can; and 2) ASAT testing is not forbidden under international law. The arms control provisions of the Outer Space Treaty forbid the placing of nuclear weapons or any other kinds of weapons of mass destruction in orbit. The treaty also forbids establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military maneuvers on the Moon and other celestial bodies. (Art. IV). However, nothing is mentioned about spacecraft destruction and space debris thus created.

The problem of existing space debris mitigation guidelines is also troubling. A few space agencies and governments have adopted mitigation guidelines. The IADC has done great progress in trying to coordinate mitigation activities and putting forward proposals. Recently, in February 2007, the UN reached a consensus on the draft of space debris mitigation guidelines and adopted them.[48] However, all of the existing guidelines remain voluntary and are not legally binding under international law. At the UN level, some nations have expressed the view that a legally non-binding set of guidelines was not sufficient. Some delegations at the Scientific and Technical Subcommittee (UNCOPUOS) expressed the view that the Subcommittee should consider submitting the space debris mitigation guidelines as a draft resolution of the General Assembly rather than as an addendum to the report of the Committee. At the meeting of UNCOPUOS on February 2007 in Vienna, the view was also expressed that the states largely responsible for the creation of the present situation and those having the capability to take action on space debris mitigation should contribute to space debris mitigation efforts in a more significant manner than other States.

Indeed, the adoption of voluntary guidelines is a major step for proposing a cooperative approach to solving emerging problems related to space debris. However, non-binding guidelines may not prove sufficient. The Chinese test and destruction of a satellite proves this case. This is why some countries are proposing a set of rules and calling for a legal regime to be implemented. For instance, many are arguing that the destruction of space systems, intentional or otherwise, which generates long-lived debris, should be prohibited in line with the enforceable space debris mitigation guidelines. What is certain is the fact that the adopted UN mitigation guideline could serve as a template for the development of a set of binding rule based on the need for orderly and predictable conduct in space. In Appendix 3, I provide the full text of the UN and IADC mitigation guidelines.

3.1.3 Weakness of the Space Liability and Dispute Settlement Mechanism

The 1972 Convention on International Liability for Damage Caused by Space Objects, commonly known as the "Liability Convention,"[49] sets forth the rules for personal injury and property damage and for resolution of those issues at the international level. Articles I and II of the agreement, for instance, provide that a country which launches or procures the launching of a space objects, or from whose territory a space object is launched, is liable for damage caused by its space object on the surface of the earth or to aircraft in flight. With respect to damage caused elsewhere than on the surface of the earth, however, the notion of liability is not clearly established.

The notion of direct damage is established under Article VII of the Outer Space Treaty. It says that each "State Party to the Treaty that launches or procures the launching of an object into outer space, including the moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the moon and other celestial bodies"[50]. However, there is a terrifyingly large legal gap when it comes to dispute resolution and compensation mechanisms. The issue of liability protocols in case of a commercial disruption by debris is also not covered by any convention.

Right now, the dispute resolution mechanism is informal. Article III Outer Space Treaty says that parties to the treaty shall carry on activities "in accordance with international law, including the Charter of the United Nations . . . ."[51] Article 33 of the UN Charter says that parties shall first "seek a solution by negotiation, enquiry, mediation, conciliation, arbitration, judicial settlement, resort to regional agencies or arrangements, or other peaceful means of their own choice."[52] In the event that such means fail to achieve a resolution of the issue, Article 36(3) indicates that "legal disputes should as a general rule be referred by the parties to the International Court of Justice …". In case of a major dispute, the following procedure would apply: claims may be asserted on behalf of corporations or individuals by their government. Claims must be presented through diplomatic channels within one year of the date on which the damage occurred. If the parties do not reach a settlement within one year from the date on which a claim is received by the launching state, then the concerned parties must establish a Claims Commission chosen jointly by both parties. The Claims Commission shall then decide the merits of the case and the amount of compensation, if any, on the basis of majority vote, within one year.[53] If the dispute cannot be resolved by the methods set forth in Article 33 and the dispute endangers the maintenance of international peace and security, then Article 37 requires the parties to refer the matter to the Security Council.

In the absence of an agreement establishing binding procedures for the field of space law, it is likely that most national governments will seek to continue to resolve their disputes through the existing diplomatic channels. Private parties to a dispute, i.e. a commercial firm, would therefore be at a disadvantage under the existing regimes. For this reason, it is advocated that an international convention set up the mechanism for resolving disputes, both public and private.

3.2 The Five Main Treaties Regulating Outer Space

There are five international treaties negotiated and drafted under the United Nations auspice at the COPUOS and adopted by the United Nations General Assembly. However, because some space-faring nations are not signatories to all treaties, there is no fully international agreement to abide by this body of law. They are summarized in the Table 3-3.[54]

Before I turn to the discussion on the proposed convention on space debris, I conclude that the present outer space regimes have no coverage of the space debris problem. The paucity or outright absence of law regarding certain key subjects such as liability and dispute resolution is causing concerns for the future. Under the scenarios discussed in Chapter 2, some regions of space are not safe anymore. Rightly, some governments and private sector actors are unsure of their rights and have no assurance that their efforts to go to space will be legally protected. This is why an international legal regime is proposed with new laws which would encourage a peaceful use of space for all.

Table 3-4 - Outer Space Treaties, Conventions and Agreements

Name of Treaty/ Convention	Short Name	Date of Signature and ratification/ signature (As at 1 January 2005)	Main Objective(s)
Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[55]	The Outer Space Treaty (OST)	Adopted on 19 December 1966. Entered into force on 10 October 1967 Ratified by 98 nations and signed by 27	Establish a framework for international space law; provide that space shall not be subject to national appropriation and that exploration and use of space shall be for the benefit of all countries; limits military use of space.
Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space	The Rescue Agreement (ARRA)	Adopted on 19 December 1967. Entered into force on 3 December 1968 Ratified by 88 nations and signed by 25	Call for the rendering of all possible assistance to astronauts in the event of accident, distress or emergency landing. Establish a procedure for returning space objects found beyond the territorial limits of the launching authority.
Convention on International Liability for Damage Caused by Space Objects	The Liability Convention (LIAB)	Adopted on 29 November 1971. Entered into force on 1 September 1971 Ratified by 82 nations and signed by 25	Provides that the launching State is liable for damage caused by its space objects on the Earth's surface or to aircraft in flight and also to space objects of another State or property onboard such objects.
Convention on Registration of Objects Launched Into Outer Space	The Registration Convention (REG)	Adopted on 12 November 1974. Entered into force on 15 September 1976 Ratified by 45 nations and signed by 4	The Convention provides that launching States shall maintain registries of space objects and furnish specified information on each space object launched, for inclusion in a central United Nations register.
Agreement Governing the Activities of States on the Moon and Other Celestial Bodies	The Moon Treaty	Adopted on 5 December 1979. Entered into force on 11 July 1984 Ratified by 11 nations and signed but not ratified by 5	Provide that the Moon and its natural resources are "the common heritage of mankind" and that an international regime should be established to govern the exploitation of such resources when such exploitation is about to become feasible.

CHAPTER 4 – A PROPOSAL FOR AN INTERNATIONAL CONVENTION ON SPACE DEBRIS

4.1 Opportunity of a Legal Regime for Space Debris

I advocate the necessity to draft and negotiate an international convention on space debris. However, I do recognize that negotiating a comprehensive convention with legal status is a long and intense process. Furthermore, the regime governing space debris to be created by this instrument would have significant legal and political consequences. The main issues are how to decide on the scope of such a convention and attach to it a proper monitoring and dispute settlement mechanism.

In the past, these issues have proven to be problematic. Treaty negotiators have revisited many issues that have been a source of debate for years, even centuries. Who has the right to participate in the drafting of such instrument and how should nations insure implementation of the convention by all signatories? Should a new convention be developed from scratch or would a Memorandum of Understanding or some other informal agreement suffice? If a new convention is needed, should it be framed on a global scale? From a technical and political point of view, who should be part of such treaty-making process? What organization can take the lead and how should compliance and monitoring be insured in a fair and equitable basis? These are the main questions that the negotiators have to answer before reaching a compromise.

In this part of the thesis, I provide some background to the convention making process and the negotiations that would have to occur to ensure successful implementation. I also discuss how a space debris convention would work, describe some of the major obstacles facing those who would be a party to such a convention, explain how to address the critical issues raised by “new entrants” in the space environment, and give some sense of what the road ahead might look like.

4.2 Memorandum of Understanding, Code of Conduct or Convention?

Experts and policy-makers diverge on the types of instrument and scope for dealing with space debris. Various proposals have been suggested, including: a Memorandum of Understanding (MOU) among space-faring nations; a code of conducts; or a broader convention. When the current work at UNCOPUOS is taken into account, one realizes that the scientific community would likely be satisfied with a framework that would seek to mitigate debris in space. From interviews with various experts, I realized that the questions related to liability, dispute system design, compensation of damages caused by debris are not included in the present discussions on space debris. Some nations would also prefer to have a set of binding instruments with a wide coverage, including registration of debris, mitigation, and dispute settlement.[56]

One approach advocated by the Henry L. Stimson Center's Space Security Project is the negotiation of a code of conduct between space-faring nations to prevent incidents and dangerous military activities in space.[57] Key activities to be covered under such a code of conduct would include avoiding collisions and simulated attacks; creating special caution and safety areas around satellites; developing safer traffic management practices; prohibiting anti-satellite tests in space; providing reassurance through information exchanges, transparency and notification measures; and adopting more stringent space debris mitigation measures.

Codes of conduct have already been used in international relations. These codes gained currency when instituted to deal with the threats posed by arms proliferation. During the

Cold War, the United States entered into executive agreements with the Soviet Union to prevent dangerous military practices at sea, on the ground, and in the air. As such, the 1989 Prevention of Dangerous Military Practices Agreement signed by Washington and Moscow continues to have great value and provides “rules of the road” to help prevent incidents and dangerous military practices. However, codes of conduct are indeed very difficult to implement among nations. They have no binding or enforcement mechanisms and it is very difficult to have all powers agree on the scope of such codes.

On the other hand, a convention is a legally binding agreement. Once a convention has been “adopted” (meaning that it is open for countries to join), countries can choose whether or not to join a convention. When they choose to join, they become “States Parties” and must comply with their obligations as described in the convention. When enough countries become States Parties, then the convention “enters into force,” meaning that it becomes active and parties must act to implement their obligations under the convention. The convention must be ratified at the national level before it is in force. A convention which has been signed but not ratified has little value. Only by signing and ratifying the convention are governments legally required to follow the recommendations of those documents.

Whatever the type of instrument chosen, the recognition and enforcement of one legal system to another has long been understood as a fundamental requirement for dealing satisfactorily with global issues. For many countries, the enforcement of international treaties is not a matter of general international law but is addressed through national negotiations, issues of sovereignty being of prime importance. This is why public awareness is so critical in dealing with issues such as space debris. If the general public is not aware of the situation, it is unlikely that politicians will put the problem on the top of their agenda. Without public awareness, the ratification process will be a struggle.

In the following sections, I discuss the various requirements to a successful space debris convention.

4.3 Framing and Drafting a Convention: Challenges and Opportunities

I believe that the way to limit the impact of space debris is to adopt a new convention that can be ratified and implemented by all space powers. The need for an international convention is based on the view that a set of international rules is needed to reduce the growth of orbital debris along with a legal regime under which liability and compensation can be assigned. Given the amount of debris in orbit, the entire space community is ready to take initiative because debris impacts can severely affect space operations and threaten the occupants of manned spacecraft. Indeed, it is crucial to internationally introduce new rules and to involve the space powers in generating a common framework governing space debris.

The space powers have much to gain from a strong, well-crafted multilateral instrument that removes or minimizes the many procedural and technical obstacles that can delay efforts to resolve the space debris problem. Although international cooperation in the space debris field is substantial, all major players need to recognize that circum-terrestrial space is a strategic resource that must be better managed. All reasonable and practicable efforts must thus be taken to preserve it for future generations.

I propose that the convention have the following broad purposes:

1. Increase the visibility of space debris problems, within the scientific community and also civil society in general;

2. Clarify the obligations of governments with respect to space debris and ensure that governments who become States Parties to the convention make legislative and programmatic changes at the national level to implement their legal obligations under the convention; and

3. Establish systems for international cooperation through which governments, space organizations, and other actors can share knowledge and ideas and work together to reduce space pollution and the dangers now posed by existing pollution.

4.4 Defining the Scope of the Convention

I am advocating a focused approach to increase the likelihood of success of a convention on space debris. The wider the scope, the more difficult it will be to implement a convention. This is why a proposed convention should be aimed at making progress in the area of risk and liability by: (1) requiring signatory countries to make certain substantive commitments for limiting space debris and providing compensation if they are deemed liable; (2) requiring Parties to adopt domestic procedures to match international standards and guidelines; and (3) providing a solid basis for international compliance and cooperation for limiting the level of space debris.

The overall purpose of a convention can be organized around four main objectives:

4.4.1 Objective 1: Independent Tracking and Cataloguing of Space Debris

Before determining the most effective measures that should be taken to solve the space debris problem in Earth orbit, it is essential to quantify the problem not only in terms of the current orbital debris environment, but also in terms of future growth potential absent remedial action. Such initiative cannot be solely carried out independently by states. In doing so, there will be a risk that data are not made available or manipulated in case of major disagreement and international litigation if a major incident occurs.

I propose that internationally independent and harmonized procedures for data quantification of space debris be the first objective of a convention. The convention should also encourage the tracking of small-size debris. An official register of space debris must be maintained and operated by an independent agency (i.e. the UN), and has the capacity to catalogue debris and make the information available to the entire community. Today various tracking and monitoring initiatives have been implemented by space-faring nations and it is important to put in place a common effort to quantify the problem. In doing so, signatory members of convention would have the means of reducing the gaps in space situational awareness. More importantly, I advocate that an independent tracking system be implemented under the auspice of the United Nations or another independent body. At present, too many nations have tracking capabilities for space debris. The leading authority for debris tracking is the US Space Surveillance Network (SSN). The USSSN publishes the Satellite Catalog and tracks objects in LEO at least 10 cm in diameter. New entrants have made the case for developing their own capabilities.

Europe has its own Space Debris Advisory Group (SDAG) and the French military ship Monge can detect objects of about 2 cm in size at a range of 1000 km. ESOC, ESA Space Operations Centers, is also coordinating all space debris research activities within ESA and maintaining a database on known space objects called DISCOS. ESA's activities are harmonized with European national space agencies with specialists from national organizations and institutes in Europe (via the Space Debris Advisory Group SDAG) and outside Europe (via the Inter-Agency Space Debris Coordination Committee IADC). A space debris monitoring center was opened in China in March 2005. The CAS Space Object and Debris Monitoring and Research Center has been founded at the Purple

Mountain Observatory (PMO) in Nanjing and it will build a security warning system in China's spaceflight field against space debris.

As a result of continuing growth, the orbital debris population will pose more problems, especially when random collisions start to occur and produce even more fragments. As more space states gain access to orbit, the possibility of interference and accidents will increase. Debris below 1 cm can be mitigated, i.e. by developing new spacecraft design and shielding systems. However, the objects between 1 cm and 5 cm are numerous and difficult to detect. As a result, an effort should be particularly targeted at smaller debris (less than 5 cm) that are the most difficult to identify and track. Debris above 5 cm is currently catalogued and tracked but still a consensus must be achieved in doing the quantification work under a single agreed methodological approach.

Indeed, there is a need to construct a uniform database from existing catalogues of space objects and new tools and models must be developed to deal with the risk of exponential growth of space debris.[58] This uniform database will be maintained by UNOOSA secretariat. Specific procedures will need to be drafted and enforced to ensure that UNOOSA collects information and data in a timely and exhaustive manner. Information being available from different nations, the UNOOSA secretariat will need to recoup the data and ensure their veracity. It is proposed that UNOOSA made this information on-line for full access by the space industry, civil society and the general public.

4.4.2 Objective 2: Adoption of Enforceable Space Debris Mitigation and Disposal Standards

I advocate the need for internationally agreed standards that can enforce appropriate debris mitigation and disposal measures for spacecraft and launch services providers. Although the voluntary implementation of debris mitigation and disposal measures by many space operators have shown indications of a changing trend toward a safer environment in the LEO and GEO region, competition and new entrants in the market may change this reality.

I do not believe that a pledge to avoid creating persistent space debris by following voluntary-adopted guidelines is sufficient. The Chinese test has proven that proven that international efforts to mitigate space debris can be easily challenged. Still, in recent years, China has made several proposals to the UN Conference on Disarmament on possible elements for a future treaty banning the weaponization of space.[59] In 2002, China had also expressed its intention to follow the IADC mitigation guidelines. Enforceable space debris mitigation measures are therefore much needed.

Several national and international organizations of the space-faring nations have established their own space debris mitigation standards or handbooks to promote efforts to deal with space debris issues. The contents of these standards and handbooks are slightly different from each other but their fundamental principles are the same: Preventing on-orbit break-ups; removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions; and limiting the objects released during normal operations. Many space powers and agencies have studied the space debris problem and have made their own recommendations as well. NASA (USA), CNES (France), NASDA (Japan), RASA (Russia) have elaborated procedures that should be harmonized into a single framework. Although most states agree that it is important to comply with some mitigation standards, there are however different expectations on various technical issues, i.e. reorbiting of satellites, passivation (deactivating an equipment), end-of-life operations and development of specific software and models for space debris. Today, due to the lack of global conventions, there are no legal means for forcing the adoption of a uniform set of rules by state members.

I am aware that the adoption last February 2007 of the UNCOPUOS STSC “Space Debris Mitigation Guidelines” sets in motion a means of achieving the goals of reaching an agreement on mitigation guidelines. The endorsement of these guidelines by the full UNCOPUOS is expected in June 2007, followed by a possible endorsement by the UN General Assembly before the end of the year. This is a major step forward for creating a uniform set of mitigation guidelines at the UN and the Working Group on Space Debris has successfully developed draft space debris mitigation guidelines. Although the space debris mitigation guidelines of the Subcommittee contain general recommendations that are not as technically stringent as the IADC Guidelines, they represent a major milestone and indicate that a consensus has been reached on the text of the document based on and still consistent with the technical content of the IADC Space Debris Mitigation Guidelines. The Subcommittee noted that the General Assembly, in its resolution 61/111, calls for the continuation of national research on the question, for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris and had agreed that international cooperation was needed to expand appropriate and affordable strategies to minimize the impact of space debris on future space missions.[60]

Today, there is however no agreement regulating space debris but only the expectation of voluntary compliance to existing standards and code of conduct. For instance, some states have implemented, through their national agencies, space debris mitigation measures consistent with the IADC Guidelines or have developed their own space debris mitigation standards based on the IADC Guidelines. Other states refer to the European code of conduct for space debris mitigation as a reference in the regulatory framework established for national space activities. Even if the UN General Assembly endorses the work of the space debris working group at UNCOPUOS (STSC) and call for further research and coordination, it is unlikely that the situation will improve due to the voluntary nature of such initiatives.

A more comprehensive and binding system is needed to account for the existing space pollution and keeping in mind that new space-faring countries and international corporations are entering the market. This is why I support the idea of a framework convention that would provide this set of binding procedures agreed to by large consensus. Under the convention, a mechanism would facilitate coordination and implementation of the guidelines. I would strongly stress the need for a high-level intergovernmental mechanism to ensure compliance and monitoring. Despite the various efforts to avoid debris, the space debris situation is unlikely to improve unless concentrated, coordinated and systematic steps are taken to mitigate the risks that are now so clearly understood. As a result, the convention must urge that every user of the various space orbits to remove its space object from orbit after its work is completed to eliminate danger to other users. This is why the space industry and professional associations have to be associated to the drafting of a space debris legal regime.

4.4.3 Objective 3: The "Space Preservation" Provision

A convention should also propose that some orbital regions be protected because of their scientific and economical importance. Examples here might include the Low Earth Orbit (LEO), ranging up to 2000 km altitude, and Geostationary Earth Orbit (GEO), about 36000 km altitude.

The international convention would ensure that no orbital debris creation takes place within these protected regions. To do so, the convention regulating space debris must incorporate a "Space Preservation" clause that would prohibit the creation of major pollution in such zones. Within the Space Preservation Provision, parties to the convention would be compelled to follow the internationally agreed standards for debris mitigation. Any party to the convention infringing on the agreed mitigation guidelines would have a penalty to pay. At the same time, the convention would implement a mechanism of conditional launch license issuance for space operators, depending on the acceptance of space debris mitigation procedures. The same measures would apply to military activities in space.

The idea of "Pollution permits" could also be developed. Under the convention, a cap that reduced on a declining scale the number of space debris being generated could be set. Then, space-faring nations and space operators would be issued tradable certificates that matched their share of the cap. Parties that cut space debris below their cap had extra certificates to sell to other parties that had not met their goals. This policy would encourage the development and adoption of space debris mitigation and disposal measures. It should be noted that emissions trading for reducing pollution has been successful in the context of various environmental programs. Experience shows that properly designed emissions trading programs can reduce compliance costs significantly.[61] The mechanism for trading debris could work as follows:

Table 4-5: Pollution Permit Mechanism for Space Debris

Pollution Permit System and Emission Trading[62]

Pollution permits work by obliging polluters to pay for their noxious emissions. Consequently, they have a clear incentive to make real reductions. A Space Debris emission trading system would be set up to allow stakeholders to the convention to define the overall level of space pollution that is socially acceptable, and then issue tradable permits corresponding to that amount.

Corporations and space agencies who wish to pollute must hold permits equal to their pollution quotas. This market-based approach to pollution control would therefore provide firms and space agencies with economic incentives to minimize pollution as they can sell unused permits to other firms or agencies rather than being charged regulatory penalties, which tend to have high costs.

Therefore, the firms and agencies adopting mitigation guidelines would be given financial incentives. Cleaner companies benefit, while polluters are forced to pay to acquire additional permits. This puts them under pressure to cut back on their emission levels in order to maintain their competitiveness and their reputation; and it is a social benefit to the entire environment if they can. If the nature of the production process makes it hard or very expensive for them to reduce emissions, they can only continue doing so by striking a deal with other firms or agencies that have already made cuts. So the overall environment gains, either way.

In the United States, the emission trading systems have been quite successful. In the Acid Rain Program launched in 1995 allowed companies to trade permits in sulphur dioxide, which is mainly produced by power generators burning high-sulphur coal. The results have been better than planned. So far the initiative is ahead of target with participating firms reducing compliance costs by up to 50 per cent. The US Acid Rain Program is based on two key criteria which encourage successful emissions trading: first, there needs to be an established regulatory and monitoring regime which pursues explicit reduction targets; and secondly, the source of pollution must be clearly traceable.[63]

The technical realities of cleaning up the space environment must also be addressed by a convention. One of the most important measures to adopt is the removal of hazardous material in space. Inactive satellites and other equipment should be removed from earth orbit. Although such an initiative has cost implications, it is important to propose clear recommendations of disposal of dangerous objects under a convention. Proposals for the "clean-up" of the satellite-crowded geostationary region may include the use of special towing spacecraft to detect, capture and transfer defunct objects to storage orbits, the establishment of space platforms with separable one-time towing modules and the transfer of uncontrollable objects to higher orbits to prevent their descent to Earth.

For instance, electrodynamic tethers or drag enhancement structures could rapidly accelerate the orbital decay of decommissioned spacecraft and rocket bodies but attaching such devices to satellites with conventional robotic means would incur excessive costs for the benefit gained.[64] The placement of ion engines on the satellites in order to direct them back to Earth is another solution to consider. However, such technique would require significant, long-term power and attitude control subsystems. Current manned spacecraft cannot reach the key orbital regimes above 600 km and are even more expensive than robotic missions. The use of ground-based lasers to perturb the orbits of the satellites is not now practical because of the considerable mass of the satellites and the consequent need to deposit extremely high amounts of energy on the vehicles to effect the necessary orbital changes.

These issues are complex and can only be addressed if space powers are committed under an enforceable framework. Signatory parties to the space debris convention could create a sub-committee to make on going practical recommendations for cleaning up space pollution from the most hazardous material. As pointed by Nicholas Johnson, Chief Scientist at NASA, the success of any environmental remediation policies will probably be dependent on the development of cost-effective, innovative ways to remove existing derelict vehicles. The development of any new technology to remediate pollution in space certainly requires both governments and the private sector working together. Without environment remediation and definition of protected zones, the risks to space system operations in near-Earth orbits will continue to climb.

4.4.4 Objective 4: Liability, Compensation and Dispute System Design

Disputes are a reality of modern life which can be costly and painful if not addressed quickly and fairly. With the rise of private activities in space, questions of the control of such activity arise, especially those of responsibility and liability.[65] Even if nations can easily agree on tracking and mitigation measures, there is still the question of liability in specific situations and how to resolve disputes.

For instance, if a debris cloud from one satellite causes damage to another, whose responsibility is it? Imagine that the recent Eutelsat satellite equipped with 64 transponders to be part of a fleet transmitting up to 950 television channels and 600 radio stations to 110 million cable customers in Europe, North Africa and the Middle East is lost due to a collision. The impact would be immense from a societal and business perspective. Who pays for the damage? What about consequential losses, i.e. loss of business due to a major disruption in satellite telecommunication? Should a polluter-payer mechanism be put in place or should spacecraft owners be fully covered under specific insurance policies, if possible?

The question of liability should be considered under the space debris convention. First, the cost of equipment is important in the space industry and any destruction could lead to massive loss of assets and business. Second, some debris present serious hazards, i.e. nuclear powered satellites. Thus, the convention should also be aimed at defining a liability and compensation regime for damage. As commercial space activities increase with new space powers entering the field, it is crucial to ensure that the space equipment on which we rely on for communication and other purposes can be safely operated while in orbit. In case of damage, loss and major disruption, it is crucial to have a dispute handling mechanism in place to determine liability and claims compensation.

It is also important to consider the liability issue for re-entry debris. For instance, in 2006, a total of 237 spacecraft, launch vehicle orbital stages, and other cataloged debris reentered during the year. No instances of injuries or property damaged were reported. The total number of uncontrolled reentries was 223, including 13 payloads and 31 launch vehicle orbital stages with a total mass of about 70 metric tons.[66]

A few victims are said to have been injured in the past. Lottie Williams is on record as the first and only person ever to be hit by man-made space debris. While walking in a park in Tulsa, Oklahoma, on January 22, 1997, she noticed a light in the sky that she said looked like a meteor. Minutes later, she was hit in the shoulder by a 6-inch blackened metal object that was later confirmed to be part of the fuel tank of a Delta II rocket which had launched a U.S. Air Force satellite in 1996. On October 10, 2006, a cottage in Germany was burned down by a fire that was believed to be started by a small debris (no more than 10mm) and 77 year old man was injured by the fire.

As a result, compensation for damage and injury or death caused by space debris should be governed by an international regime elaborated under the auspices of the UN. I suggest that the "Convention on International Liability for Damage Caused by Space Objects" be extended to cover space debris and define the dispute handling mechanism in more details. The convention would lay down the principle of strict liability and create a system of compulsory liability insurance. In terms of damage coverage, space equipment is usually covered by insurance policy. Coverage is usually split into the launch and in-orbit phase. The launch part is particularly risky and includes transport of the satellite through the Earth's atmosphere into space, the positioning of the satellite in orbit followed by commissioning and testing of all systems. The in-orbit policy, usually renewed yearly, covers damage to the satellite caused by technical failures, the harsh space environment with extreme temperatures, high solar radiations and solar flares, and exposure to meteoroids. Orbital debris is also usually covered as well. On the other hand, space equipment beyond normal years of operation but still providing a service is not necessarily covered.

Because insurance companies are risk-adverse, it is likely that they will discontinue their coverage when the risk posed by space debris becomes unbearable for them. This is the reason why the proposed convention needs to incorporate a specific mechanism for settling disputes when they arise. While several mechanisms can help parties to the space debris convention reach an amicable settlement (for example through mediation), all of them depend, ultimately, on the goodwill and cooperation of the parties. This is why the convention must set out clearly the mechanism for resolving disputes under which a final and enforceable decision can be obtained in a cost-effective manner. I propose the creation of a Dispute Board set up at the outset of the convention. In Section 4.5, I provide the details of a proposed dispute mechanism.

4.5 A Space Debris Convention: Implementation Strategies

The complex interactions and procedures by which a space debris convention must be formulated, ratified and implemented are cumbersome. For a space debris convention to guarantee improvements, it is important to have a clear sense of purpose. This is why convention objectives must be clearly established initially. I believe that a convention would produce dramatic progress in the sense that it seeks to coordinate actions and harmonize mitigation and remediation procedures and guidelines. In case of liability, it would also provide the mechanism to address disputes and provide compensation when required. It does impose new financial burden on member states and, thus, requires a pooling of financial and technical resources to better serve the purpose of reducing future debris rather than relying solely on individual and national initiatives that currently duplicate one another.

4.5.1 Timing of the Space Debris Convention

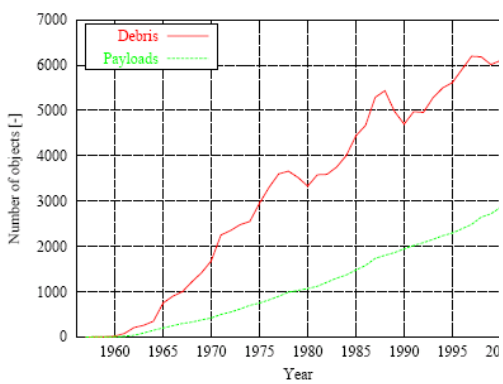
There is the question of when: "Why worry about space debris and why propose a multi-lateral convention now?" I advocate drafting a convention as soon as possible. Drafting, implementing, and ratifying a convention is a lengthy process. Indeed, it takes time to organize the drafting of a large convention with delegates working in various groups and coming from all over the world. For convention making, the time and place have to be agreed well in advance and then delegates, sponsors, speakers, special guests and others arrive to discuss proposals. A successful convention is therefore a logistical exercise that depends on starting with a precise and detailed plan. As a result, the plan for a space debris convention has to start as soon as possible.

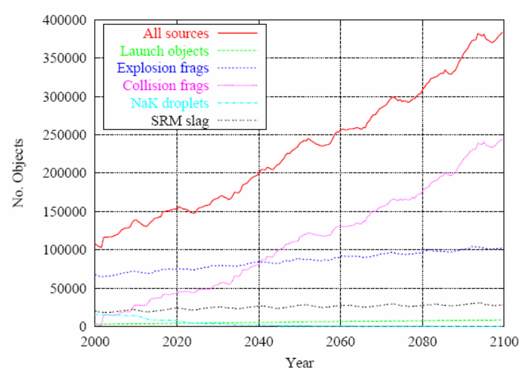
Other factors make it necessary to consider a convention now. First, from a commercial perspective, space activities are on an upward trajectory and new space powers are entering the commercial launching and space exploration market. As a result, most experts agree that space debris will continue to grow in the coming years. It should also be noted that space debris[67] increase exponentially as compared to payloads (See Figure 4-4 below).

Second, from a technical perspective, random collisions will soon start to occur and produce even more fragments. Under the "business-as-usual" scenario for future space flight activities, we should expect higher level of interactive collisions among larger, catalogued objects. Thus, fragments from collisions will grow to dominate the man made debris that are larger than 1 cm in diameter. When orbiting debris collides, it usually does so at such a speed that it is more than pulverized; it is liquefied and turned into not one or two, not even dozens, but millions of new fragments. All of them are hazardous. This process of “collisional cascading” will result in a non linear growth (collisional fragments that will trigger further collisions).

Third, a convention is needed to reduce hazardous objects in space. A less well-known threat is that posed by earth satellites and equipment carrying hazardous materials. As a notorious case, the Radar-equipped Ocean Reconnaissance SATellite or RORSAT is an example. These nuclear-powered satellites were launched between 1967 and 1988 by the Soviet Union to monitor NATO and merchant vessels using active radar. Many incidents have occurred. As mentioned in Chapter 3, the satellite Cosmos 954 failed to boost into a nuclear-safe storage orbit as planned. Nuclear materials re-entered the Earth's atmosphere in 1978 and left a trail of radioactive pollution over an estimated 124,000 km² of Canada's Northwest Territories. Cleaning up the environment remains a technical and economic challenge but guidelines will at least start the process under the convention.

Figure 4-1: Evolution of Debris and Collisions



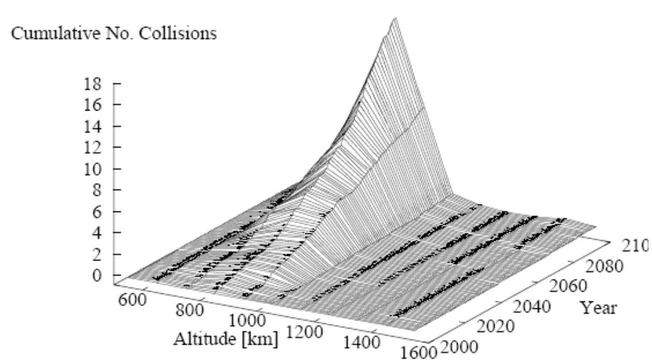


Above: This graph shows the current number of on-orbit catalogued objects versus time for payloads and debris (As at 5 September 2001).

Above and Right: The evolution of the number of objects in LEO > 1 cm in size broken down by source type for the Business As Usual scenario.

Opposite: The cumulative number of collisions in LEO over altitude for the Business As Usual scenario

Source: ESA Space Debris Mitigation Handbook



It will take time for the international community to draft a convention on space debris. The negotiations process itself may span several years. Negotiations on such a convention should begin soon so that countries can get down to the business of implementing the convention and mitigating the global problem of space debris.

One example of a convention which was drafted and implemented effectively and swiftly is the "Ottawa Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction". The work started in October 1996 at a conference in Ottawa, Canada by 50 participating countries, 24 observer states and dozens of international and non-governmental organizations. In the months following the conference, a 111 states' meeting was held in Vienna, Austria, in February 1997 for the first discussion of a draft convention. In June 1997, at a follow-up meeting, 97 countries signed the Brussels Declaration announcing their support for a convention to ban anti-personnel mines no later than December 1997.

The Convention was then negotiated over the course of three weeks in Oslo, Norway, in September 1997, with international and non-governmental organizations continuing to play an unprecedented role in the process by joining government delegations at the negotiating table. In December 1997, representatives from 150 governments attended the convention signing conference. 122 countries signed. By signing such a convention, countries signaled their intention to adhere formally to the instrument at a later date once the ratification at the national level is completed. They also promise to do nothing to undermine the objective and purpose of the convention. Less than nine months after the 1997 signing ceremony, 40 states had formally agreed to be bound by the convention by ratifying or acceding to the Convention – the number required for the Convention's entry-into-force. With this milestone having been achieved, the Convention entered into force on March 1, 1999.[68] This was a two and a half year process.

The Ottawa Convention process illustrates that the drafting, negotiating and implementing of a convention can be done under a tight time frame. This is particularly true for a well focused convention arising within a context of mounting political pressures.

4.5.2 Mobilizing and Finding Sponsoring States and/or Organizations

Obviously, an idea that eventually becomes an international convention on space debris originates somewhere in the brain of some person, though in retrospect it may be impossible to identify the original author. The creative process may also have been a substantially collective one from the very beginning. In any case, someone or a group sharing the same interests have to put forward a proposal that will enter the consciousness of the international community when it is first advanced.

For space debris, existing groups can lead the process to initiate a process for formulating a convention, i.e. IADC or members of UNCOPUOS. The lead for proposing a convention on space debris may also come from a few space-faring nations, i.e. the ones creating the more debris today. However, it should be noted that, to date, the US has been reluctant to participate in the drafting of an international convention on space debris. The main reason is the fact that part of the debris is coming from the US since the 1960s. As such, the country has taken a position toward the adoption of voluntary guidelines against a more stringent binding regime (See also Figure 2-3 on page 33).

New entrants to the space market have also a crucial role to play and may wish to seize the opportunity to create a consensus among them and speak with one voice for moving their agenda on space debris issues. Indeed, it is important for the convention not be limited to just the major powers. It should include the rapidly developing societies such as China, India, Korea, Brazil, Ukraine and many others. Most of these countries are now developing space programs. The organization and drafting of the convention has to be as democratic as possible and allow broad-based ownership of ideas. Many countries without space activities claim that they want to have the possibility to use space in a safe manner in the future. Therefore, the convention should not be limited to existing space powers. It should encourage the participation of all interest groups. Rather than a “treaty of scientific specialists”, the convention has to encourage active involvement of all space powers as well as countries with an interest in shaping international space policy.

I propose that the convention go through the UN General Assembly; first, specific countries will have to put the idea of the convention on their political agendas. The members of the STSC group at UNCOPUOS constitute a reference group that could take the lead. This group must clearly include the most visible space-faring nations that are at the source of the space debris problem, including but not limited to Europe, China, and Russia.

4.5.3 Entry point for the space debris convention

The United Nations Office for Outer Space Affairs (UNOOSA) and its Committee on the Peaceful Uses of Outer Space (UNCOPUOS) are ideally suited to be the natural and legitimate entry point for the space debris convention.

Because the convention must be global, it thus needs to be drafted under the auspice of the United Nations. Over the last years, UNCOPUOS and its secretariat at UNOOSA has been promoting a cohesive and integrated response to space challenges. Since the first launch of a satellite into space, the UN has provided a unique forum for countries, international organizations and non-governmental organizations to discuss issues related to the peaceful uses and exploration of outer space. Moreover, to date, the UN has organized three United Nations Conferences on the Exploration and Peaceful Uses of Outer Space (UNISPACE). It therefore has considerable experience in working with the various space stakeholders.

Since 1959, UNOOSA has annually reviewed the scope of international cooperation in the peaceful uses of outer space, devised programs in this field to be undertaken under UN auspices, encouraged continued research and dissemination of information on outer space matters, and studied legal problems arising from the exploration of outer space. It has considered such issues as space debris, the use of nuclear power sources in outer space, the potential danger of near-Earth objects, disaster management with the use of space technologies, the use of space technologies in water resource management and telemedicine, as well as many other similar issues. Thus, UNOOSA seems to be the appropriate institution to serve as entry point to the convention.

Once a consensus has been obtained to initiate a process for formulating a convention, the first step should be for UNOOSA to empower exiting international consultative bodies that would discuss the perceived needs for a convention and the anticipated value of the proposed instrument, and the likelihood of achieving the drafting according to a realistic time table.

For moving the political agenda, one option is to mobilize members of the Inter-Agency Space Debris Coordination Committee (IADC) formed in 1993. The IADC member agencies include the main space agencies from the following countries: Italy, UK, France, China, Germany, India, Japan, USA, Ukraine, Russia and Europe represented by the European Space Agency (ESA).[69] However, the IADC is not well-suited for such an undertaking and represents only a small minority of the members of the United Nations. Although IACD members share a common objective and have discussed and implemented various cooperative activities, the Coordination Committee is too limited in its scope to address the issues of space clean up and liability. Furthermore, it has no enforcement procedures. Thus, IADC needs to broaden the scope of its present mandate in order to consider all relevant technical and legal issues and raise awareness among the growing body of space professionals and practitioners. Because IADC has the lead on issues related to space debris and already has extensive experience of working closely with national space agencies and governments, I propose that it play an important role in contributing to the making of the convention, the main entry point being UNOOSA.

4.5.4 Start Building the Consensus Early in the Process

I propose a global convention that would involve all state members at the UN General assembly. The question of whether any limits should be placed on the initiation of the multilateral treaty-making process is important. I refrain from establishing any explicit restraints because it would allegedly incompatible with the sovereign right of any state to participate in the discussion and negotiating of proposals in any international organ in which it participates. As a result, the multilateral negotiating process that will take place before agreeing on the text of the space debris convention will require strong consensus building.

To start the consensus-building process on the space debris convention, I propose that a World Space Debris Congress (WSDC) be convened by UNOOSA. For the convention to be successful, I have argued that it is crucial to reach out to as many groups, associations, and experts as possible from the private and civil society and seek their views on the opportunities and difficulties it presents to draft a convention. During the drafting process, representatives from all space-faring nations must be included along with members of the leading space corporations and academic researchers. Other actors should also be involved: astronautical societies and other professional societies sharing an interest in astronautics, space agencies and international organizations interested in space programs, space applications and space policy matters, space industries and companies involved the applications of space technology as well as related policy and legal activities, universities and research institutes, and non-profit organizations with interests in space matters. To represent the science community, the backing from major space agencies such as NASA and ESA is necessary. The US may be particularly active in the discussion. After all, it has been a key player in space exploration and is still the top space-faring nations. To represent industry, national space industry associations and leading prime contractors are obvious choices.

Consensus building is important for succeeding in agreeing a space debris convention. As discussed earlier in the thesis, diverse groups of people with different interests must be involved in the drafting of the convention. It includes policy-makers from space-faring nations and new countries entering the market, civil society, space industry and the scientific community. I propose that consensus building be enacted early in the process. This is important for the parties to the convention and all other interested stakeholders to fully collaborate on solving the complex problem of space debris in ways that are acceptable to all. More importantly, the consensus-building process must allow a great variety of people to have input into decision-making processes, rather than leaving controversial decisions up to a group of nations or experts. Ideally, through the process of consensus-building, the relevant interests of stakeholders will be discussed and taken into consideration in order to reach a unanimous agreement during the final drafting of the convention.[70]

I propose that the World Space Debris Congress take place as soon as possible with a gathering together all stakeholders. The Congress would have the following goals:

1. **Defining the scope of the problem and a joint fact finding[71] process:** This is the initial stage where the space debris problem is identified and defined. Before actions can be taken, it is important to have an objective assessment of the situation. Many consensus-building processes involve technical issues in which scientific facts are in dispute. In the case of space debris, the scope of the problem is unusually well defined. As a result, it is unlikely that the process of "adversary science" so common in many international environmental negotiations will be a major constraint in the drafting process. Still, it is vital to define the problem and share information and resources.

During the Congress, experts, decision makers, and key stakeholders from opposing sides will be asked to work together. The task of convening the Congress will be assigned to UNCOPUOS's secretariat, which can either perform it with its own resources, with specially engaged staff backed up by consultants.

2. **Identifying stakeholders:** Before the Congress take place, it is important to mobilize all potential participants because the space debris problem will be resolved only if the interests of multiple stakeholders are addressed. In addition to the obvious parties, i.e. space agencies from space-faring nations, there are other parties not as visible but they need to be involved and get their needs met, i.e. space industry, civil society.

3. **Delimiting the legitimacy of representatives:** Each party that would participate in the drafting of the convention must ensure that the people involved in the consensus effort really represent who they say they represent and can speak for that group with legitimacy. For instance, traditionally the NGOs are seen as informal and disorganized in their approach, splinter groups forming on ideological ground and breaking away from the original stakeholder group. It is important that each group speaks with a unique voice and be organized for the drafting process to work smoothly. The World Space Debris Congress would constitute a unique opportunity to identify leadership in each interest groups and discuss how the organizations will mobilize resources.

4. **Convening of the Congress:** I propose that the UNCOPUOS convene the World Space Debris Congress. However, it is important to extend the coverage because the present group working at the UN under the UNCOPUOS banner (STSC) is too limited in participation. For instance, it

does not directly include the views from the corporate world and the civil society. UNCOPUOS has the required resources to secure the funds, find a location, and choose a convener for the discussion to take place. This is why I suggest that the United Nations be the ideal place to locate such congress and provide the technical and financial resources. In this sense, the convening of the Congress will be seen as "neutral." Other forums exist and could be used for the purpose of discussing the space debris agenda. For instance, in September 2007, the 58th Session of IAC will be hosted in Hyderabad, India under the theme "Touching Humanity: Space for Improving Quality of Life."[72] About 2000 space professionals engaged in space activities all over the world will participate in this week-long Congress. The issues discussed range from new technology and infrastructure to exploration and society. Among a large number of technical workshops, a space debris symposium will convene with the objective to address the complete spectrum of technical issues of space debris: measurements and space surveillance, modeling, risk assessment in space and on the ground, reentry, hypervelocity impacts and protection, mitigation, and standards. However, such large forums have the major disadvantage of being too large in scope to address the space debris problem in full. Moreover, they tend to focus on technical issues and not on aspects related to liability, dispute mechanisms and legal regime. This is why I propose to organize an independent and specific congress for space debris.

5. **Designing the process and setting up the agenda:** Prior to the convening of the Congress, participants would have the opportunity to propose an agenda. The initial agenda must be constructed carefully so no legitimate stakeholders feel their interests are being ignored. It must also include a reasonable timetable as well. Typically, each stakeholder has different interests and concerns, and defines the problem somewhat differently. For example, some nations prefer to have a binding system for enforcing mitigation guidelines

while other nations argue that voluntary guidelines are sufficient. The purpose of the Congress is to bridge the gap as long as all the issues are identified in advance and put on the agenda. With a carefully crafted agenda, a more complete picture of the problem will emerge as more stakeholders share their perceptions and come to understand how all their concerns and interests are interrelated. Recognizing this interdependence is crucial to consensus building, it ensures that each interested party will have at least some power in the negotiation during the drafting of the space debris convention.

6. **Identifying alternative solutions:** Before deciding on any single course of action, it is best to explore a variety of options or alternative solutions. This is extremely important in multiparty negotiation of legal regimes because it is unlikely that any single option will satisfy all parties equally. During the Congress, participants should be encouraged to develop creative options that satisfy their interests and others'. As a great variety of options are explored for drafting the space debris convention, participants become able to think in terms of trade-offs and to recognize a range of possible solutions. During the Congress, I propose that the headlines of a possible convention be exchanged. Rather than starting with a complete draft text and spelling out completely substantive provisions, even if only tentatively, it is preferable to start with only "heads of agreement," i.e. with just indications of the principal issues and how it is proposed to resolve them. The formal or "final clauses" may be omitted at this stage and be discussed at subsequent meetings.

It is not the scope of the Congress to narrow the choice to one approach. It is the first step of a consensus building approach. The drafting of the convention, the approval and implementation procedures, can be discussed but will need to be fine-tuned during subsequent meetings. At the end of the Congress, I propose that a committee including representatives of all stakeholder groups be formed to address and resolve questions related to space debris in the future. This group will monitor the progress on the drafting and seek to improve relationships between the adversaries and deal with unforeseen problems as they inevitably develop.

4.5.5 Overcoming United Nations Convention Constraints

One of the criticisms this proposal may face is that most of the existing specialized agencies of the United Nations are saddled with an overbearing bureaucracy, insufficient resources, and limited powers of enforcement. It has been argued by state members of the UN that the General assembly is overburdened with treaties and conventions. The treaty-making process is constrained by the global interplay of politics of member states and issues of sovereignty. Moreover, the power of secretariats implementing and monitoring conventions is often limited. As a result, not surprisingly, many conventions do not produce the desired results or are difficult to amend. For instance, I noted earlier that it is unlikely that the Outer Space Treaty can be amended in the foreseeable future. The reason is that many space-faring nations seem to believe that discussing a new space agreement or amending of the Outer Space Treaty would be time consuming and ultimately futile, because of entrenched differences regarding resource appropriation, property rights and other issues relating to commercial activity.

Unfortunately, any other approach to drafting a convention will face the same constraints. The key to success is therefore to get as many parties with vested interests involved as soon as possible. Other bureaucratic constraints that have to be overcome are worth mentioning:

- The likelihood that the proposed instrument will be accepted by a sufficient number of significant states

- An anticipated and realistic time-schedule for the project to reach a consensus

- The costs of formulating and adopting the proposed instrument, both to the UN and to the states participating in the process

- The time and cost to carry out extensive scientific studies or research to determine the parameters of the problem and the lines of potential solutions

4.5.6 Ratification Threshold for a Space Debris Convention

For a new space convention to be fully implemented, it is crucial that it be ratified by member states and incorporated into the national laws of the states involved. National space agencies must also be closely involved in the drafting and implementing of conventions. As stated in "Environmental Diplomacy," if too few countries "ratify an agreement, the cumulative efforts of those living up to their promises may be insufficient to reverse the problem."[73]

In the list of treaties and conventions mentioned in Chapter 4, only the Moon Treaty did not achieve success. It has only 12 signatories. Most knowledgeable observers consider it to be a failed treaty because of its limited acceptance. The Moon Treaty, on the other hand, is limited in scope. UN delegates apparently intended that the Moon Treaty serve as a new comprehensive treaty which would supersede or supplement the Outer Space Treaty, most notably by elaborating upon the Outer Space Treaty's provisions regarding resource appropriation and prohibition of territorial sovereignty.

In terms of acceptance of other space treaties and convention, they have been largely accepted by national governments. The Outer Space Treaty is the most widely-adopted one. As of January 2006, 98 countries are party to the treaty. Another 27 have signed the treaty but have not yet completed ratification. Concerning the Rescue Agreement, as of 1 January 2005, 88 States have ratified, 25 have signed the Agreement and one international intergovernmental organization (European Space Agency) has declared its acceptance of the rights and obligations provided for by the Agreement. The Liability

Convention has been ratified by 82 nations and two international intergovernmental organizations (European Space Agency and European Telecommunications Satellite Organization).

The Registration Convention, which can serve as a useful model for the tracking and cataloging of debris, was built on an existing 1962 resolution for maintaining a record of launches. The Convention was opened for signature on 14 January 1975. It entered into force on 15 September 1976. Two international inter-governmental organizations (European Space Agency and European Organization for the Exploitation of Meteorological Satellites) declared their acceptance of the rights and obligations provided for in the Convention. Under this Convention, all objects launched into earth orbit or beyond into outer space must be recorded with an appropriate national space agency. Information on the object launched into space, including the date and territory or location of the launch, essential orbital parameters, and the function or role of the object in space is to be communicated to the UN Secretary-General.

As a result, I believe that a convention on space debris could be successful. Issues related to space activities have obtained high level of attention and recognition in the past.

4.5.7 Designing the Liability Mechanism: Benchmark from other Conventions

The greatest difficulty is related to the design and implementation of the liability regime for space debris. The question is how to start working on the design of such a system. Yet, oil pollution conventions have been enacted in the past, many of them including a liability and compensation mechanism and these conventions could serve as benchmark for a new space debris convention.[74]

In the late 1ate 1970s, discussion about the liability and compensation regimes for pollution damage caused by oil tankers began with the Torrey Canyon incident in 1967. Following this incident, it had become evident that existing maritime legislation was inadequate to solve the numerous legal problems arising out of catastrophes of that kind. As a result, two Conventions were adopted, the 1969 Convention on Civil Liability for Oil Pollution Damage (Civil Liability Convention) and the 1971 Convention on the Establishment of the International Fund for Compensation for Oil Pollution Damage (Fund Convention).[75] Both the 1969 Civil Liability Convention and the 1971 Fund Convention were preceded by two industry agreements, the Tanker Owners Voluntary Agreement concerning Liability for Oil Pollution (TOVALOP) and the Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution (CRISTAL).

The ratification success of the 1969/1971 conventions and their subsequent 1992 amendments in addressing questions of liability and compensation for oil spills is obvious from the stand point of the purpose and timeliness of such conventions. In the case of the 1969/1971 and 1992 conventions, we have a set of very well targeted instruments related to oil pollution damage. When the 1971 Fund was set up in 1978 it had just 14 Member States. By 1 September 2004 the 1992 Fund will have 86 Member States. Today, the 1992 Fund Convention has been ratified by 91 States, representing 88.39 per cent of world merchant shipping tonnage. The 1992 Civil Liability Convention has been ratified by 104 States (93.44 per cent). In terms of success of such agreement, this is therefore a major achievement which makes implementation and compliance much easier.

We have argued in the above pages that it is important to have a clear entry point for convention drafting and amendments. It is also very important for conventions to be amendable after they enter in force and whenever necessary. In the case of Oil Pollution conventions the International maritime Organization (IMO) has been the ideal place for meetings to take place and organizing delegate review of new scientific and technical information. As such, the liability regime has been efficiently revisited whenever necessary and the claims mechanism has benefited from various improvements under the IMO banner. For instance, a Claims Manual has been drafted over time and is now implemented as the main ruling tool for oil pollution claims eligibility and compensation. In particular, if defines issues related to property damage, consequential loss, use of Advisors, submission and assessment of claims, etc.

The oil pollution conventions have been successful in terms of the compensation provisions adopted over the years. The 1992 Fund, for instance, was established in 1996 under the 1992 Fund Convention and is financed by companies and other entities in member states that receive certain types of oil carried by sea. The Fund, an intergovernmental organization set up and governed by member states, is governed by two bodies: the Assembly and the Executive Committee. The Assembly is composed of representatives of the governments of all member states. The Executive Committee, composed of 15 member states, is a subsidiary body elected by the Assembly. Standard procedures are endorsed consistently by the governing bodies of the IOPC Funds and reflected in their Claims Manuals. A secretariat is also located in London with the necessary legal and expertise staff necessary to implement the standard operating procedures for settlement of claims. In the case of the 1992 Convention, most claims have been settled without the need to resort to litigation. This is another indicator of the success of the convention. When signatory members agree to use a multilateral system of settling disputes, the convention is providing a tremendous advantage.

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It is not surprising that the oil pollution conventions have served as a model for other treaties or conventions. The success of the 1992 regime is reflected in the fact that the 1992 conventions have served as a models for a number of other regimes, notably for the planned regime in the 1996 Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS Convention) and, partly, the 2001 Convention on Civil Liability for Bunker Oil Pollution (Bunker Convention). Many of the provisions of those Conventions are identical to those in the 1992 oil regime. For instance, the obligation to maintain insurance included in the Athens Convention on Carriage of Passengers and their Luggage by Sea (Athens Convention) has been inspired by equivalent provisions in the 1992 conventions. Even in the Basel Protocol on Liability and Compensation for Damage resulting from Transboundary Movements of Hazardous Wastes and their Disposal some traces of the oil model can be found.

I argue that the liability and compensation mechanism for a space debris convention can be drafted from experience on the oil pollution conventions. This rule formulation and implementation of the 1992 conventions attests to the significance of legal norms in constituting new spaces of financial accountability for environmental harm. In the case of space debris, the convention is targeted to determining liability and evaluating damages in case of disputes. The oil conventions can serve as great precedent setter.

4.5.8 Raising Awareness on the Space Debris Problem on a On-going Basis

Because the space debris issue has not received coverage outside the scientific community, it is crucial to embark on a public education campaign before attempting a draft of the convention. It is important to do so because space technology has advanced rapidly in recent years and a number of countries still lack the technical and financial resources required to highlight the key issues and dangers of space exploration and technology. The Programme on Space Applications (PSA), implemented by UNOOSA, is well placed to carry out the task of information sharing to the wider public. Since its creation in 1971, PSA has made substantial progress in furthering knowledge of and experience with space applications around the world. Provision of country capacity-building, research and development support and technical advisory services by the program have helped to reduce the gap between the industrialized and developing countries.

4.4.9 Organizational Development of a Secretariat and Financial Sustainability

I suggest that UNOOSA be allocated resources from the UN to form a dedicated secretariat for drafting, implementing and monitoring a space debris convention. The Office already serves as the secretariat for the General Assembly's committees dealing exclusively with international cooperation: the Committee on the Peaceful Uses of Outer Space. It has 67 member states and 20 organizations with observer status, annual meetings, and two subsidiary bodies. As a result, it already has some resources and experience that would be very valuable to the drafting of the convention. At the moment, UNOOSA has existing capacity as a secretariat to insure coordination of the drafting of such an agreement (It has about 20 staff members working for two sections: Committee Services and Research Section and the Space Applications Section). For UNOOSA to agree to work on the entire drafting process, including the convening of a congress and various follow up meetings, it means that additional financial resources are needed from the UN regular budget.

From the outset, it is important to justify the commitment of the resources expected to be required to formulate, adopt, and bring the instrument into force. According to a first estimation, such cost could be in the range of USD200-300 million for the three years envisaged for the drafting of the space debris convention.[76] Because this range is approximate at this stage, I recommend the development of a Medium Term Budget Framework for UNOOSA to prepare the convention. Such a framework may entail the following tasks:

- Initiating a process of rigorous analysis of the costs and sources of revenues for dealing specifically with the drafting of the convention at UNOOSA;

- Developing a three-year framework as a starting point and utilising improved techniques for revenue and expenditure forecasting, and publishing the basis and assumptions for medium-term forecasts (It is important for member states to understand financial implications of the new instrument);

- Establishing a financial review team with the task of developing broad aggregates for revenues and sectoral expenditure ceilings;

To further improve the drafting of the convention, I propose that reporting systems, both for accounting and performance purposes, are developed and tuned for quick and reliable reporting. In order to monitor progress made on the drafting and negotiating of the convention, they will allow for organizational goal-setting and performance measurement.

Because UN budgets can be limited, I propose that UNOOSA raise funds from special appeal campaign and from a group of donors ("The Friends", being a group of space-faring nations for instance), mostly in form of earmarked contributions on a thematic basis. It is important for UNOOSA to be able to secure an increasing level of support for the convention, both political and financial. As such, UNOOSA will need to define its strategy so that it supports the development of the convention over time. As part of its sustainability strategy to access and improve financial capacity, the Office will need to focus on leveraging diversified sources of funds and quality human resources, optimizing seed money and burden sharing for administrative and operational costs.

4.6 Proposed Dispute Settlement Design to Administer Space Debris Claims

I have advocated that it is important the international convention on space debris incorporate a proper dispute settlement mechanism to resolve space disputes. In the following section, I propose a design of such a mechanism.

4.6.1 The Institutional Framework

This preliminary design of the international dispute settlement mechanism for space debris liability claims is based on the assumption that the claims will be addressed and resolved under the Space Debris Convention once it has been signed and ratified by parties. A key issue to be decided is whether a new, free-standing organization should be established to administer the international dispute settlement mechanism for space debris, or whether the mechanism should be hosted and serviced by an existing international organization, for instance UNOOSA.

A number of reasons suggest the latter solution, including the possibility of drawing on existing administrative resources and, in particular, the likely faster operationalization of the mechanism. However, I must note that no international organization is presently fully equipped to deal with all aspects of the dispute process. Any organization would need time and additional resources to become fully functional. Moreover, on balance, the importance of assigning the task to an organization that is focused on and devoted to managing space issues at the United Nations and whose decision-making structures, procedures and funding mechanisms are designed to serve the specific task at hand, outweighs the benefit of establishing to establish an entirely new and independent organization.

I propose that an organization be established at the headquarters of UNCOPUOS. It would be comprised of a secretariat in charge of developing and maintaining the dispue resolution procedures. The Secretariat would also operate the dispute board to be constituted for reviewing and assessing claims. It would also maintain a list of arbitrators and experts that could serve on the dispute board.

4.6.2 Basic Design of the International Mechanism

The international dispute settlement mechanism must be designed in such a way that it will be capable of organizing, managing and resolving large and complex claims. The scale of the international mechanism and the resources available to it must reflect these requirements. The administrative, operational and logistical requirements of such a mechanism are those generally applicable to the implementation of large-scale international arbitration efforts. Experience gained in these efforts should be taken into account, while keeping in mind the specific nature, scope and complexity of the space debris issue.

The principal requirements applicable to the design of the mechanism are outlined below:

(1) Effectiveness. The requirement of effectiveness means that the process produces results and achieves its goals within a reasonable period of time. A precise temporal goal for the resolution of a claim should be established.

(2) Efficiency. Efficiency means that the international dispute settlement mechanism be designed in such a way that it achieves its goals with minimum expenditure of resources. Consequently, the procedures of the mechanism should be designed to further this goal and adjust, as appropriate and necessary, traditional rules regarding the allocation of burden of proof and standards of evidence. This is the reason why the Space Debris Convention should develop an independent tracking and cataloguing capacity. In order to promote efficiency, it is also important to ensure that the mechanism, including its key decision-making functions, are staffed on the basis of professional and technical competency and experience.

(3) Transparency. Transparency means that eligibility and other criteria, including the loss types covered and the valuation methods available for quantifying damages, and all principal documents be made public. The policy-making body for the international mechanism should also include representatives of the parties and the international community. However, this does not mean that

these parties will have a decisive role in the decision-making process; this role should in principle be preserved for the independent arbitrators adjudicating the space debris claims. Standard operating procedures should be developed to guide the operation of the claims process. Rules of procedure should be adopted for the claims process that embody and reflect applicable international legal standards.

4.6.3 Valuation Standards for Damage Assessment

As a general principle, compensation in most cases would be calculated on the basis of internationally-recognized principles of valuation found in arbitration, loss adjusting and accounting professions. It is important that the basis of valuation for economic and non-economic losses related to space debris be based upon internationally accepted professional valuation standards.

At the general level, in the sake of efficiency, the guiding valuation principles would be as follows:

- Simple and consistent, rather than subtle and arbitrary. This allows easy and transparent processing of claims, consistency and accuracy of the valuation work.

- Seek to integrate generally-accepted valuation standards and procedures in order to maximize accuracy and reliability of awards.

- Rely, as much as possible on independent evidence for assessing liability (i.e. an independent catalogue of tracked debris in order to minimize areas of judgment applied in the dispute resolution work).

4.6.4 Claims Process and Dispute Board Members

Under the space debris convention, the claims process is essentially a quasi-judicial function and should be organized accordingly. As such, the design should incorporate the applicable international legal standards and the “best practices” of international claims resolution systems. The principal function of these standards and practices is to ensure that the minimum requirements of due process are respected while ensuring that the process is executed in an efficient and effective manner and without undue delay.

The principal unit of the claims process is the secretariat attached to UNCOPUOS in Vienna. The support services provided by the secretariat should include, in particular, legal support in processing the claims, technical support (both scientific and valuation expertise), administrative and financial support, and a claims registry (i.e. a procedure for filing claims).

Responsibility for the resolution of the claims should be vested with a dispute board comprised of arbitrators. Given the different types of expertise required, it is advisable to create a panel of arbitrators with different professional backgrounds (i.e. scientific as much as valuation knowledge). The members of the dispute board should be appointed by the policy-making body for the convention on the basis of a nomination by an appointing authority designated in advance. One member of the dispute board should be appointed to serve as Chairman of the Board.

In line with the independent, professional nature of their function, the members of the boards should serve in their personal capacity and not as representatives of their governments. The plenary of the dispute board, sitting as the claims commission, should be authorized to adopt its own rules of procedure or, alternatively, draft these rules and submit them for approval to the policy-making body.

The decisions of the dispute board should be final and not subject to review by the policy-making body. The extent to which appeals from the decisions of the dispute board will be allowed should be carefully considered in view of the number of claims to be processed and the mass nature of the process. It may be efficient to use other procedures, including external audits, to monitor the appropriateness and accuracy of the decisions.

4.6.5 Use of Independent Experts

Expert advice in settling disputes related to space debris may be important. Competent, objective, professionally developed valuations are required in all cases. As such, it will be important for the dispute board to be able to use various experts, including scientists, and loss adjusters and accountants to carry out the verification and quantification of claims.

It is vital for the dispute board to have the opportunity to be able to ask the secretariat to appoint an expert to administer the proceedings. To make the right choice, the secretariat will maintain a list of potential independent experts, relying on its own extensive contacts. Expertise provided through the secretariat can assist amicable settlement of a dispute or resolve a difference of opinion. It may do no more than remove uncertainty about a set of facts. If the parties wish, the findings can be binding.

4.6.6 Funding

Securing appropriate funding for the dispute resolution mechanism is crucial. State parties to the space debris convention must be expected to make a contribution to funding the liability and dispute settlement mechanism. The size of this contribution remains a matter of negotiations between the parties.

Chapter 5 – Conclusion and recommendations

The Chinese destruction of a satellite came as a surprise since China had played a growing international role in fighting the proliferation of space junk. In addition to introducing a renewed military dimension to space, the destruction of the Chinese satellite has sent a strong signal to the world that the problem of space debris has not been resolved. The new threat posed by the destruction of satellites shows the difficulties of achieving international cooperation to find solutions to a problem that eventually threatens to limit humanity's reach for the stars.

Today, orbital debris continues to be a growing problem for government and commercial satellite operators and manufacturers. Since 2000, the number of in-orbit objects larger than a bowling ball has increased by nearly 10 percent, with the United States and Russia each contributing approximately 40 percent of the total debris. Orbital debris will continue to grow as long as there are launches of satellites and other spacecraft. It is obvious that space corporations can take significant steps towards minimizing the amount of debris that remains in space. However, the greatest challenge is not a technological one. Rather, the greatest obstacle comes in our ability to successfully coordinate and implement with force a set of measures to deal with space debris in the coming years.

A global convention is thus warranted for the simple reason that the successful approval of voluntary guidelines has not been consistent over the last few decades. Furthermore, the convention would cast in stone some of the principles for dispute resolution and liability damage. The convention is to be organized around the following four objectives:

- Objective 1: Independent Tracking and Cataloguing of Space Debris. Before determining the most effective measures that should be taken to solve the space debris problem in Earth orbit, it is essential to quantify the problem not only in terms of the current orbital debris environment, but also in terms of future growth potential absent remedial action. I propose that a uniform database be maintained by UNOOSA secretariat. Specific procedures will need to be drafted and enforced to ensure that UNOOSA collects information and data in a timely and exhaustive manner.

- Objective 2: Adoption of Enforceable Space Debris Mitigation and Disposal Standards. I advocate the need for internationally agreed standards that can enforce appropriate debris mitigation and disposal measures for spacecraft and launch services providers.

- Objective 3: The "Space Preservation" Provision. The convention must propose that some orbital regions be protected because of their scientific and economical importance: the Low Earth Orbit (LEO), ranging from 200 km to 2000 km altitude, and the Geostationary Earth Orbit (GEO) between 33000 and 36000 km altitude.

- Objective 4: Liability, Compensation and Dispute System Design. The convention must set out clearly the mechanism for resolving disputes under which a final and enforceable decision can be obtained in a cost-effective manner. I propose the creation of a Dispute Board set up at the outset of the convention. UNOOSA will ensure support to the dispute settlement mechanism.

With that in mind, I recommend the following milestones over the next 5 years for drafting and implementing a space debris convention:

Date	Tasks
2008	- Convention objectives are established and an entry point defined (UNOOSA). - A dedicated staff within UNOOSA is identified to draft the convention agenda and organize a first World Space Debris Congress in order to share a common vision of the problem. Participants to the Congress are all members of space-faring and non space-faring nations, civil society, space industry and academia. This is the starting point for the consensus building process that will end up with the adoption and ratification of the convention - Measure of success and targets are developed for the drafting of the convention. - Specific assessment studies are prepared and expert information is collected by UNOOSA. - Rigorous analysis of costs and sources of revenues for dealing specifically with the drafting of the convention at UNOOSA is completed. Resources mobilization takes place to ensure financial sustainability of the making of the convention.
2009	- A rigorous benchmark is carried out to highlight best practices and lessons from other conventions, space and non-space related. - The drafting of the convention is organized at UNOOSA and an agenda for approval by the UN General Assembly is set. - A second World Space Debris Congress is organized. In conjunction, UNPSA starts to organize workshops and seminars on space debris to continue to mobilize all participants to the 2008 and 2009 Congresses. - Working groups are established following the 2009 Congress to address key issues. The dispute mechanism is also discussed on a legal stand point.
2010	- A Drafting Committee is set up at UNOOSA and is composed of a representation of all stakeholders. A first draft of the convention is

	being circulated among the various stakeholders, including the private sectors and NGOs. - The negotiating process starts and consultations with governments are carried out. Consultations with civil society are organized. - A third World Space Debris Congress is organized with the main objective to discuss the draft convention.
2011	- The adoption forum for the convention is the UN General Assembly (GA). As a result, the draft convention is now presented to the GA. - During the year, the working groups meet to finalize the convention. The following tasks are performed: o Completion of the substantive negotiations - usually only on a few especially difficult points that the primary negotiations were not able to resolve; o Perfection of the text with the help of the Drafting Committee; o Formulation of the final clauses, which determine inter alia what entities can become parties to the proposed instrument and on what terms; o The making of a formal record to enable all potential parties to announce and have preserved their interpretations of the instrument and politically important statements and reservations.
2012	- The text is adopted by the GA and the monitoring body is implemented. - Ratification by enough countries for the convention to enter into force
2012-2015	States parties embark upon implementation of national and corporate action plans and launching agencies start implementing measures for limiting space debris

It is important to look over the horizon and head off problems before they occur rather than waiting for the problems to find us unprepared. It is obvious that many development issues deserve great attention on Earth. However, this is not a reason to forget that our space environment needs protection in much the same way that our oceans, rivers, and forests have to be preserved for future generations.

Recent activities in space have produced a considerable increase of knowledge about the debris population in the orbital environment. This should help motivate the design and implementation of a space debris convention. Even though the current space debris population may not represent an immediate danger, the risk of collision with debris is growing. The severity of damage and its consequences are also increasing as we rely heavily on equipment placed in orbit. Now is the time to take action to preserve the scientifically and commercially valuable space environment for future space users. More efficient measures are needed including continuous monitoring of space debris, selective de-orbiting of spacecraft and rocket stages at completion of their missions, drafting of remediation actions for eliminating the most hazardous debris, and designing the liability and compensation regimes.

More than ever, the space debris problem is hindering space commerce, space tourism, the scientific exploration of space, the use of raw materials from space (including materials from the Moon), and even distant plans for the future settlement of space. A new space debris convention is thus warranted.

APPENDICES

Appendix 1: Draft space debris convention (A hypothetical example)

Preamble

The States Party to this Agreement,

Inspired by the great prospects opening up before mankind as a result of man's entry into outer space;

Believing that the exploration and use of outer space should be carried on for the benefit of all peoples irrespective of the degree of their economic or scientific development;

Recalling the promotion of the peaceful uses of outer space in the Treaty Banning Nuclear Tests in the Atmosphere, Outer Space and Under Water; the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies; the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space; the Convention on International Liability for Damage Caused by Space Objects; the Convention on Registration of Objects Launched into Outer Space; and the Agreement Governing Activities of States on the Moon and Other Celestial Bodies;

Recognizing the fragility of the outer space environment and conscious of the dangers of space debris in low earth and geosynchronous orbits;

Recognizing the necessity of international cooperation for limiting space debris;

Recognizing that it is in the interest of all mankind that space shall continue for ever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord;

Reaffirming that outer space is an indispensable medium for civil, scientific, and commercial endeavor, technological advancement, and national security;

Recognizing that incidents from space debris in outer space would impair the peaceful exploration and use of space;

Desiring to prevent outer space from becoming an arena of conflict;

Desiring to adopt uniform international rules and procedures for limiting, mitigating and eliminating space debris;

Desiring to ensure that adequate compensation is available to anyone who suffer damage caused by space debris;

Have agreed on the following:

Article I [Definitions]

For the purpose of this Agreement, the following definitions shall apply:

1. “Space debris” means all man made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non functional.

2. “Space Systems” refers to spacecraft, orbital stages, and orbiting object designed to perform a specific function or mission (e.g. communications, navigation or Earth observation).

3. “Launch vehicle” means any vehicle constructed for ascent to outer space, and for placing one or more objects in outer space, and any sub-orbital rocket.

4. “Satellite” means a man-made body that revolves around the Earth, that transmits or receives an electromagnetic signal or that previously has transmitted or received an electromagnetic signal.

5. “Low Earth Orbit” (LEO) means an orbit within the locus extending from the Earth’s surface up to an altitude of 2,000 km. Given the rapid orbital decay of objects below approximately 200 km, the commonly accepted definition for LEO is between 200-2000 km (124-1240 miles). Geo Synchronous Orbit (GEO) means an orbit at about 36,000 km.

6. “Mitigation measures” means any reasonable measures taken by any space-faring State and organization, public or private, to prevent or minimize debris pollution and damage.

7. “Person” means any individual or partnership or any public or private body, whether corporate or not, including a state or any of its constituent subdivisions.

8. “Incident” means any occurrence, or series of occurrences having the same origin, which causes damage.

9. “Damage” means loss or damage caused by space debris, registered or not, and including costs of preventive and remediation measures and further consequential loss or damage caused by the debris, including business interruption and physical losses.

Article II [Purpose]

1. The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.

2. Outer space, shall be free from debris and any kind of pollution that may prevent exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.

3. A “Space Preservation” Provision shall be adopted to ensure that orbital debris creation is controlled within these protected regions. To do so, the convention regulating space debris shall define and incorporate debris emissions quotas.

4. There shall be collaboration and coordination of activities for curbing the level of space pollution, and States shall facilitate and encourage international cooperation for investigation of damage. A dispute mechanism shall be designed to address questions of liability and compensation of such damage.

Article III [General Obligation]

1. Each Party shall conduct military, scientific and commercial exploration and use of outer space in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding.

2. In accordance with the provisions of this Agreement, each Party shall seek to promote the peaceful uses of outer space by avoiding incidents and refraining from dangerous practices in space, including engaging in actions that increase the risk of debris, and using a directed source of power to disrupt, degrade, impair, or destroy a satellite and thus voluntarily creating debris.

3. The Parties to this agreement agree to follow the fundamental principles mentioned below:

(a) Taking mitigation measures to prevent the accumulation of space debris

(b) Preventing on-orbit break-ups;

(c) Removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions; and

(d) Limiting the objects released during normal operations.

Article IV [Tracking and Cataloguing of Space Debris]

1. An official independent catalogue of space debris will be maintained by the United Nations Office for Outer Space Affairs (UNOOSA).

2. In accordance with the provisions of this Agreement, each Party agrees to inform UNOOSA of any event generating new space debris.

3. UNOOSA shall be empowered to maintain an up-to-date catalogue of space debris and to make it available to the international community at large. The catalogue shall be maintained on-line. Under this agreement, UNOOSA agrees to provide the necessary financial means for developing models for tracking smaller-size debris (below 5 cm).

Article V [Prevention and Mitigation Guidelines]

1. The Parties to this agreement agree to study the impact of any program, project or experiment that will release objects in orbit. Such program, project or experiment should not be planned unless an adequate assessment can verify that the effect on effect on the orbital environment, and the hazard to other operating space systems, is acceptably low in the long-term.

2. The Parties shall enforce all the mitigation guidelines developed and adopted by the United Nations on the Committee on the Peaceful Uses of Outer Space (UNCOPUOS) on 27 February 2007. The parties agree to enforce all updated version of the mitigation guidelines as presented and adopted to UNCOPUSO.

3. In accordance with the provisions of the mitigation guidelines, each Party agrees to follow the guidelines applicable to mission planning and the design and operation of spacecraft and orbital stages that will be injected into Earth orbit.

Article VI [Creation of Protected Zones]

1. One purpose of this agreement is to create protected zones. Within the specified zones, the Parties to this agreement agree to limit the creation and accumulation of space debris.

2. The protection zones are defined as follows:

   a. Low Earth orbit (LEO) between 200 - 1500 km

   b. Geostationary orbit (GEO) between 33000 – 37000 km

3. The Parties to this agreement agree to dispose of any object at end-of-mission. Debris created within the specified zones would have to be reported for tracking and cataloguing to the appropriate monitoring body created for this purpose under the convention.

4. Within the specified zones, the Parties agree to avoid creating debris intentionally by use of power and military actions. In case of malfunction of equipment or machinery breakdowns within the specified zones, the Parties agree to report the information to the specified body created under this convention.

Article VII [General Responsibility]

1. States Parties to the Treaty shall bear international responsibility for national activities in outer space, whether such activities are carried on by governmental agencies or by non-governmental entities, including commercial and military activities.

2. States Parties to the Treaty shall be responsible for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, shall done under the responsibility and supervision of the appropriate State Party to the Treaty.

3. States Parties to this agreement shall be absolutely liable to any damage caused by space debris falling under their responsibility and pay compensation for the damage caused on the surface of the Earth or to aircraft in flight.

4. As per the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies", each State Party to the Treaty that launches or procures the launching of an object into outer space is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space. The present agreement shall apply this definition for any damage caused by space debris whose origin is known.

Article VIII [Mediation and Dispute Handling Mechanism]

1. To promote the objectives and proper implementation of and compliance with the provisions of this Agreement, the Parties shall resolve to establish a system of consultation for the purpose of resolving expeditiously any incident, ambiguous development, or concern which may arise pertinent to the obligations contained in this Agreement. Mediation shall be conducted in accordance with the rules of UNOOSA.

2. In case of disagreement, the dispute handling mechanism will be as follows:

a. A claims mechanism is created under the convention and its secretariat is hosted at UNOOSA in Vienna

b. Parties to the convention are entitled to put forward any claim to the Claims Secretariat

c. The Standard Operating Procedures developed under this convention for governing disputes shall apply in any circumstance.

5. In case of damage suffered from a space debris, claims from any Party shall be notified within 10 days after the incident has occurred to the appropriate body designed for administering the claims. Within a month after the date of the incident, a Dispute Board will be nominated in accordance with the Standard Operating Procedures ("The Rules") established under the convention. The claims will then be administered according to the Rules.

Article IX [Communication and Notification of Debris Threat]

1. To promote the objectives and implementation of the provisions of this Agreement, the Parties shall resolve to establish a mandatory system of communication of information about potential collision and dangers posed by debris within forty-five days after this Agreement has entered into force.

2. To promote the objectives and proper implementation of the provisions of this Agreement, the Parties shall resolve to provide notice of launches into outer space to the other Parties in accordance with the system of communication of information established above.

3. The Parties shall agree to notify each other about the creation of new debris no later than 50 hours after the launch of all satellites from their territory, and the launch from foreign territory of all satellites owned or controlled by nationals or entities resident in their territory.

Article X [Monitoring]

1. For the purpose of providing assurance of proper implementation and compliance with the provisions of this Agreement, each Party shall use national or multinational technical means of verification and space tracking capabilities at its disposal in a manner consistent with generally recognized principles of international law.

2. For the purpose of providing assurance of proper implementation and compliance with the provisions of this Agreement, all Parties to this Agreement shall not interfere with national or multinational technical means of verification or space tracking capabilities of another Party or Parties to this Agreement operating in a manner consistent with generally recognized principles of international law.

3. For the purpose of providing assurance of proper implementation and compliance with the provisions of this Agreement, all Parties to this Agreement shall not conceal from national or multinational technical means of verification of another Party or Parties to this Agreement operating in a manner consistent with generally recognized principles of international law.

4. States Parties to this agreement shall provide the required financial means to UNOOSA to develop and maintain a Monitoring Office what shall be responsible for coordination and implementing the oversight function for this Convention.

5. To ensure the viability and effectiveness of this Agreement, each Party agrees on evaluating twice a year the outcomes produced by this Convention and therefore enhance reassurance of compliance of the undertakings established under the Convention.

Article XI [Entry into Force]

This Agreement shall enter into force on the date of its signature by the Parties.

Article XII [Withdrawal]

Each Party shall, in exercising its national sovereignty, have the right to withdraw from this Agreement if it decides that extraordinary events related to the subject matter of this Agreement have jeopardized its supreme interests. It shall give notice of its decision to the other Party or Parties one month prior to withdrawal from this Agreement. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests.

Appendix 2: Table of Existing Launchers as a Source of Debris

In the following table, I provide a list of launchers, the maximum payload that can be sent to space, the cost of launch and the region targeted in space.

Vehicle	Max Payload (kg)	Cost	Comments
Ariane 4	2600		
Ariane 44L	4460	$140M - $160M	Launch to GEO transfer
Ariane 5 (single)	6900	$150M - $165M	Launch to GEO transfer
Ariane 5 (double)	5950	$150M - $165M	Launch to GEO transfer
Ariane 5 (triple)	5115	$150M - $165M	Launch to GEO transfer, wikipedia claims these boosted most payload ever (8.2 tons)
Atlas I (Medium 3.3m OD)	2375		Launch to GTO
Atlas I (Large 4.2m OD)	2255		Launch to GTO
Atlas II (Medium 3.3m OD)	2950	$60M - $70M	Launch to GTO
Atlas II (Large 4.2m OD)	2810	$60M - $70M	Launch to GTO
Atlas IIA (Medium 3.3m OD)	3160	$65M - $80M	Launch to GTO
Atlas IIA (Large 4.2m OD)	3045	$65M - $80M	Launch to GTO
Atlas IIAS (Medium 3.3m OD)	3830	$90M - $100M	Launch to GTO
Atlas IIAS (Large 4.2m OD)	3700	$90M - $100M	Launch to GTO
Delta II 7325: (2.9m fairing)	1002	$50M - $55M	Launch to GTO, only $45M for US government launches
Delta II 7425: (2.9m fairing)	1129	$50M - $55M	Launch to GTO, only $45M for US government launches
Delta II 7925 (2.9m fairing)	1869	$50M - $55M	Launch to GTO, only $45M for US government launches
Delta III	3810	$80M - $85M	Launch to GTO
Titan	14742	$160M - $270M	Launch to LEO, was used for INTELSAT VI.
Long March LM-1D	1000	$10M	Launch to LEO, quantity bought affects price, 28.5 inclination
Long March LM-2C	2800	$19.5M	Launch to LEO, quantity bought affects price, 28.5 inclination
Long March LM-2E	9200	$40M - $50M	Launch to LEO, quantity bought affects price, 28.5 inclination
Long March LM-2E (PAM-4)	3200	$35M - $56M	Launch to GTO, quantity bought affects price, 28.5 inclination
Long March LM-3	1500	$35M - $40M	Launch to GTO, quantity bought affects price, 31.1 inclination
Long March LM-3A	2300	$35M - $45M	Launch to GTO, quantity bought affects price, 31.1 inclination

Long March LM-3B	4800	$60M - $70M	Launch to GTO, quantity bought affects price, 31.1 inclination
Long March LM-4	2500	$24M	Launch to LEO, quantity bought affects price, 90 inclination (sun synchronous)
Long March LMLV-1 (Athena)	635	$16M - $17M	Launch to LEO, 100 n mile orbit
Long March LMLV-2 (Athena 2)	1814	$24M	Launch to LEO
Pegasus	275	$7.4M - $12M	Launch to LEO
H-2 (Japanese)		$181M - $200M	
H-2A (Japanese)			Wikipedia claims that the H-IIA222 variant can transport up to 9.5 tons to GTO
Cosmos SL-8	1400	$10M	Launch to LEO
Proton SL12 (Russian)	5500	$90M	Launch to GEO transfer,
Zenit	2500	$25M - $40M	Launch to GEO transfer, 21 successes out of 24 launches
Zenit 2	13740	$45M	Launch to LEO
Zenit 3 (Sea Launch)	2500	$59M - $67M	Launch to GEO, wikipedia says they charge $90M and have 6 ton payload
Land Launch	4500	$40M	Sea Launch planning to launch from Plesetsk, $40M is minimum cost, uses Russian fairing because the US export control required retrieval of any US fairing dropped in Russia.
Soyuz SL-4	1350	$40M	Launch to geostationary transfer orbit

Source: Gregor Z. Hanuschak, Chang Yi-Chiun, Thierry Senechal, Takayuki Nakamura (2007). Space Tethers, Linking Earth and Space. MIT.

Appendix 3: Existing Space Debris Mitigation Guidelines

Space debris mitigation guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space

Adopted in Vienna in February 2007 (Document A/AC.105/890)

1. Background

Since the Committee on the Peaceful Uses of Outer Space published its Technical Report on Space Debris in 1999, a it has been a common understanding that the current space debris environment poses a risk to spacecraft in Earth orbit. For the purpose of this document, space debris is defined as all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional. As the population of debris continues to grow, the probability of collisions that could lead to potential damage will consequently increase. In addition, there is also the risk of damage on the ground, if debris survives Earth's atmospheric re-entry. The prompt implementation of appropriate debris mitigation measures is therefore considered a prudent and necessary step towards preserving the outer space environment for future generations.

Historically, the primary sources of space debris in Earth orbits have been (a) accidental and intentional break-ups which produce long-lived debris and (b) debris released intentionally during the operation of launch vehicle orbital stages and spacecraft. In the future, fragments generated by collisions are expected to be a significant source of space debris.

Space debris mitigation measures can be divided into two broad categories: those that curtail the generation of potentially harmful space debris in the near term; and those that limit their generation over the longer term. The former involves the curtailment of the production of mission-related space debris and the avoidance of break-ups. The latter concerns end-of-life procedures that remove decommissioned spacecraft and launch vehicle orbital stages from regions populated by operational spacecraft.

2. Rationale

The implementation of space debris mitigation measures is recommended since some space debris has the potential to damage spacecraft, leading to loss of mission, or loss of life in the case of manned spacecraft. For manned flight orbits, space debris mitigation measures are highly relevant due to crew safety implications.

A set of mitigation guidelines has been developed by the Inter-Agency Space Debris Coordination Committee (IADC), reflecting the fundamental mitigation elements of a series of existing practices, standards, codes and handbooks developed by a number of national and international organizations. The Committee on the Peaceful Uses of Outer Space acknowledges the benefit of a set of high-level qualitative guidelines, having wider acceptance among the global space community. The Working Group on Space Debris was therefore established (by the Scientific and Technical Subcommittee of the Committee) to develop a set of recommended guidelines based on the technical content and the basic definitions of the IADC space debris mitigation guidelines, taking into consideration the United Nations treaties and principles on outer space.

3. Application

Member States and international organizations should voluntarily take measures, through national mechanisms or through their own applicable mechanisms, to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures.

These guidelines are applicable to mission planning and operation of newly designed spacecraft and orbital stages and, if possible, to existing ones. They are not legally binding under international law.

It is also recognized that exceptions to the implementation of individual guidelines or elements thereof may be justified, for example, by the provisions of the United Nations treaties and principles on outer space.

4. Space debris mitigation guidelines

The following guidelines should be considered for the mission planning, design, manufacture and operational (launch, mission and disposal) phases of spacecraft and launch vehicle orbital stages:

Guideline 1: Limit debris released during normal operations

Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.
During the early decades of the space age, launch vehicle and spacecraft designers permitted the intentional release of numerous mission-related objects into Earth orbit, including, among other things, sensor covers, separation mechanisms and deployment articles. Dedicated design efforts, prompted by the recognition of the threat posed by such objects, have proved effective in reducing this source of space debris.

Guideline 2: Minimize the potential for break-ups during operational phases

Spacecraft and launch vehicle orbital stages should be designed to avoid failure modes which may lead to accidental break-ups. In cases where a condition leading to such a failure is detected, disposal and passivation measures should be planned and executed to avoid break-ups. Historically, some break-ups have been caused by space system malfunctions, such as catastrophic failures of propulsion and power systems. By incorporating potential break-up scenarios in failure mode analysis, the probability of these catastrophic events can be reduced.

Guideline 3: Limit the probability of accidental collision in orbit

In developing the design and mission profile of spacecraft and launch vehicle stages, the probability of accidental collision with known objects during the system's launch phase and orbital lifetime should be estimated and limited. If available orbital data indicate a potential collision, adjustment of the launch time or an on-orbit avoidance manoeuvre should be considered. Some accidental collisions have already been identified. Numerous studies indicate that, as the number and mass of space debris increase, the primary source of new space debris is likely to be from collisions. Collision avoidance procedures have already been adopted by some Member States and international organizations.

Guideline 4: Avoid intentional destruction and other harmful activities

Recognizing that an increased risk of collision could pose a threat to space operations, the intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided. When intentional break-ups are necessary, they should be conducted at sufficiently low altitudes to limit the orbital lifetime of resulting fragments.

Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy
In order to limit the risk to other spacecraft and launch vehicle orbital stages from accidental break-ups, all on-board sources of stored energy should be depleted or made safe when they are no longer required for mission operations or post-mission disposal. By far the largest percentage of the catalogued space debris population originated from the fragmentation of spacecraft and launch vehicle orbital stages. The majority of those break-ups were unintentional, many arising from the abandonment of spacecraft and launch vehicle orbital stages with significant amounts of stored energy. The most effective mitigation measures have been the passivation of spacecraft and launch vehicle orbital stages at the end of their mission. Passivation requires the removal of all forms of stored energy, including residual propellants and compressed fluids and the discharge of electrical storage devices.

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission
Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the LEO region should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits that avoid their long-term presence in the LEO region. When making determinations regarding potential solutions for removing objects from LEO, due consideration should be given to ensure that debris that survives to reach the surface of the Earth does not pose an undue risk to people or property, including through environmental pollution caused by hazardous substances.

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission
Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the GEO region should be left in orbits that avoid their long-term interference with the GEO region. For space objects in or near the GEO region, the potential for future collisions can be reduced by leaving objects at the end of their mission in an orbit above the GEO region such that they will not interfere with, or return to, the GEO region.

5. Updates
Research by Member States and international organizations in the area of space debris should continue in a spirit of international cooperation to maximize the benefits of space debris mitigation initiatives. This document will be reviewed and may be revised, as warranted, in the light of new findings.

6. Reference
The reference version of the IADC space debris mitigation guidelines at the time of the publication of this document is contained in the annex to document A/AC.105/C.1/L.260. For more in-depth descriptions and recommendations pertaining to space debris mitigation measures, Member States and international organizations may refer to the latest version of the IADC space debris mitigation guidelines and other supporting documents, which can be found on the IADC website (www.iadc-online.org).

IADC Space Debris Mitigation Guidelines

Version 2002

1 Scope

The IADC Space Debris Mitigation Guidelines describe existing practices that have been identified and evaluated for limiting the generation of space debris in the environment.
The Guidelines cover the overall environmental impact of the missions with a focus on the following:

(1) Limitation of debris released during normal operations
(2) Minimisation of the potential for on-orbit break-ups
(3) Post-mission disposal
(4) Prevention of on-orbit collisions.

2 Application

The IADC Space Debris Mitigation Guidelines are applicable to mission planning and the design and operation of spacecraft and orbital stages (defined here as space systems) that will be injected into Earth orbit. Organisations are encouraged to use these Guidelines in identifying the standards that they will apply when establishing the mission requirements for planned space systems. Operators of existing space systems are encouraged to apply these guidelines to the greatest extent possible.

3 Terms and definitions

The following terms and definitions are added for the convenience of the readers of this document. They should not necessarily be considered to apply more generally.

3.1 Space Debris

Space debris are all man made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non functional.

3.2 Space Systems

Spacecraft and orbital stages are defined as space systems within this document.

3.2.1 Spacecraft – an orbiting object designed to perform a specific function or mission (e.g. communications, navigation or Earth observation). A spacecraft that can no longer fulfil its intended mission is considered nonfunctional. (Spacecraft in reserve or standby modes awaiting possible reactivation are considered functional.)

3.2.2 Launch vehicle – any vehicle constructed for ascent to outer space, and for placing one or more objects in outer space, and any sub-orbital rocket.

3.2.3 Launch vehicle orbital stages □ any stage of a launch vehicle left in Earth orbit.

3.3 Orbits and Protected Regions

3.3.1 Equatorial radius of the Earth - the equatorial radius of the Earth is taken as 6,378 km and this radius is used as the reference for the Earth's surface from which the orbit regions are defined.

3.3.2 Protected regions any activity that takes place in outer space should be performed while recognising the unique nature of the following regions, A and B, of outer space (see Figure 1), to ensure their future safe and sustainable use. These regions should be protected regions with regard to the generation of space debris.

(1) Region A, **Low Earth Orbit** (or LEO) Region – spherical region that extends from the Earth's surface up to an altitude (Z) of 2,000 km

(2) Region B, the **Geosynchronous Region** - a segment of the spherical shell defined by the following:

lower altitude = geostationary altitude minus 200 km
upper altitude = geostationary altitude plus 200 km
-15 degrees ≤ latitude ≤ +15 degrees
geostationary altitude (Z_{GEO}) = 35,786 km (the altitude of the geostationary Earth orbit)

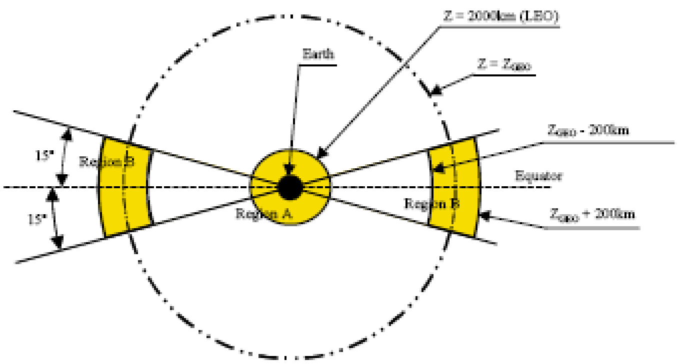

Figure 1 - Protected regions

3.3.3 Geostationary Earth Orbit (GEO) Earth orbit having zero inclination and zero eccentricity, whose orbital period is equal to the Earth's sidereal period. The altitude of this unique circular orbit is close to 35,786 km.

3.3.4 Geostationary Transfer Orbit (GTO) an Earth orbit which is or can be used to transfer space systems from lower orbits to the geosynchronous region. Such orbits typically have perigees within LEO region and apogees near or above GEO.

3.4 Mitigation Measures and Related Terms

3.4.1 Passivation – the elimination of all stored energy on a space system to reduce the chance of break-up. Typical passivation measures include venting or burning excess propellant, discharging batteries and relieving pressure vessels.

3.4.2 De-orbit – intentional changing of orbit for re-entry of a space system into the Earth's atmosphere to eliminate the hazard it poses to other space systems, by applying a retarding force, usually via a propulsion system.

3.4.3 Re-orbit – intentional changing of a space system's orbit

3.4.4 Break-up any event that generates fragments, which are released into Earth orbit. This includes:

(1) An explosion caused by the chemical or thermal energy from propellants, pyrotechnics and so on

(2) A rupture caused by an increase in internal pressure

(3) A break-up caused by energy from collision with other objects

However, the following events are excluded from this definition:
- A break-up during the re-entry phase caused by aerodynamic forces
- The generation of fragments, such as paint flakes, resulting from the ageing and degradation of a space system.

3.5 Operational Phases

3.5.1 Launch phase - begins when the launch vehicle is no longer in physical contact with equipment and ground installations that made its preparation and ignition possible (or when the launch vehicle is dropped from the carrier aircraft, if any), and continues up to the end of the mission assigned to the launch vehicle.

3.5.2 Mission phase - the phase where the space system fulfils its mission. Begins at the end of the launch phase and ends at the beginning of the disposal phase.

3.5.3 Disposal phase - begins at the end of the mission phase for a space system and ends when the space system has performed the actions to reduce the hazards it poses to other space systems.

4 General Guidance

During an organisation's planning for and operation of a space system it should take systematic actions to reduce adverse effects on the orbital environment by introducing space debris mitigation measures into the space system's lifecycle, from the mission requirement analysis and definition phases. In order to manage the implementation of space debris mitigation measures, it is recommended that a feasible Space Debris Mitigation Plan be established and documented for each program and project. The Mitigation Plan should include the following items:

(1) A management plan addressing space debris mitigation activities

(2) A plan for the assessment and mitigation of risks related to space debris, including applicable standards

(3) The measures minimising the hazard related to malfunctions that have a potential for generating space debris

(4) A plan for disposal of the space system at end of mission

(5) Justification of choice and selection when several possibilities exist

(6) Compliance matrix addressing the recommendations of these Guidelines.

5 Mitigation Measures

5.1 Limit Debris Released during Normal Operations

In all operational orbit regimes, space systems should be designed not to release debris during normal operations. Where this is not feasible any release of debris should be minimised in number, area and orbital lifetime. Any program, project or experiment that will release objects in orbit should not be planned unless an adequate assessment can verify that the effect on the orbital environment, and the hazard to other operating space systems, is acceptably low in the long-term. The potential hazard of tethered systems should be analysed by considering both an intact and severed system.

5.2 Minimise the Potential for On-Orbit Break-ups

On-orbit break-ups caused by the following factors should be prevented using the measures described in 5.2.1 – 5.2.3:

(1) The potential for break-ups during mission should be minimised

(2) All space systems should be designed and operated so as to prevent accidental explosions and ruptures at end-of mission

(3) Intentional destructions, which will generate long-lived orbital debris, should not be planned or conducted.

5.2.1 Minimise the potential for post mission break-ups resulting from stored energy

In order to limit the risk to other space systems from accidental break-ups after the completion of mission operations, all on-board sources of stored energy of a space system, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels and momentum wheels, should be depleted or safed when they are no longer required for mission operations or post-mission disposal. Depletion should occur as soon as this operation does not pose an unacceptable risk to the payload. Mitigation measures should be carefully designed not to create other risks.

(1) Residual propellants and other fluids, such as pressurant, should be depleted as thoroughly as possible, either by depletion burns or venting, to prevent accidental break-ups by over-pressurisation or chemical reaction.

(2) Batteries should be adequately designed and manufactured, both structurally and electrically, to prevent breakups. Pressure increase in battery cells and assemblies could be prevented by mechanical measures unless these measures cause an excessive reduction of mission assurance. At the end of operations battery charging lines should be de-activated.

(3) High-pressure vessels should be vented to a level guaranteeing that no break-ups can occur. Leak-before-burst designs are beneficial but are not sufficient to meet all passivation recommendations of propulsion and pressurisation systems. Heat pipes may be left pressurised if the probability of rupture can be demonstrated to be very low.

(4) Self-destruct systems should be designed not to cause unintentional destruction due to inadvertent commands, thermal heating, or radio frequency interference.

(5) Power to flywheels and momentum wheels should be terminated during the disposal phase.

(6) Other forms of stored energy should be assessed and adequate mitigation measures should be applied.

5.2.2 Minimise the potential for break-ups during operational phases

During the design of a space system, each program or project should demonstrate, using failure mode and effects analyses or an equivalent analysis, that there is no probable failure mode leading to accidental break-ups. If such failures cannot be excluded, the design or operational procedures should minimise the probability of their occurrence. During the operational phases, a space system should be periodically monitored to detect malfunctions that could lead to a break-up or loss of control function. In the case that a malfunction is detected, adequate recovery measures should be planned and conducted; otherwise disposal and passivation measures for the system should be planned and conducted.

5.2.3 Avoidance of intentional destruction and other harmful activities

Intentional destruction of a space system, (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other systems should be avoided. For instance, intentional break-ups should be conducted at sufficiently low altitudes so that orbital fragments are short lived.

5.3 Post Mission Disposal

5.3.1 Geosynchronous Region

Spacecraft that have terminated their mission should be manoeuvred far enough away from GEO so as not to cause interference with space systems still in geostationary orbit. The recommended minimum increase in perigee altitude at the end of re-orbiting, which takes into account all orbital perturbations, is:

$$235 \text{ km} + (1000 \cdot C_R \cdot A/m)$$

where C_R: Solar radiation pressure coefficient (typical values are between 1 & 2),
A/m: Aspect area to dry mass ratio [m^2/kg]
235 km: Sum of the upper altitude of the GEO protected region (200 km) and the maximum descent of a re-orbited space system due to luni-solar and geopotential perturbations (35 km).
The propulsion system for a GEO spacecraft should be designed not to be separated from the spacecraft. In the case that there are unavoidable reasons that require separation, the propulsion system should be designed to be left in an orbit that is, and will remain, outside of the protected geosynchronous region. Regardless of whether it is separated or not, a propulsion system should be designed for passivation. Operators should avoid the long term presence of launch vehicle orbital stages in the geosynchronous region.

5.3.2 Objects Passing Through the LEO Region

Whenever possible space systems that are terminating their operational phases in orbits that pass through the LEO region, or have the potential to interfere with the LEO region, should be de-orbited (direct re-entry is preferred) or where appropriate manoeuvred into an orbit with a reduced lifetime. Retrieval is also a disposal option.

A space system should be left in an orbit in which, using an accepted nominal projection for solar activity, atmospheric drag will limit the orbital lifetime after completion of operations. A study on the effect of post-mission orbital lifetime limitation on collision rate and debris population growth has been performed by the IADC. This IADC and some other studies and a number of existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit. If a space system is to be disposed of by re-entry into the atmosphere, debris that survives to reach the surface of the Earth should not pose an undue risk to people or property. This may be accomplished by limiting the amount of surviving debris or confining the debris to uninhabited regions, such as broad ocean areas. Also, ground environmental pollution, caused by radioactive

substances, toxic substances or any other environmental pollutants resulting from onboard articles, should be prevented or minimised in order to be accepted as permissible.
In the case of a controlled re-entry of a space system, the operator of the system should inform the relevant air traffic and maritime traffic authorities of the re-entry time and trajectory and the associated ground area.

5.3.3 Other Orbits

Space systems that are terminating their operational phases in other orbital regions should be manoeuvred to reduce their orbital lifetime, commensurate with LEO lifetime limitations, or relocated if they cause interference with highly utilised orbit regions.

5.4 Prevention of On-Orbit Collisions

In developing the design and mission profile of a space system, a program or project should estimate and limit the probability of accidental collision with known objects during the system's orbital lifetime. If reliable orbital data is available, avoidance manoeuvres for spacecraft and co-ordination of launch windows may be considered if the collision risk is not considered negligible. Spacecraft design should limit the probability of collision with small debris which could cause a loss of control, thus preventing post-mission disposal.

6 Update

These guidelines may be updated as new information becomes available regarding space activities and their influence on the space environment.

Appendix 3: The Author

Thierry Sénéchal has authored this thesis. He is presently a Sloan Fellow at the Massachusetts Institute of Technology (MIT). He has more than 12 years of practical experience in senior policy positions. He has served as an expert advisor in a broad range of international litigation and arbitration cases around the world, in particular in arbitration involving States and international organizations both at private and governmental levels. His fields of expertise are: trade and finance, environmental risks and assessment, transfer of technology.

Between 1997 and 2001, he served as senior evaluator/First Officer with the United Nations Security Council (UNCC) with a mandate to review Gulf War restitution claims brought against Iraq. For UNCC, he helped several panels of Commissioners in drafting valuation methodologies and guidelines. More recently, he has provided expert advice for preparing one of the files at the Permanent Status Negotiation (Palestinian refugee's property losses as a result of their displacement in 1948). Formerly, he was Director of Financial Audit with the Mazars Group and has provided expert advice for a host of internationally recognizable corporate clients and international organizations and regulatory bodies (United Nations, World Bank, Adam Smith Institute, European Commission, French Prime Minister's Office, etc.) as well as international tribunals (LCIA, ICC, ICSID, UNCC).

Thierry holds degrees from Harvard University, London Business School, and Columbia University (Phi Beta Kappa). He is a member of the French National Committee of the International Chamber of Commerce, the Commission on Arbitration, Task Force on Guidelines for ICC Expertise Proceedings. He is an Associate Member, Chartered Institute of Arbitrators (London).

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Space Generation Advisory Council (SGAC) is a non-governmental organisation http://www.spacegeneration.org.

ESA Spacecraft Operations, http://www.esa.int/spacecraftops/ESOC-Article-fullArticle_par-40_1092735450198.html.

The following research institutes provide information on space debris:

- Space Debris Activities at ESOC
- CNUCE Spaceflight Dynamics Section - Space Debris
- Institute of Aerospace Systems (ILR/TUBS)
- Spacecraft Safety Technology at Ernst-Mach-Institut, Freiburg

NASA's Meteorites and Debris database, http://www-curator.jsc.nasa.gov/seh/ldef/ldef.cfm.

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Notes

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[8] These data are extracted from a presentation to the 44th Session of the Scientific and Technical Subcommittee Committee on the Peaceful Uses of Outer Space United Nations

(STSC) called USA" Space Debris Environment and Policy Updates," 12-23 February 2007, NASA.

[9] Discussion with Geoffrey E. Forden, Research Associate, Program in Science, Technology and Society, Massachusetts Institute of Technology, 12 March 2007.

[10] See also the following websites for more information: http://history.nasa.gov/SP-4217/intro.htm and http://space.skyrocket.de/index_frame.htm? http://space.skyrocket.de/doc_sdat/westford.htm.

[11] The Space Surveillance Network (SSN) is a worldwide network of 21 ground-based optical and radar sensors and one space-based sensor. Space surveillance involves detecting, tracking, cataloging and identifying man-made objects orbiting Earth, i.e., active/inactive satellites, spent rocket bodies, debris, and fragments. Space surveillance accomplishes the following: Predict when and where a decaying space object will re-enter the Earth's atmosphere; Prevent a returning space object, which to radar looks like a missile, from triggering a false alarm in missile-attack warning sensors of the U.S. and other countries; Chart the present position of space objects and plot their anticipated orbital paths; Detect new man-made objects in space; Produce a running catalog of man-made space objects; Determine which country owns a re-entering space object; Inform NASA whether objects may interfere with the orbits of the Space Shuttle and the International Space Station. See also the following link for more information:
http://www.stratcom.mil/fact_sheets/fact_spc.html

[12] See an article on the ESA site at http://www.esa.int/spacecraftops/ESOC-Article-fullArticle_item_selected-2_1_01_par-40_1092735450198.html.

[13] See “China's Anti-Satellite Test: Worrisome Debris Cloud Circles Earth”, David, Leornard. 2 February 2007, Space.com.

[14] Newman, D., 2002, Interactive Aerospace Engineering and Design, McGrawHill, p. 187.

[15] See United Nations (2005). Space Solutions for the World's Problems: How the United Nations family is using space technology for sustainable development. Brochure produced by the UN Inter-Agency Meeting on Outer Space Activities, p. 17.

[16] For further details, see http://orbitaldebris.jsc.nasa.gov/index.html.

[17] Newman, D., 2002, Interactive Aerospace Engineering and Design, McGraw Hill, p. 187.

[18] For a complete analysis of the space debris simulations based upon NASA LEGEND model, see Johnson, N. and Liou, J.-C., 20 January 2006, Risks in Space from Orbiting Debris, Vol. 311 Science, pp. 340-341.

[19] LEGEND (LEO-to-GEO Environment Debris model), is a high-fidelity three-dimensional physical model developed by the U.S. National Aeronautics and Space Administration (NASA) that is capable of simulating the historical environment, as well as the evolution of future debris populations. The LEGEND future projection adopts a Monte Carlo approach to simulate future onorbit explosions and collisions (16). A total of 50 (17), 200-year future projection Monte Carlo simulations were executed and evaluated, under the assumptions that no rocket bodies and spacecraft were launched after December 2004 and that no future disposal maneuvers were allowed for existing spacecraft (few of which currently have such a capability). See Johnson, N. and Liou, J.-

C., 20 January 2006, Risks in Space from Orbiting Debris, Vol. 311 Science, pp. 340-341.

[20] Johnson, N. and Liou, J.-C., 20 January 2006, Risks in Space from Orbiting Debris, Vol. 311 Science, pp. 340-341.

[21] For a complete business analysis, see the Frost & Sullivan report entitled World Civil and Military Space Systems Markets, 2 February 2006.

[22] See the ESA site for a complete review of the market. http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=456

[23] For a complete business analysis, see the Frost & Sullivan report entitled World Civil and Military Space Systems Markets, 2 February 2006.

[24] See a study made by the Futron Corporation entitled “State of the Satellite Industry Report”, June 2006.

[25] See the article published in China Daily on 14 November 2003, “Record number of satellites to lift off”.

[26] Klinkrad, H. 2006. “Space Debris Activities in an International Context,” in Space Debris, Models and Risk Analysis, Praxis Publishing Ltd, Springer-Verlag Berlin, pp. 311-314.

[27] The author of the thesis has conducted many interviews with Mr. Nicholas Johnson, Chief Scientist with NASA’s Orbital Debris program Office.

[28] "Orbital Debris Mitigation: Regulatory Challenges and Market Opportunities", 15 March 2006, Futron Corporation, p. 1.

[29] See U.S. National Space Policy, Office of Science and Technology Policy, 31 August 2006, http://www.ostp.gov/html/US%20National%20Space%20Policy.pdf

[30] See a study carried out by the Futron Corporation entitled "Orbital Debris Mitigation: Regulatory Challenges and Market Opportunities", 15 March 2006.

[31] Presentation entitled "Activity of Russian Federation on Space Debris Problem," 44-th session of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPOUS) in February 2007.

[32] For more information on ESA's activities related to space debris, one can access the ESA website at http://www.esa.int/SPECIALS/ESOC/SEMU2CW4QWD_0.html.

[33] The updated version of ESA Space Debris Mitigation Handbook (July 2002) can be uploaded at http://www.esa.int/gsp/completed/execsum00_N06.pdf.

[34] Klinkrad, H. 2006. "Space Debris Activities in an International Context," in Space Debris, Models and Risk Analysis, Praxis Publishing Ltd, Springer-Verlag Berlin, p. 313.

[35] Low Earth orbit (LEO), medium Earth orbit (MEO), geosynchronous Earth orbit (GEO), Geo Transfer Orbit (GTO).

[36] Information can be found at http://www.unoosa.org/oosa/en/OOSA/index.html.

[37] See http://www.unoosa.org/oosa/en/sapidx.html.

[38] For more information on corporate social responsibility, one can access information on the website of the Mossavar-Rahmani Center for Business and Government at Harvard University: http://www.ksg.harvard.edu/m-rcbg/CSRI/home.html

[39] "International reference guide to space launch systems 4th edition", Steven J. Isakowitz et al, AIAA, 2004.

[40] "Small Launch Vehicle Services: Supply and Demand Through 2010", Jeff Foust et al, Space 2004 Conference and Exhibit, CA, 28 - 30 September 2004.

[41] "CHANGING THE LOW-COST LAUNCH GAME", John W. Croft, Aerospace America Online, 2004
http://www.aiaa.org/aerospace/Article.cfm?issuetocid=460&ArchiveIssueID=49

[42] Encyclopedia Astronautica", http://www.astronautix.com/lvs/index.htm

[43] This table is adapted from the MIT Disruptive Technology Class at MIT, Spring 2007.

[44] Orbital Debris Mitigation: Regulatory Challenges and Market Opportunities, Futron Corporation, March 15, 2006.

[45] See, for instance, a study entitled "Analyzing costs of space debris mitigation methods" by Wiedemann, C., Krag, H., Bendisch, J.; Sdunnus, H. presented at the 34th COSPAR Scientific Assembly, The Second World Space Congress, held 10-19 October, 2002 in Houston, USA.

[46] I am currently working on a project for the Lunar Ventures Competition based on tethers. The project is being carried out by a team of MIT students and alumni.

[47] See the article entitiled "Shoestring picosat experiment to demonstrate unique space tether technologies" available on the internet at http://www.spaceref.com/news/viewpr.html?pid=22390

[48] Report of the Scientific and Technical Subcommittee on its forty-fourth session, A/AC.105/890, General Assembly, 6 March 2007, Committee on the Peaceful Uses of Outer Space, Fiftieth session, Vienna, 6-15 June 2007.

[49] Convention on International Liability for Damage Caused by Space Objects, March 29, 1972, 24 U.S.T. 2389, T.I.A.S. No. 7762.

[50] See the full text of the Outer Space Treaty at the Edwin Ginn Library of The Fletcher School, Tufts University (http://fletcher.tufts.edu/multi/texts/BH500.txt).

[51] Convention on International Liability for Damage Caused by Space Objects, March 29, 1972, 24 U.S.T. 2389, T.I.A.S. No. 7762

[52] Charter of the United Nations and Statute of the International Court of Justice, done June 26, 1945, (entered into force Oct. 24, 1945).

[53] For a complete discussion of the legal regimes in place for outer space activity, see the following reference: White, W. (2001). The Legal Regime for Private Activities in Outer Space. Cato Institute.

[54] COPUOS is organized by two subcommittees, the Scientific and Technical Subcommittee and the Legal Subcommittee. The COPUOS Legal Subcommittee has been the primary forum for discussion and negotiation of international agreements relating to outer space.

[55] See the full text and the list of signatories on the US State Department site at http://www.state.gov/t/ac/trt/5181.htm.

[56] The United nations General Assembly resolution A/RES/61/611 at http://daccessdds.un.org/doc/UNDOC/GEN/N06/501/09/PDF/N0650109.pdf?OpenElement provides a summary of the different opinions voices at the 2007 Vienna meeting.

[57] Krepon, M., Heller, M. (May/June 2004). "A Model Code of Conduct for Space Assurance," Disarmament Diplomacy, Issue No. 77

[58] According to many studies, when the rate of fragments being produced by random collisions exceeds the rate at which they are being removed by atmospheric drag, the debris population will start to grow exponentially as collision fragments cause more collisions, and so on.

[59] Forden, G. April 2007. After China's Test: Time For a Limited Ban on Anti-Satellite Weapons, Arms Control Today, p. 21.

[60] See also the full text of the United nations General Assembly A/RES/61/611 at http://daccessdds.un.org/doc/UNDOC/GEN/N06/501/09/PDF/N0650109.pdf?OpenElement

[61] See the study written by Paul Joskow (MIT) and David Harrison (NERA) entitled Emissions Trading in the US: Experience, Lessons, and Considerations for Greehouse Gases, May 2003 (http://web.mit.edu/ceepr/www/R2003-169.pdf).

[62] Emissions trading systems have been designed in various contexts. For instance, such system is set out in Article 17 of the Kyoto Protocol and it provides for Annex I Parties to

acquire units from other Annex I Parties and use them towards meeting their emissions targets under the Kyoto Protocol. This enables Parties to make use of lower cost opportunities to reduce emissions, irrespective of the Party in which Party those opportunities exist, in order to lower the overall cost of reducing emissions. See also the site of the United Nations Framework Convention on Climate Change at http://unfccc.int/2860.php

[63] See the article study edited by E. Butler and K. Boyfield "80 ideas in economic and social reform". It describes reform ideas illustrated by practical examples from around the World. The work has been done by the Adam Smith Institute (UK), 2002.

[64] Johnson, N. and Liou, J.-C., 20 January 2006, Risks in Space from Orbiting Debris, Vol. 311 Science, pp. 340-341.

[65] See Remarks on the Responsibility and Liability for Damages other than Those Caused by the Fall of a Space Object, Armel Kerrest, IISL 97, University of West Brittany.

[66] Extracted from the NASA presentation of the 44-th session of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPOUS) in February 2007.

[67] On 5 September 2001, the catalogue population consisted of 30.6% operational and non-operational payloads (= 2,567), 16.7% rocket bodies (= 1,400), 9.8% operational debris (= 821) and 42.9% payload and rocket debris (= 3,595). Only about 6% of the catalogue population can be assumed to be operational payloads.

[68] Information on the drafting of such Convention can be found on the website of the Foreign Affairs and International Trade Department of Canada. See http://www.mines.gc.ca/menu-en.asp

[69] Members of the IADC are the Italian Space Agency (ASI), British National Space Centre (BNSC), the Centre National d'Etudes Spatiales (CNES), China National Space Administration (CNSA), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), the European Space Agency (ESA), the Indian Space Research Organisation (ISRO), Japan Aerospace Exploration Agency (JAXA), the National Aeronautics and Space Administration (NASA), the National Space Agency of the Ukraine (NSAU) and the Russian Federal Space Agency (ROSCOSMOS).

[70] See also the following publication for references and material on consensus-building. The consensus building handbook : a comprehensive guide to reaching agreement. Editors, Lawrence Susskind, Sarah McKearnan, Jennifer Thomas-Larmer. Published Thousand Oaks, Calif. : Sage Publications, 1999.

[71] Ehrmann, J.R. and B.L. Stinson. 1999. "Joint Fact-Finding and the Use of Technical Experts" in The Consensus Building Handbook: A Comprehensive Guide to Reaching Agreement. Eds. Lawrence Susskind, Sarah McKearnan, and Jennifer Thomas-Larmer. The Consensus Building Institute. pp. 375-399.

[72] For more details on the IAC, one can visit the following website: http://www.iac2007.org/script/aboutthe%20congress.aspx

[73] Susskind, L., 1994, *Environmental Diplomacy*, Oxford University Press: New York.

[74] See details of these conventions on the International Oil Pollution Compensation Funds website, www.iopcfund.org.

[75] The full text of these conventions is available at the Edwin Ginn Library of the Fletcher School of Law and Diplomacy, Tufts University. The Multilaterals Project, which begun in 1992, is an ongoing project at The Fletcher School to make available the texts of international multilateral conventions and other instruments. The information is available at http://fletcher.tufts.edu/multilaterals.html.

[76] Such estimation comes from the experience of the author in the United Nations system. The budget of developing the United Nations Compensation Commission in the mid-1990s has been about USD30 million a year to culminate to USD100 million a year once the organization was fully in place and staff deployed. On the conservative side, I have estimated that the costs of drafting a convention for space debris would be about USD200-300 million, including the World Space Debris Congress, the various meetings in Vienna, the Secretariat staff (about 5 professionals) and the various administrative expenses.