

# Space debris: On collision course for insurers?

The implications of debris colliding with operational satellites from a technical, legal and insurance perspective



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Space debris is no longer an academic issue. Nor is it merely an “environmental” problem; rather, debris has the potential to damage or destroy high-value, operational satellites with resulting revenue losses running into billions of U.S. dollars.

Orbital debris poses two questions for insurers: What steps can they take to promote debris mitigation? And what measures may they need to adopt to protect the viability of their business lines if debris mitigation fails to keep collision risk at acceptable levels?

# 1. Executive summary

On February 11, 2009, the defunct Russian Cosmos 2251 satellite collided violently with an operational satellite in the Iridium constellation (Iridium-33). The collision occurred at an altitude of 790 km. It was the first collision ever between two intact spacecraft. The Iridium satellite was a part of Iridium LLC's constellation of 66 satellites used for worldwide telephony to hand-held devices and other communications services.

## **Littered with debris**

More recently, in 2010, the uncontrollable drift of Intelsat's Galaxy 15 communications satellite along the Geostationary Orbit (GEO) drew attention to the perils of drifting satellites in this popular orbit. The immediate concern with Galaxy 15 was radio interference as the satellite continued to transmit. However, the incident did highlight that there are more than 500 defunct satellites, over 200 spent rocket stages, and thousands of smaller pieces of debris littering GEO. After drifting past many operational satellites for eight months, contact with Galaxy 15 was restored.

## **No longer just an environmental problem**

As these facts highlight, space debris is no longer an academic issue. Nor is it merely an "environmental" problem; rather, debris has the potential to damage or destroy high-value, operational satellites with resulting revenue losses in the billions of dollars or euros. The amount of orbital debris today is double that of 20 years ago and over 30% higher than just five years ago.

Damage from debris is covered under today's conventional "all risk" satellite property insurance policies, but incidents such as those described above have caused Swiss Re to examine the orbital debris risk more closely. A leader in the space insurance market, Swiss Re currently insures over 110 commercial satellites. The total insurance value for the market stands at approximately USD 20 billion. In a proactive approach to understanding the risk posed by debris to insured assets, Swiss Re has reached out to leading experts in the field of orbital debris. Their insights are reflected in this publication.

Our focus is debris collision risk in GEO, which is a unique orbit at 35 786 km in altitude and zero inclination, where most of the insured satellite assets are located. It is the most popular orbit for large, high-capacity communications, broadcasting, and meteorological satellites. Attention was also devoted to the Low Earth Orbit (LEO) in part because much study has already been devoted to LEO and collision risk there is well documented. Our examination of GEO collision risk reveals several critical new insights:

- The probability of a collision in GEO is not uniform by longitude; it is, on average, seven times greater in regions centered about the so-called "geopotential wells", which exert a gravity pull on drifting satellites and other debris. They accumulate in these wells while satellites worth hundreds of millions of dollars continue to operate in and near these locations.
- While the current probability of collision in GEO has been assessed as relatively low, future projections have significant uncertainty due to our limited ability to observe objects in GEO and the lack of knowledge surrounding past and future debris-generating events in GEO. True risk projections must consequently factor in that:
  - Approximately 2200 objects in the 10 cm–1 m range have been observed in GEO, but not yet catalogued;
  - Hardware in GEO "graveyard" disposal orbits may be shedding highly mobile debris whose secondary risk to operational GEO satellites is not fully understood; and
  - There is an explosion risk posed by nearly 200 spent rocket bodies in GEO.
- The collision risk in GEO is likely to increase over time despite current efforts to move decommissioned satellites to a graveyard orbit. This is because there is no natural orbit clearing mechanism in GEO to remove debris, such as atmospheric drag in LEO. In addition, there is unabated strong interest in deploying satellites to GEO.

### **A hypothetical case**

Given the risk of collision in GEO, Swiss Re also examines the legal ramifications. The reader will meet plaintiff and defendant in a dispute arising out of a hypothetical debris collision in GEO between a drifting derelict satellite (OMEGA-1) and a recently-launched, fully operational one (ALPHA-5). We examine emerging legal standards in this new field of law, where the defendant owner of the drifting satellite has failed to conduct end-of-life disposal manoeuvres contrary to its pledge to the U.S. regulatory authorities. The question is whether the defendant's conduct gives rise to liability. There is no obvious path to liability under current law, but this may change: As debris mitigation in the form of post-mission disposal becomes even more uniform as the legal norms strengthen, and the collision probability mounts, it will be increasingly difficult to escape liability for debris impact.

### **Insurance challenges**

Finally, we turn to insurance. We discuss the two types of insurance that are particularly relevant in the orbital debris context: Launch and in-orbit insurance and third party liability insurance. The former protects the owner or operator of the impacted satellite; the latter addresses the liability of the satellite owner/operator whose satellite or debris has caused the impact or collision.

There are more than 500 defunct satellites, over 200 spent rocket stages and thousands of smaller pieces of debris littering GEO. The amount of orbital debris today is double that of 20 years ago and over 30% higher than just five years ago.

## 2. What is happening up there: A technical perspective

### 2.1 Sources of orbital debris

Since 1957, satellites have been launched into a variety of orbits in the pursuit of numerous military, civil and commercial missions. Half a century later, there are more than 16 000 man-made space objects catalogued of which fewer than a thousand are operational spacecraft. Therefore, over 90% of the objects circling Earth consist of orbital debris. Figure 1 shows the different categories of objects in Earth orbit and the relative percentages of each by number.

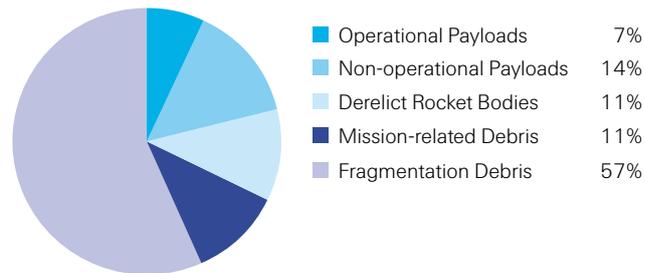


Figure 1. A depiction of the Earth orbit population in 2010, shows that the majority of the objects are fragmentation debris from over 200 breakup events.

#### Factors driving collision hazard

More than half (57%) of the in-orbit population is fragmentation debris. Non-operational satellites and spent rocket bodies together make up only 25% by number while they contribute over 90% of the mass of the in-orbit population. The number of objects in-orbit drive the current collision hazard while the mass in-orbit will drive the future collision hazard since this mass provides a potential source for future debris-generating collisions.

The four categories of debris introduced above are defined as:

- **Non-operational payloads** are those that have completed their design lives or that have malfunctioned prematurely. The typical mission lifetime in GEO is currently about 15 years.
- **Spent (or derelict) rocket bodies** are components of a multi-stage expendable launch vehicle used to place a satellite into orbit that are left in-orbit after a completed launch mission. The lower launch vehicle stages are designed to re-enter over the ocean or uninhabited areas on the ground. Fewer spent rocket bodies are being deposited in GEO as they are now often incorporated into the satellite payload structure rather than being released after satellite deployment.

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## 2. What is happening up there: A technical perspective

- **Mission-related debris** is hardware released as part of the normal deployment and operations of a spacecraft. A typical space mission involves the launch of one or more satellites into orbit while releasing a variety of pieces of hardware along the way from the launch process, such as explosive bolts and adaptor rings. Spent rocket bodies are a special type of mission-related debris treated separately due to their large mass and proclivity to explode. Likewise, once the satellite is placed into its final orbit, hardware may also be released as the satellite is “started up”. This mission-related debris includes lens covers, solar panel clamps and the like. There are even smaller debris particles still (1µm to 1cm) – these result from the deterioration of spacecraft surfaces and remnants of solid rocket motor firings associated with the routine operations of space systems.<sup>8</sup>
- **Fragmentation debris** is created when payloads and rocket bodies explode due to onboard self-destruct devices, over-pressurisation of propellant tanks, inadvertent mixing of hypergolic fuels, anti-satellite testing, accidental collision between orbital objects or overheating of batteries. To date, nearly 200 known debris-generating events have occurred in space. Explosion of rocket bodies has been a major source of fragmentation debris historically, while only four accidental collisions between catalogued space objects have occurred.<sup>6</sup>

Two recent collisions have contributed greatly to the increase in fragmentation debris in LEO: The 2009 accidental collision between an Iridium satellite and the non-functioning Russian Cosmos 2251 satellite generated almost 2000 pieces of debris. And the 2007 intentional in-orbit destruction of the FengYun-1C spacecraft by China, with over 3000 pieces.<sup>2, 16</sup>

While collisions between large objects in LEO may create thousands of smaller fragments, GEO collisions will likely create only hundreds of large fragments. The higher orbital velocity in LEO compared to GEO (7.6 km/s vs 3 km/s) and greater inclinations in LEO (28°–115° vs 0°–15°) make typical collisions in LEO about 400 times more destructive than those in GEO.

Debris comes in many forms, shapes, and sizes, ranging from microns to meters, from paint flakes to school bus-size satellites as shown in Figure 2.

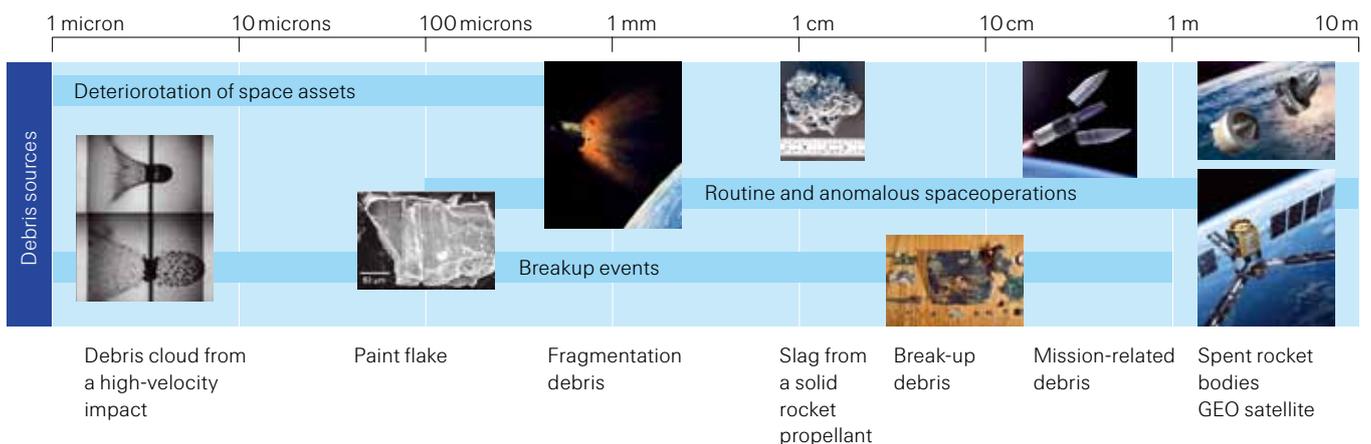


Figure 2. Orbital debris comes from a variety of sources and covers a wide range of sizes.

## 2.2 Key orbital regions

While space is vast, space activities tend to be concentrated in three main regions of Earth orbit. These regions are LEO, semi-synchronous (SSO), and GEO. Each of these three regions has its own benefits and there is little activity outside of these three orbital bands.

LEO comprises all orbits with average altitudes below 2000 km (or 127 minute orbital period). The subset of LEO between 250 km and 450 km is often referred to as the manned spaceflight corridor. This is where the International Space Station is located, where the U.S. Space Shuttle flies and where astronauts conduct extravehicular activity.

LEO is also home to several large communications satellite constellations, such as Iridium.

GEO is a unique orbit at 35 786 km in altitude and zero inclination, so that a satellite remains over a single point along the Earth's equator. Here, satellites orbit the Earth at a velocity corresponding to the Earth's spin. For this reason, GEO is the most popular orbit for large, high-capacity communications, broadcasting and meteorological satellites worth hundreds of millions of dollars.

The sun-synchronous orbit region (generally 600–1100 km and inclinations of 98–100°) is where the commercial remote sensing and imaging satellites are located along with some military reconnaissance and surveillance systems. The combination of orbital period and inclination creates opportunities for these satellites to have repeatable ground passes both geographically and over time. This attribute is optimal for remote sensing applications.

LEO (90–127 min orbital period)		SSO* (12 hr orbital period)	GEO (24 hr orbital period)
250–450 km	600–1100 km	~20 000 km	36 000 km
International Space Station and manned flight	Commercial imaging; Communications satellite constellations; military reconnaissance	Global navigation and positioning	Communications, broadcast, and meteorological satellites
			

\* Semi-synchronous orbit

Figure 3. Key orbital regions for space activity highlight the space missions suited optimally for each.

## 2. What is happening up there: A technical perspective

The U.S. Global Positioning System (GPS) and other dedicated navigation and positioning constellations are located at approximately 20,000 km altitude. This altitude has an orbital period of about one half day (thus the term “semi-synchronous”) and, with moderately high inclinations (~55–65°) this orbit provides persistent global coverage needed for the positioning and navigation services supplied by these platforms.

GEO is a unique orbit at 35 786 km in altitude and zero inclination, so that the satellite remains over a single point along the Earth’s equator. Here, satellites orbit the Earth at a velocity corresponding to the Earth’s spin. Thus they appear fixed with respect to a point on Earth. The orbit is particularly well suited for satellite communications and broadcasting, as the satellites remain stationary with respect to designated ground stations. For this reason, GEO is the most popular orbit for large, high-capacity communications, broadcasting, and meteorological satellites worth hundreds of millions of US dollars.

### 2.3 Who tracks orbital debris?

The U.S. Strategic Command’s (STRATCOM) Space Surveillance Network (SSN) has catalogued and actively tracks over 16 000 objects in space: ~12 000 in LEO, ~100 in Semi-Synchronous Orbit, and ~1000 in GEO. This is in addition to several thousand objects in highly eccentric orbits that cross between LEO and GEO.<sup>21</sup> The SSN is a worldwide network of 15–22 radar and optical sites coordinated with data integration, analysis, and distribution software run by the Joint Space Operations Center (JSpOC). Other space surveillance systems, such as the Russian ISON Network, provide information worldwide on in-orbiting objects. However, the US SSN is the most comprehensive in its collection and distribution of information. An object is considered catalogued when it is tracked reliably enough such that a precise orbit can be determined and updated over time, and thus be included in a “catalogue”<sup>1,2.</sup>

Today, cataloguing capabilities are limited to objects of approximately 10 cm in diameter in LEO and only about 1 meter in GEO. The higher altitude at GEO makes object resolution more difficult with the emphasis being optical detection due to the range limitations of most ground-based radars. Other observation systems augment the SSN, periodically providing a statistical accounting (but not a catalogue) of smaller “trackable” objects: down to 1cm in LEO and 10cm in GEO. For these characterisations, we can estimate the number of objects in these size ranges at given altitudes but cannot determine precise orbital elements for each individual object.

## 2.4 Distribution of objects in LEO and GEO

Of the more than 16 000 catalogued objects, the majority (approximately 12 000) are in LEO. There have been many more reported breakups in LEO than GEO. Objects in LEO are more easily detected and thus catalogued. It is interesting to note that there are about 1600 objects in LEO greater in size than 1m (the smallest catalogued size in GEO); this number would then be much closer to the GEO catalogued population of 1000.

Figure 4 shows the distribution of objects in LEO and GEO, both in terms of the number of objects and mass.

Object Type	LEO (>10 cm)		GEO (>1 m)	
	Number	Mass (kg)	Number	Mass (kg)
Controlled Payloads	~400	~400 000	~350	~600 000
Drifting or Trapped Payloads	~1 600	~800 000	~480	~600 000
Rocket Bodies	~900	~1 100 000	~190	~400 000
Fragmentation Debris	~8 100	~100 000	3	~5
Mission-Related Debris	~1 000	~ 2 000	16	~100
<b>Total</b>	<b>~12 000</b>	<b>~2 400 000</b>	<b>~1 000*</b>	<b>~1 600 000</b>

\* ~2 200 additional detected down to 10 cm

*Figure 4. The distribution of man-made objects in LEO and GEO shows drastically different distributions by mass and number by orbit type.<sup>1, 4</sup>*

### Limited tracking capability in GEO

Catalogued debris in LEO includes approximately 1600 non-functional satellites, 900 spent rocket bodies, 8100 pieces of fragmentation debris, and 1000 pieces of mission-related debris. In GEO, the catalogued numbers are smaller: about 480 non-functional satellites, about 190 spent rocket bodies, only three pieces of fragmentation debris and sixteen pieces of mission-related debris. The relatively small number of catalogued fragmentation and mission-related debris in GEO is largely due to the limited capabilities to reliably track and catalogue small objects in this orbit.

There are roughly the same number of operational satellites in LEO and GEO: about 350–400. Two commercial communications satellite constellations contribute substantially to the LEO population: the Iridium constellation with 66 satellites and Globalstar constellation with 32. The LEO population also includes a number of reconnaissance and surveillance, remote sensing, communications, navigation, and imaging satellites. The largest single object in LEO is the International Space Station, which spans 357.5 feet or 109 metres<sup>17</sup> – one third the height of the Eiffel Tower.

GEO is home to hundreds of large, high-capacity communications, remote sensing, and meteorological satellites used for a variety of purposes including video, data, and voice transmission; weather support; television/audio broadcasting; and broadband applications. The four largest GEO satellite fleet operators include Intelsat with a fleet of approximately 50 satellites, the SES Group with 43, Eutelsat with 26 and Telesat Canada with 12 satellites.<sup>4, 11, 18</sup>

If the primary metric is mass in-orbit, rather than the number of objects, the LEO-GEO distinction is less pronounced: over 2.4 million kg in LEO versus over 1.6 million kg in GEO. This is because the satellites tend to be much larger and heavier in GEO while many of the objects in LEO are less massive debris fragments.

### 2.5 Does debris disappear over time?

Whether debris remains in-orbit for long periods of time depends primarily on the altitude of the object. In LEO orbits below 800–1000km, the objects are affected by atmospheric drag to varying amounts. This means that the atmospheric gases produce a drag force on a satellite which may slowly erode its orbital energy and thus reduce its altitude. Atmospheric drag effects are accentuated when the area-to-mass ratio of the object is high. Intact payloads have very small area-to-mass ratios ( $\sim 0.01 \text{ m}^2/\text{kg}$ ) whereas some debris fragments can have very large values ( $\sim 10 \text{ m}^2/\text{kg}$ ) and are, therefore, affected to a much greater extent by atmospheric drag resulting in shorter orbital lifetimes.

Atmospheric drag effects are absent in GEO due to the lack of an atmosphere at those altitudes, so satellites and large objects will remain at GEO altitudes for centuries, if not indefinitely, unless removed by human agency.

When an object can no longer maintain an orbit, it re-enters the atmosphere and usually burns up. It is estimated that while hundreds of objects re-enter each year, intact remains of space objects strike the Earth only tens of times a year; the vast majority of space hardware burns up during atmospheric re-entry.

Atmospheric drag effects are absent in GEO due to the lack of an atmosphere at those altitudes, so satellites and large objects will remain at GEO altitudes for centuries, if not indefinitely, unless removed by human agency. In summary, large releases of debris from accidental or purposeful events may be cleansed over time by atmospheric drag from LEO but there is no such natural debris removal mechanism at GEO.

### 2.6 Debris mitigation and graveyard orbits

Over the past decades, international organisations, nations, satellite operators and launch-service providers have become increasingly aware of the need to mitigate the growth of space debris. As a result, debris mitigation requirements, guidelines and practices have emerged to guide satellite and launch vehicle operators in their mission planning and the end-of life disposal of satellites and rocket bodies.<sup>21</sup> These guidelines aim to:

- Minimise the release of mission-related debris during nominal missions, for example, by retaining rather than releasing discarded items.
- Prevent spent rocket bodies from exploding due to over-pressurisation, or inadvertent mixture of hypergolic fuels, which may occur if excess fuel from the launch is allowed to remain in the rocket bodies. The guidelines call for venting of excess fuel.
- Remove non-operational satellites from LEO or GEO orbits at end-of-life. The guidelines focus on disposing of GEO satellites in “graveyard” orbits and LEO satellites through re-entry into the Earth’s atmosphere. Iridium, for example, disposes of satellites in its constellation by performing a re-entry manoeuvre. Even when de-orbiting LEO satellites, there are guidelines to keep the risk to people on the ground to a minimum. This is achieved by limiting the amount of hardware that survives re-entry and by directing it to fall in sparsely populated areas such as oceans and uninhabited regions. However, it should be noted that the Globalstar constellation that maintains a fleet of spacecraft around 1400 km in LEO, has opted to move their decommissioned satellites to a LEO “graveyard” orbit around 2000 km in altitude.<sup>22</sup>

### Space in short supply

For GEO satellites, a graveyard orbit is the only option. This typically involves moving a derelict satellite several hundred kilometers above GEO altitude. Satellite operators recognised the scarcity of space in GEO and started moving satellites at the end of their operational life to graveyard orbits above the GEO arc decades ago. The first transfer to a graveyard orbit took place in 1977. Since 1977, about 300 satellites have performed end-of-life manoeuvres to a graveyard orbit.

The current international standard for a graveyard orbit is provided by:  
 (1)  $\Delta H = 235 \text{ km} + (1000 * C_R * \{A/M\}) \text{ km}$

Where

$\Delta H$  = average height of the graveyard orbit above GEO  
 $C_R$  = solar radiation pressure coefficient, ~1.2–1.5  
 $A/M$  = area to mass ratio,  $\text{m}^2/\text{kg}$

The standard formulation begins with a 200 km baseline then a 35 km variation to account for gravitational perturbations plus a variable term for potential solar radiation pressure perturbations proportional to that object's area-to-mass ratio.

Today, disposal of GEO satellites into a graveyard orbit is common practice among satellite operators. The inset displays the international guidelines for executing a graveyard orbit manoeuvre. The U.S. Federal Communications Commission (FCC), which licenses communications satellites, requires that satellite operators describe their "post-mission disposal plans," including the "quantity of fuel – if any – that will be reserved" for an end-of-life manoeuvre. GEO satellite operators must disclose the altitude of the disposal orbit and the calculations that are used in deriving the disposal altitude. The FCC rules fall short of dictating specific debris mitigation requirements. Over the years, debris mitigation has occurred as a result of voluntary initiatives by major satellite operators simply as a matter of self-interest in keeping the orbit clean.

Historically, GEO graveyard orbits have varied widely, as shown in Figure 5. The average disposal orbit was about 375 km above GEO in 2010, above NASA and international guidelines, as shown in the earlier inset.<sup>12, 13, 14</sup> However, not all satellites have made it to a nominal graveyard orbit successfully. The typical propulsive requirement to move a satellite from GEO to a graveyard orbit is 9–12 m/s, usually performed in two burns.

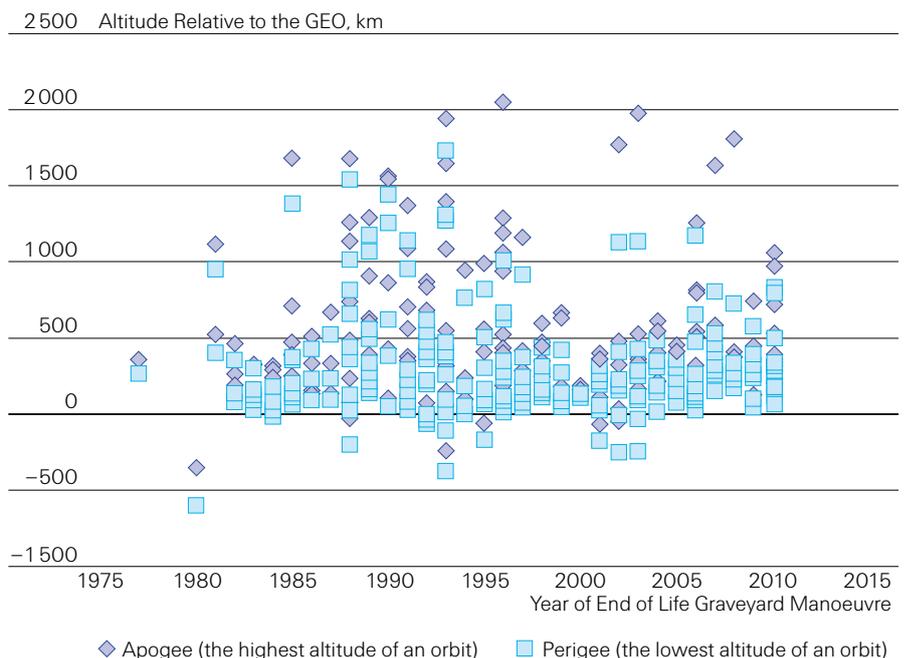


Figure 5. Graveyard orbits are spread across a wide altitude expanse and the average height above the GEO arc is above the nominal 200 km altitude threshold, as described by IADC GEO guidelines. [Data provided by NASA]

In 2009, the FCC expressed concern that decommissioned satellites may still wander back into the GEO orbit if the disposal altitude is too low. And it asked one company proposing a graveyard orbit of 150 km above GEO to submit an analysis of the long-term evolution of the proposed relatively low disposal orbit.<sup>19</sup>

### 2.7 Debris collision risk in LEO

Much has been written about the collision risk in LEO and the results are well documented. For example, in sun-synchronous orbit within LEO, the annual probability of collision of a 1 cm size debris with a 10 m<sup>2</sup> satellite exceeds 0.8%. This is the largest debris collision hazard anywhere in Earth orbit.

There are four major commercial satellite constellations in LEO:

- Iridium, with 66 communications satellites (and seven spares) in 6 polar orbits with 11 satellites in each orbit, at approximately 790 km;
- Globalstar, with 32 communications satellites at about 1414 km;
- GeoEye, with three imaging satellites at 705, 681, and 681 km; and
- Digital Globe, with three satellites at 770, 496, and 450 km.

In sun-synchronous orbit within LEO, the annual probability of collision of a 1 cm size debris with a 10 m<sup>2</sup> satellite exceeds 0.8%. This is the largest debris collision hazard anywhere in Earth orbit.

The annual collision risk for a 10 m<sup>2</sup> satellite across LEO is plotted in Figure 6 highlighting the range of risks. Note that the annual collision risk at 750–900 km is on average seven times greater than at 500 km .

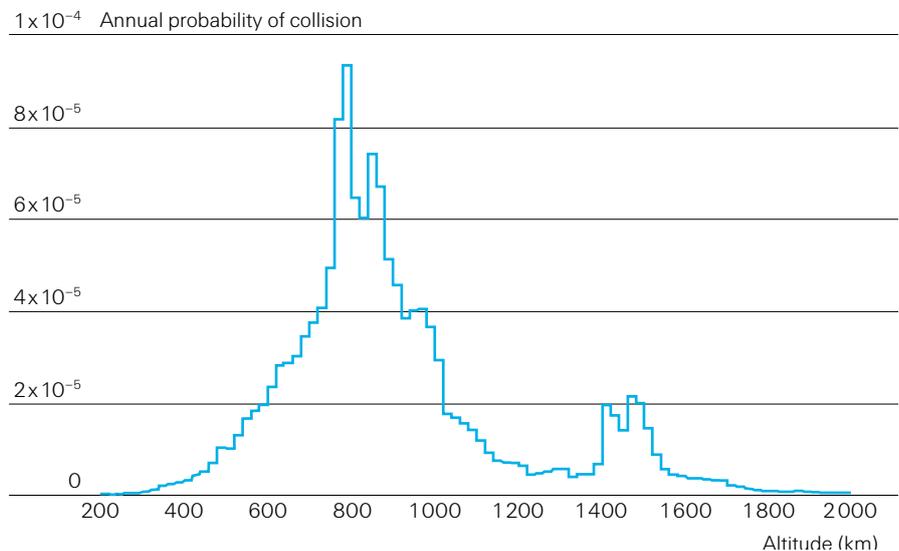


Figure 6. Four major LEO commercial constellations are in considerably different debris environments within LEO. [Collision risk derived from data supplied by NASA]

The variation in collision risk across these satellite constellations is due to objects deposited in the past from breakup events and routine space operations. The 750–900 km altitude range, where the probability of collision peaks, is representative of the sun-synchronous orbit discussed earlier. The drop-off from 800 km to 400 km and below is largely due to the effects of increased atmospheric drag with decreasing altitude.

## 2.8 The GEO population

There are currently about 1000 catalogued objects located along the 265 000km GEO arc. Approximately 350 of the catalogued objects in GEO are operational satellites while the rest are dead satellites, spent rocket bodies, fragmentation debris, and other mission-related debris.

Figure 7 illustrates the GEO catalogued population in two ways: (1) object type, and (2) age. The object type description highlights the large percentage of massive payloads, both operational and non-operational, in GEO. The age of GEO objects accentuates the increased level of activity at GEO with 400 objects being in-orbit for less than 10 years. Coincidentally, while there are 400 objects less than 10 years old, there are about an equal number (350) of operational satellites.

Object type	Payloads ~830			Rocket bodies ~190
	Operational ~350	Inactive ~480		
Age	Less than 10 years ~360	10–20 years ~280	20–30 years ~220	More than 30 years ~170

\* Mission-related debris 16 and Fragmentation debris 3

Figure 7. Catalogued objects in GEO are generally massive payloads that have been deployed in the last ten years. However, the ageing, derelict population is beginning to accumulate.<sup>4</sup>

## 2.9 Forces affecting objects in GEO

While we discuss the “geosynchronous region”, only satellites with exactly a 24 hour orbital period are actually in a geosynchronous orbit. In addition, if a satellite is both geosynchronous and has a zero degree inclination, it becomes a geostationary orbit. A geostationary orbit remains above the same point along the equator throughout its transit. However, there are many objects in the region that still pose a collision hazard to the station-kept satellites maintained precisely along the GEO arc. The objects that are considered to be “drifting” relative to the GEO arc have this relative motion due to their average altitude differing from the 35 786 km altitude.

Objects that have an average altitude less than the GEO arc will have a shorter orbital period and will thus appear to drift east relative to the GEO arc (i.e. they move faster). Conversely, the objects with an average altitude greater than the GEO arc will appear to drift west relative to the station-kept population. Of the over 500 objects in the geosynchronous region that are drifting relative to the GEO arc more than 100 actually cross the GEO arc and another 100 objects cross within 200 km of the GEO arc. These drifting objects, therefore, slowly encounter all parts of the GEO arc over time sharing the space with the nearly 350 operational geostationary satellites.

There are two main types of forces that drive the dynamic behaviour of geostationary satellites: east-west and north-south drift. Operational satellites counter these drifts by performing propulsive station-keeping manoeuvres.

## 2. What is happening up there: A technical perspective

### East-west drift: The Geopotential Wells

Due to the non-spherical nature of the Earth there are gravitational forces that pull objects toward two so-called “geopotential wells” along the GEO arc.

The centres of the two “wells” are at 75°E and 105°W. If objects are abandoned in a GEO slot, they will naturally be “captured” in the closest geopotential well and will continuously oscillate about the centre of the well for eternity, transiting longitudes only near those wells. To complete one full cycle across a geopotential well takes two–five years, depending upon the range of the oscillation. There are about 160 objects “trapped” in the wells, while 18 of these objects oscillate through both geopotential wells before eventually turning around and heading back the other direction.

Trapped Object	75° East Well	105° West Well	Trapped in both Wells
Payload: Largely Radugas (29), Gorizonts (9) and Ekrans (8)	83	39	15
Rocket Body: Largely Proton-K Fourth Stages	17	3	3
Debris: 2006 Feng Yun and 1978 Ekran 2	2	0	0

Figure 8. Objects in the geopotential wells, especially the West well, are mostly abandoned payloads.<sup>4</sup>

### North-south drift

If a GEO satellite has a non-zero inclination, then each day it will transit north-south latitudinal limits equal to its inclination. Due to the orientation of the Earth’s orbital plane relative to the Sun, there is a long-term cyclical perturbation on GEO objects; this force will cause the orbital inclination of an object left unattended to go from zero to 15° over 26 years and then back to zero again in another 26 years. It is interesting to note that if a satellite operator deployed their satellite into a 7.5° inclination orbit then the solar gravitational effects would work to keep the satellite exactly at 7.5° inclination.

Figure 9 shows the current population of abandoned objects near the GEO altitude, highlighting that the first objects abandoned in GEO have been up there for more than 26 years so they have progressed up to the maximum 15° inclination and are now actually migrating back to lower inclinations. While this trend seems imposing, the overall effect on collision hazard in GEO is minimal.

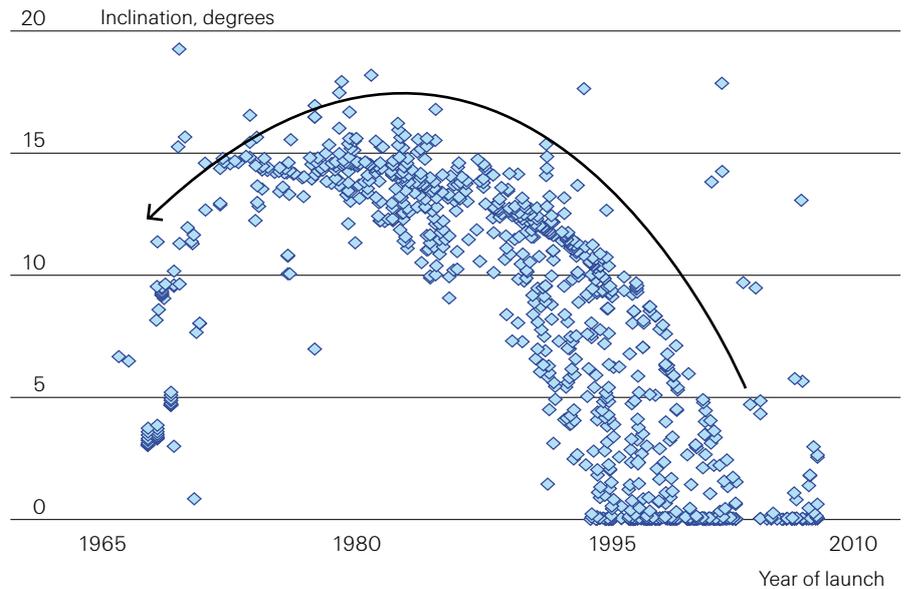


Figure 9. An abandoned GEO object will have its inclination drift up to 15° then back toward 0° in a cyclical fashion over 52 years.

## 2.10 Collision hazard in GEO: Risk factors

Collision hazards to operational satellites in GEO are posed by uncontrolled satellites, spent rocket bodies and other debris, that are drifting along the entire GEO arc or are trapped in the geopotential wells. These additional risk factors may increase the hazard, namely:

- 1) The potential for satellite break-ups and rocket body explosions;
- 2) An estimated 2200 pieces in the 10 cm–1 m size range that have been detected, but not catalogued, and whose source are not well understood; and
- 3) Satellites disposed in graveyard orbits and objects breaking off may dip close to or across the GEO arc.

Operational, station-kept satellites do not pose a hazard to other operational spacecraft since they have no chance of colliding with one another while they are operating properly within their assigned positions; that said, these satellites are potential collision targets for GEO debris.

Collision hazards to operational satellites in GEO are posed by uncontrolled satellites, spent rocket bodies, and other debris, that are drifting along the entire GEO arc or are trapped in the geopotential wells.

## 2. What is happening up there: A technical perspective

### Objects trapped in the geopotential wells

Objects trapped in the two geopotential wells do not transit the entire GEO arc, so they pose a hazard only to operational GEO satellites located near the geopotential wells. For example, the majority of the objects trapped in the Eastern geopotential well (at 75°E) oscillate between 60°–90°E while the trapped object with the greatest range in longitude moves from 355°W to 155°E. Even though this trapped population of about 170 objects is only roughly 15% of the GEO catalogued population, they do pose a substantial hazard to operational satellites. This is because trapped objects have altitudes less than 40–80 km above or below the GEO arc. If an object's altitude varies by more than this it will not be affected enough by the geopotential wells as to force them into oscillating orbits. As a result, they will simply drift relative to the GEO arc, either eastward (if lower than GEO arc) or westward (if higher than GEO arc).

### Payload breakups

While orbital breakups are considered to be a significant contributor to the orbital population in LEO, so far, only one payload breakup is known to have taken place in GEO when the battery casing for an Ekran satellite ruptured. Some researchers have inferred from observational data that there may have been several more.<sup>3,4</sup> Objects created from a breakup event in GEO are affected by the same two major orbital perturbations discussed above: east-west and north-south drift.

### Spent rocket body explosions

In examining GEO, the population of 190 rocket bodies residing near the GEO arc is troubling. Historically, the explosion of rocket bodies has been a major contributor to the debris environment with nearly 100 rocket body fragmentations leading to nearly 40% of the total in-orbit population catalogued, mostly in LEO. Many of these events happened years after the rocket body's release in-orbit. While about a third of the rocket body explosions occurred soon after satellite deployment, the remaining events occurred on average 7 years after last use and one even occurred 24 years later.

The explosion of rocket bodies has been a major contributor to the debris environment with nearly 100 fragmentations leading to nearly 40% of the total in-orbit catalogued population.

These derelict rocket bodies orbiting in or near the GEO arc have an average age in-orbit of 23 years. Although one of the only two confirmed breakups at GEO was the explosion of a Titan Transtage, the remaining 190 derelict propulsive devices possess the potential for future explosive events (without any collisions taking place) since there are 33 more Titan Transtages drifting in GEO. There are also nearly 140 Proton-K 4th Stages (Block DM) abandoned in GEO; this type of hardware has also had numerous breakup events detected in LEO.

### 2200 detected, but uncatalogued objects.

Approximately 2200 objects between 10 cm and 1 m in size have been detected in GEO, but they have not yet been catalogued. These uncatalogued objects may have been created from breakup events or the result of objects released during routine deployments.<sup>1,2,3,9,19</sup> Objects in the graveyard orbits, just above the GEO arc, are especially suspected of contributing to this "new", dynamic population. Objects in the graveyard orbit may be physically degrading under the influence of solar radiation that over long periods of time makes material weaker and more brittle. In combination with the thermal cycling of satellites (i.e. as they move in and out of the sunlight), the sloughing off of sheets of insulation and pieces of hardware are possible. We see many of these same effects in LEO and as these massive objects age this concern will only grow. These objects pose a collision hazard to objects in the GEO arc; the numbers and behaviour of this potentially highly dynamic population are still being studied.

## Calculating collision risk in GEO

Collision hazard calculations in GEO are based on the kinetic theory of gases whereby it is assumed that objects are randomly distributed and can all pose a collision risk to each other. [Ref. 10] The probability of collision (PC) equation for GEO, as well as for LEO, is:

$$PC = 1 - \exp(-VR \cdot SPD \cdot [AC/1\,000\,000] \cdot T) \approx VR \cdot SPD \cdot [AC/1\,000\,000] \cdot T$$

Where

VR = relative collision velocity, km/s

SPD = spatial density, #/km<sup>3</sup>

AC = collision cross-section of satellite at risk, m<sup>2</sup>

T = time at risk, sec (1 year = 31 557 600 sec)

The four key parameters of the PC calculation are defined below.

*Relative Velocity (VR).* The relative collision velocity is determined by the orbital velocity of colliding objects and the angle at which the two objects strike. Collision velocities in GEO are on the order of ~150–800 m/s with an average around 500 m/s.

*Spatial Density (SPD).* The spatial density is determined by first creating a “risk cell” with a length along the GEO arc of 736 km (equivalent to 1° in longitude), depth of 400 km in the altitude dimension (i.e. ± 200 km), and a height of 736 km (equivalent to 1° in latitude) as shown in Figure 10. These dimensions were selected to be consistent with standard definitions of the GEO regime. [Ref. 4 and 12] The volume of a single GEO “risk cell” is about 43 million km<sup>3</sup> and 360 of these cells comprise the entire GEO arc.

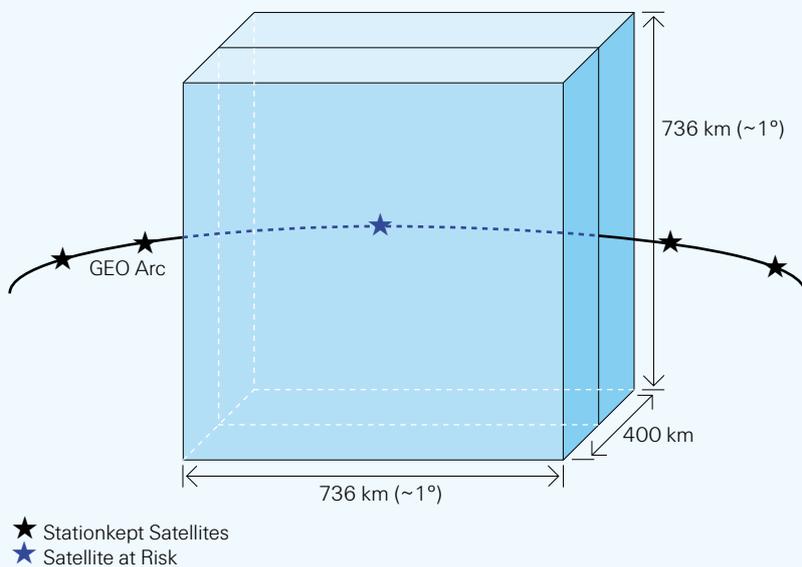


Figure 10. A risk cell is defined as a subset of the GEO arc to permit a longitudinally-dependent probability of collision value to be calculated.

## 2. What is happening up there: A technical perspective

The number of objects within each cell is calculated by determining the amount of time each type of object – trapped and drifting – reside in each cell, and each of the contributions is summed. The amount of time spent in the cell is the product of the three percentages of time in each dimension:

- In longitude – clumped for trapped objects but along the entire GEO arc for drifting objects;
- In altitude – determine for each object but >95% of trapped and 60% of the drifting objects stay within the  $\pm 200$  km span; and
- In latitude/inclination – all objects with inclinations above  $0.5^\circ$  spend time outside of the risk cell contributing significantly to the reduction of collision hazard.

The total number of “objects” in each cell is then divided by the volume of the cell to determine the spatial density. The spatial density for this analysis has been modified to eliminate station-kept satellites and account for the longitudinal bunching of trapped objects.

Collision Cross-section (AC) is a measure of how the sizes of two impacting objects will interact during a collision and is dependent on both the impacted satellite and the object hitting it. A  $100\text{ m}^2$  value is used as a nominal value for AC in the calculation of PC since the average AC between the 50 targets objects in GEO is roughly  $100\text{ m}^2$ .

*Time at Risk (T)* The time at risk for a station-kept satellite in the cell is one year for the annual probability of collision.

## 2.11 Debris collision risk in GEO

The annual probability of collision (PC) for any station-kept satellite as a function of longitude is now calculated and the results are summarized in Figure 11. Contributions from the trapped and drifting objects are shown separately, highlighting the importance of the trapped objects to the overall calculations. It is seen that the worst case PC at the centre of the wells is a factor of seven greater than the longitudes far from the geopotential wells.

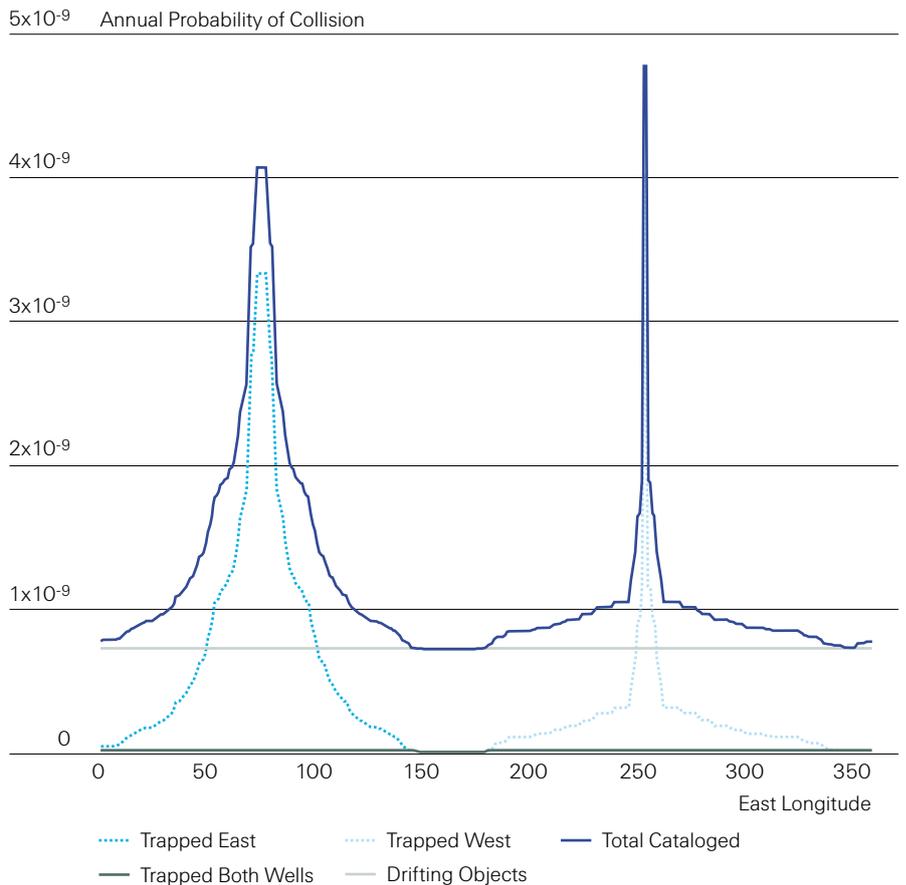


Figure 11. The collision hazard, formulated for the first time and accounting properly for trapped objects and station-kept satellites, is lower than previous calculations.

As shown, the annual probability of collision from the catalogued population for a station-kept satellite at the center of a geopotential wells exceeds  $4 \times 10^{-9}$ . This is equivalent to one chance in 250 million of a collision between an operational satellite and a catalogued object over a year's time. However, the probability that any two catalogued objects will collide each year is  $1.5 \times 10^{-8}$  or one chance in 75 million.

Considering the estimated 2200 objects larger than 10 cm but not catalogued, the probability of collision between any two of these objects increases to  $7 \times 10^{-6}$  per year or one chance in 150 000 each year.

## 2. What is happening up there: A technical perspective

The comparison of probabilities highlights the uncertainty attempting to predict the frequency of an event that has not occurred on a regular basis, if at all. The uncertainty in those predictions may be fairly large. For example, when having only one occurrence for an event that we wish to predict in the future, the uncertainty in the predictions will be a factor of 1000. This means that a single event could indicate a collision rate anywhere between 0.01 and 10. As events start to occur, the uncertainty bands will gradually reduce. Further, after five events have occurred, the uncertainty in the collision rate will only be a factor of ten.<sup>19</sup>

However, the collision between two objects in GEO would likely increase the overall GEO hazard. While it would take several breakups at and around the GEO arc to increase the average GEO collision hazard to levels that currently exist in LEO, the geopotential well configuration will always make the average somewhat less relevant since the maximum at the wells will accumulate so much more quickly, as was evidenced from the PC values at the centre of the geopotential wells versus the rest of GEO.

### Micrometeoroid hazard

The impact hazard from the natural micrometeoroid environment in GEO is still not well understood despite the decades of operations in space. What is known is that for the smaller size range (centimeter and below) the natural micrometeoroid population exceeds the manmade space debris population in GEO. That used to be the case in LEO, where now the debris hazard exceeds the meteoroid hazard for all particle sizes above 10 micron. The complexity of determining the cause of impact-induced satellite failures in the future will be complicated by uncertainties in failure mode analysis due to:

- Small impactors on large, complex GEO satellites;
- Unclear relationships between physical impacts and electrical failures;
- The uncertainties in the micrometeoroid environment and
- The escalating space debris hazard in GEO.<sup>22</sup>

### To sum up:

- The probability of collision in GEO is not uniform by longitude; it is seven times greater in regions centred about the so-called “geopotential wells,” where drifting satellites and other debris tend to accumulate while satellites worth hundreds of millions of dollars continue to operate.
- Although the current probability of collision in GEO has been assessed as relatively low, future projections are difficult to make due to our limited ability to observe objects in GEO and the uncertainty surrounding past and future debris-generating events.<sup>5, 11, 18</sup> True risk projections therefore must factor in:
  - Approximately 2200 objects in the 10 cm–1 m range that have been observed in GEO, but not yet catalogued;
  - Hardware in GEO “graveyard” disposal orbits that may be shedding highly mobile debris whose secondary risk to operational GEO satellites is not fully understood; and
  - The potential explosion risk posed by nearly 200 spent rocket bodies in GEO
- The collision risk in GEO is likely to increase over time despite current efforts to move decommissioned satellites to a graveyard orbit since there is no natural orbit clearing mechanism at GEO – such as atmospheric drag in LEO – to remove debris, and there is continual strong interest in deploying satellites to GEO.

*Space debris, in this case a foot restraint that strayed from the Challenger Shuttle in February 1984.*



## 3. From a legal vantage point: A hypothetical case

### 3.1 The scenario

It is 5:00 am GMT. The news breaks that two large communications satellites – ALPHA-5 and OMEGA-1 – have collided in the geostationary orbit, generating hundreds of pieces of debris. The report puts the estimated value of the recently-launched ALPHA-5 at close to USD 400 million and estimates revenue losses in the billions of US dollars. OMEGA-1 was long past its 15-year design life and had been drifting for about three months before the collision.

#### **Ageing satellite**

Alpha Ltd., registered in the English Channel Island of Guernsey, owns what is left of ALPHA-5, now just drifting debris. The satellite was operated by Alpha's wholly owned UK-registered and licensed<sup>1</sup> subsidiary as part of Alpha's 5-satellite fleet. OMEGA-1 was owned by Omega LLC, a U.S. entrepreneurial start-up company with its main offices in Los Angeles. Omega's business is to acquire inexpensive, ageing satellite assets, 13 years or older, and push the boundaries on their typically 15-year design lives. Omega operated OMEGA-1, which was launched from the U.S., from a geostationary slot licensed to it by the U.S. Federal Communications Commission (FCC).

#### **Circumstances surrounding collision unknown**

Alpha's CEO learned of the collision only an hour before the story broke, when he received a call from Alpha's satellite control centre. The CEO convened an emergency meeting that morning in London, the home of most of Alpha's officers and directors. Alpha's CTO, risk manager, communications director, CFO, and general counsel, a U.S.-educated lawyer, are all present.

The drafters of the treaty shed little light on the meaning of “fault” and the term as it appears in the treaty has never been tested in a formal way.

The facts regarding the collision at this point are sparse, although Alpha's CEO is in constant communication with U.S. Strategic Command Support Office for updates. All that is known is that the U.S. Joint Space Operations Center had been tracking OMEGA-1 and ALPHA-5 along with over 20 000 other space objects<sup>2</sup> prior to collision, and that neither Alpha nor Omega had been alerted. Also known is that the debris clouds generated by the collision are spreading along the GEO arc, with each of the hundreds of fragments crossing through the altitude of the operational satellites on a daily basis.

#### **Expired insurance coverage**

Among the first questions the Alpha CEO puts to the risk manager is: “Are we insured for this?” The risk manager has a sinking feeling: The insurance policy for ALPHA-5 had expired. Alpha had purchased satellite launch-plus-one-year “all risk” coverage. The policy expired seventy days before the collision. In a cost-saving measure, despite advice from its insurance broker to the contrary, Alpha had decided not to renew the policy and instead assume the risk of any satellite failure after one year. Alpha's CTO and risk manager had concluded that given the track record of the ALPHA-5 satellite model and payload, this was an acceptable risk. The debris collision risk had seemed so small as to be negligible.

Alpha's CEO can recall the discussion about insurance, but not the details of the decision not to buy insurance beyond one year. After a lengthy discussion with the CFO and communications director regarding disclosure, investor relations, and damage control, he next turns to the general counsel: "What are our legal options?" The counsel explains:

"There are two possible approaches: 1) Request the UK (and not Guernsey<sup>3</sup>) to bring a claim on our behalf under the United Nations space treaties through diplomatic channels between nations; or 2) Bring a tort claim against Omega in a U.S. domestic court, e.g., a California court. Either way, Alpha may need to prove that Omega was at fault. We can't pursue both tracks at the same time. There does not appear to be a basis for legal action against OMEGA-1's manufacturer as there is no indication of defect or malfunction."

### 3.2 The international legal track: UN Space Treaties – U.K. versus the USA

The Outer Space Treaty<sup>4</sup> of 1967 and the Liability Convention<sup>5</sup> of 1972 are the key treaties governing liability in space. The Outer Space Treaty, Article 7, and the Liability Convention hold a "launching state" liable for damage caused by its "space object" to a space object of another launching state.<sup>6</sup> Both ALPHA-5 and OMEGA-1 qualify as "space objects" as defined in the Liability Convention.<sup>7</sup> The U.S., Guernsey (a British Crown Dependency<sup>8</sup>), and the U.K. may all qualify as launching States, at least if we assume that both Alpha and its operating subsidiary "procured" the launch of Alpha.<sup>9</sup> A nation is responsible, and thus may be held liable, for its national activities in space, including those of private companies, according to the Outer Space Treaty.<sup>10</sup> Accordingly, the U.S. would be responsible for the conduct of Omega which led to the damage.

#### No clear definition of "fault"

The treaties require proof of fault for liability to attach when the damage occurs in space. Article 3 of the Liability Convention makes "fault" an express requirement, but fails to define the term.<sup>11</sup> The drafters of the treaty shed little light on the meaning of "fault" and the term as it appears in the treaty has never been tested in a formal way. Carl Christol, in *The Modern International Law of Outer Space*, suggests that if the drafters (representing many different countries and legal systems) had tried to define this term, they would still be working on the Convention.<sup>12</sup>

Accordingly, we are left with other means of treaty interpretation, including dictionary definitions to find the plain meaning of the word and searching for contextual clues in the Convention itself.<sup>13</sup> Black's Law Dictionary defines fault as "[a]n error of judgment or of conduct; any deviation from prudence or duty resulting from inattention, incapacity, perversity, bad faith, or mismanagement."<sup>14</sup> Article 5 of the Liability Convention uses the term "gross negligence" in another context, which suggests that fault is something other than gross negligence.

#### Diverging interpretations

There are indications that the U.S. government, in connection with the ratification process for the Liability Convention, equated fault to negligence<sup>15</sup> but, even so, the interpretation of one country is obviously not determinative.<sup>16</sup> Furthermore we cannot assume that the reference point for "fault" should be the Anglo-American "negligence" rather than the civil law standard of culpa. Culpa is the failure to act as the "reasonable man" under the circumstances; the question is whether the reasonable man would have foreseen the likelihood of harm and acted differently.<sup>17</sup> Negligence is a less flexible term; it requires the existence of a duty, based on law or custom, and the breach of that duty.<sup>18</sup>

Alpha would oppose the use of the Liability Convention by a California court on the grounds that the treaty is not applicable law in the U.S., as it is not “self-executing” and has not been implemented in U.S. legislation.

By contrast to the fault requirement for liability for damage in space, launching states are “absolutely liable” for damage to property on the Earth’s surface.<sup>19</sup> In other words, it is not necessary to show fault for damage done to property on the ground. For example, injury or damage on the ground in a foreign country caused by debris from a failed launch would as a rule subject the launching State to absolute liability.

The remedy for liability under the Liability Convention is payment or other damages “in accordance with international law and the principles of justice and equity, in order to ... restore the person ... to the condition which would have existed if the damage had not occurred.”<sup>20</sup> It is not clear how far this restoration principle extends and whether it would cover, eg, lost revenue and profits or other damages that may be recovered under the U.S. or other national legal system.

If Alpha decides to use the UN treaty track to file a claim, it would need to appeal to the United Kingdom (probably not Guernsey<sup>21</sup>) to bring a claim on Alpha’s behalf against the U.S.<sup>22</sup> Alpha could not bring a claim under the treaties in its own right against the U.S. or Omega; only States can make claims under these treaties.<sup>23</sup>

A claim for compensation for damage to ALPHA-5 would have to be presented through diplomatic channels according to the Liability Convention.<sup>24</sup> The statute of limitations, or deadline, is one year from the date of the collision.<sup>25</sup> If the U.S. and the U.K. are not able to resolve the matter through diplomatic talks, the Liability Convention provides a dispute resolution mechanism in the form of a three-member international tribunal, called the Claims Commission, tasked with resolving the dispute.<sup>26</sup>

To our knowledge, the Liability Convention has been invoked formally only once. In 1979, Canada claimed CAD 6 million under the Liability Convention for damage caused by radioactive debris from the re-entry of the Soviet Cosmos 954, an ocean surveillance satellite.<sup>27</sup> The satellite, with a uranium-235 isotope nuclear reactor on board, disintegrated as it re-entered the atmosphere and Canadian airspace.<sup>28</sup> Radioactive debris surviving the re-entry was scattered over large areas of the Canadian North West Territories, Alberta and Saskatchewan.<sup>29</sup> The CAD 6 million claim was reported to represent the clean-up costs.<sup>30</sup>

The Soviet Union contended that the debris posed no harm to Canada and its citizens.<sup>31</sup> Two years later, in 1981, Canada and the Soviet Union settled the claim at CAD 3 million,<sup>32</sup> with no admission of liability on the part of the Soviet Union.<sup>33</sup>

### 3.3 The national legal track: A tort claim in a California court: Alpha versus Omega

The other option is to bring a claim against Omega in a California federal court<sup>34</sup> based on California state tort law. The Liability Convention specifically allows for a claim in a local court as an alternative to the treaty process: “Nothing in this Convention shall prevent ... natural or juridical persons ... from pursuing a claim in the courts or administrative tribunals or agencies of a launching State.”<sup>35</sup> The U.S. is a launching State for OMEGA-1.<sup>36</sup> California is the domicile of Omega and it has a reputation as a plaintiff-friendly jurisdiction. Omega may still challenge the court’s jurisdiction and suitability, as well as the application of California law to a collision in space.

It will be hard for Omega to successfully challenge the California federal court’s jurisdiction,<sup>37</sup> given Omega’s domicile in California, which establishes personal jurisdiction,<sup>38</sup> and the international character of the dispute and the significant amount of money involved, which gives the court subject matter jurisdiction.<sup>39</sup> Omega may argue that even if a California court has jurisdiction, a court in the U.K. (or Guernsey) would be more suitable (*forum non conveniens*).<sup>40</sup> The court would look at several factors, including the adequacy of litigation forums in foreign courts.<sup>41</sup> It is the rare case that is dismissed for *forum non conveniens*, as the doctrine is “an exceptional tool to be employed sparingly.”<sup>42</sup>

Even though the California court may have jurisdiction and be suitable, it is not a given that California law will apply. Omega may challenge the extraterritorial application of California tort law – to a collision in space; it might argue that space is a *res communis* and that U.S. law does not apply there<sup>43</sup> and that the satellite had been abandoned and was no longer operated from California so therefore there was no basis upon which to extend California law to outer space.

#### Conflicting interests of litigants

Even if this challenge does not succeed, Omega may still urge the court to instead apply U.K. law, Guernsey law, or the “fault” standard of the Liability Convention, especially if these impose a greater burden on Alpha and allow less damages. Traditionally, U.S. courts applied the law of the place of the tort (*lex loci delicti*). California abandoned that approach in the landmark 1967 California Supreme Court case, *Reich v. Purcell*, in favour of the more nebulous “governmental interest” approach.<sup>44</sup> The court looks to determine what law most appropriately addresses the concerns of countries and litigants involved.<sup>45</sup> Alpha would presumably oppose the use of the Liability Convention by a California court on the grounds that the treaty is not applicable law in the United States, as it is not “self-executing” and has not been implemented in U.S. legislation.

If California law applies, a tort claim for negligence would require Alpha to show that: 1) Omega had a duty to avoid the collision with ALPHA-5; 2) Omega failed to conform to a required standard of conduct in light of that duty; 3) A reasonably close connection between Alpha’s conduct and the collision (“proximate cause”); and 4) Alpha suffered an actual loss as a result of the collision.<sup>46</sup> One way to satisfy the first two prongs is to show that Omega violated the law; the violation caused the collision; the law was intended to prevent such collisions; and Alpha is of a class the law aims to protect.<sup>47</sup> This is called negligence *per se*.

Alpha can explore other causes of actions under California law. It will be a challenge to find a cause of action that does not require Alpha to show negligence in this case.

### 3.4 Requirements for liability: Was Omega's conduct wrongful?

Regardless of whether Alpha uses the treaty track or the U.S. courts, it will have to show that Omega was in the wrong. The particular legal standard (fault, negligence, culpa, or some other standard) and the burden of proof will vary, depending on the applicable law.

One way to establish a wrongful act or omission is to show that Omega violated legal norms for conduct in space, especially for the disposal of satellites at end-of-life. Depending on the nature and strength of these norms – a moral imperative or binding legal requirement – the norm may not be sufficient to support liability.

#### **International guidelines on debris mitigation**

Apart from the Outer Space Treaty and Liability Convention, which concern State liability for damage caused by satellites in space, there are no treaties regulating space debris, but there are non-binding international guidelines. For example, in December 2007, the United Nations General Assembly endorsed the debris mitigation guidelines adopted by its Committee on the Peaceful Uses of Outer Space (UNCOPUOS).<sup>48</sup> The guidelines direct satellite and launch vehicle operators to consider measures to “limit the probability of accidental collision[s] in-orbit”.<sup>49</sup>

In 2010, the International Telecommunication Union<sup>50</sup> recommended “that before complete exhaustion of its propellant, a geostationary satellite at the end of its life should be removed from the GSO region” and be boosted to a “graveyard” storage orbit, “such that under the influence of perturbing forces on its trajectory, it would subsequently remain in an orbit with a perigee no less than 200 km above the geostationary altitude.”<sup>51</sup>

While these guidelines clearly dictate debris mitigation measures that Omega did not take, they are not binding law, and violation of these rules would in and of itself probably not be a sufficient basis for liability. Alpha would argue that the requirement to boost a satellite to graveyard orbit by now has attained the status of customary international law, which is binding. This is debatable.

The remedy under the Liability Convention is payment or other damages “in accordance with international law and the principles of justice and equity, in order to ... restore the person ... to the condition which would have existed if the damage had not occurred”. It is not clear how far this restoration principle extends.

### **U.S. regulations on debris mitigation**

As noted, Omega was operating under an FCC license. FCC regulations require companies applying for a satellite license to describe the operational strategies they will use to mitigate orbital debris.<sup>52</sup> This includes detailing the post-mission disposal plans for the satellite at end of life, “including the quantity of fuel – if any – that will be reserved for post-mission disposal manoeuvres.”<sup>53</sup> The statement “must disclose the altitude selected for a post-mission disposal orbit and the calculations that are used in deriving the disposal altitude.”<sup>54</sup> Omega would have had to comply with this requirement to obtain a license.

The FCC does not specify a post mission disposal altitude. The FCC noted as early as 2004 that the “current practice of several U.S. operators is, barring catastrophic hardware failures, to execute end-of-life manoeuvres that result in a disposal altitude of no less than 150 kilometers above [the geostationary altitude].”<sup>55</sup> It said that large satellite operators, such as Intelsat and SES Americom, boost their satellites 300 km above the geostationary orbit.<sup>56</sup>

Alpha would argue that Omega violated its FCC license and the FCC requirement to comply with the debris disposal plan outlined in the license, which was intended to protect other satellite operators, such as Alpha, from precisely this sort of collision; therefore Omega was negligent. Omega would argue that the FCC requirement was merely one to supply information about planned post-mission disposal and that there was no hard legal requirement to boost the satellite to a higher orbit (although Omega had disclosed to the FCC that it had used up some of its fuel reserve before suddenly losing contact with the OMEGA-1). Omega would maintain that if the FCC had intended a legal requirement to boost the satellite to graveyard orbit, it would have imposed one.

In any event, Omega would assert there are no grounds for negligence because the damage to ALPHA-5 was too remote; there was no “proximate cause” (a legal doctrine that cuts off liability for consequences that are so far removed from the conduct at issue that there is no justification for imposing liability).<sup>57</sup> Alpha would reject the argument.

Whatever the outcome of Alpha v. Omega or United Kingdom v. United States., what is clear is this: As debris mitigation in the form of post-mission disposal becomes even more uniform and universally adhered to – and as the collision probability mounts – it will be increasingly difficult to escape liability for debris impact.

*In sun-synchronous orbit, the Soil Moisture and Ocean Salinity (SMOS) satellite was launched in 2009.*



## 4. Insurance considerations

Two types of insurance contracts are particularly relevant in the orbital debris context: Launch and in-orbit insurance, and third party liability insurance. The former protects the owner or operator of the impacted satellite; the latter is designed to cover or address liability of the satellite owner/operator whose satellite or debris is considered responsible for the impact or collision.

### 4.1 Launch and in-orbit insurance

In the hypothetical scenario presented in Section 3, one of the first questions Alpha asked after its satellite was damaged by the collision was: Is the satellite insured? Unfortunately, in that scenario Alpha's insurance had expired. The type of insurance that would have protected Alpha in this situation – where Alpha's satellite was lost as a result of the debris collision with the drifting satellite – OMEGA-1 – is described as in-orbit insurance.

Launch and in-orbit insurance are typically purchased by insureds as combined policies, i.e. coverage commences at intentional ignition of the launch vehicle engine and extends to the "life" of the satellite, the duration being predetermined by the insured and insurer.

The policy can be described as an all risk policy designed to cover loss, damage, malfunction or any defect that impacts the operation of the satellite. In the context of debris or collision, such a typical policy definition in terms of trigger would conceivably also extend to cover "accidental loss or damage" from any form of space debris that may collide with the insured's satellite during either the launch or, more realistically, during the in-orbit phase of coverage.

Importantly, launch and in-orbit policies provide first party property insurance responding in the event of loss or damage to the satellite and are typically purchased by the owner or operator of the satellite. While some of the larger satellite operators may elect to self insure at least the in-orbit phase (essentially the remaining operating life of the satellite), satellite operators generally purchase coverage for one-year following successful launch. Although subject to prevailing market conditions, in-orbit coverage in conjunction with launch coverage, may be acquired for a period up to five years. Alternatively, one year in-orbit coverage may be renewed and extended on an annual basis.

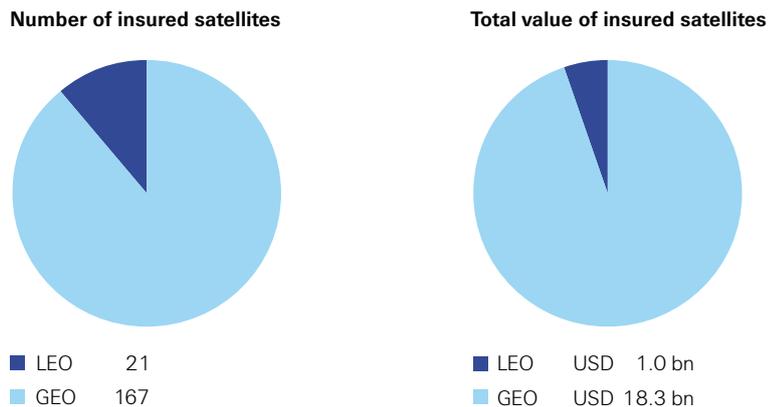


Figure 12. Most insured satellites are in GEO (as of 2011)

#### Current assessment of debris risk

Historically, the insurance market has considered the debris risk, especially in GEO, to be low in terms of probability of collision between a satellite and a piece of debris or collision between two satellites. This assessment by insurers also extended to debris risk in more exposed locations such as geopotential wells.

With recent developments (e.g. Galaxy 15) and the resultant heightened awareness, insurers are reassessing their potential exposure to damage as a result of collision.

#### Types of losses covered by the launch and in-orbit policy specific to collision

In that they are first party property policies, launch and in-orbit policies typically respond to partial, total and/or constructive total losses. Damage to an insured satellite as a result of collision with debris, obviously, must meet or conform with the loss criteria detailed in the policy wording.

The loss criteria (or policy triggers) are carefully defined in terms of the loss of capacity and/or lifetime of the insured satellite and vary according to the payload of the satellite and the satellite's mission (i.e. broadcasting or remote sensing).

In the Alpha hypothetical, the satellite would have qualified as a total loss. Had the satellite been hit by a tiny paint flake, according to the trigger under the policy, it may have qualified as a partial loss, depending on the extent of the damage.

Historically, the insurance market has considered the debris risk to be low in terms of probability of collision between a satellite and a piece of debris. With recent developments and the resultant heightened awareness, insurers are reassessing their potential exposure to damage as a result of collision.

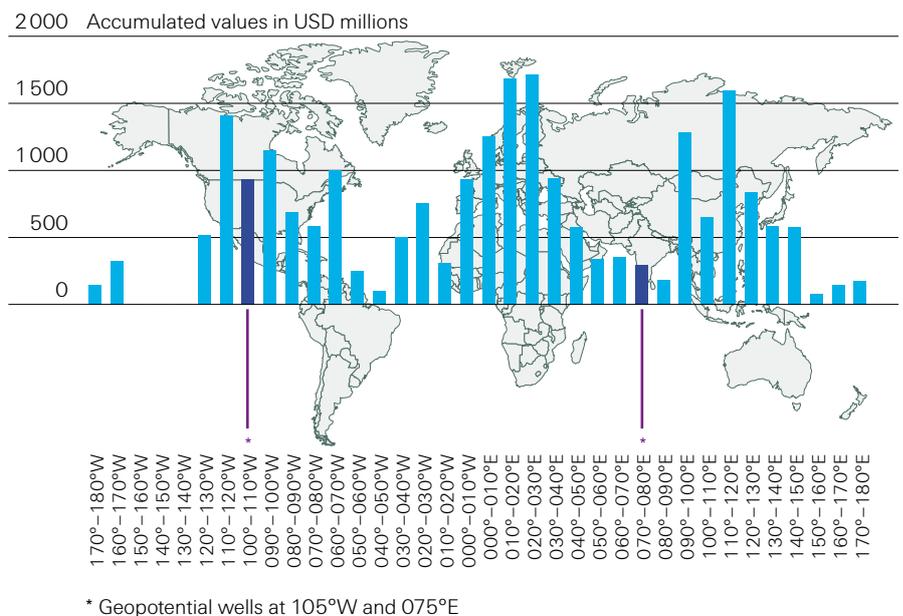
### Agreed value policies

Satellite insurance policies are written on an agreed-value basis which in turn is usually determined by reference to the net book value or replacement costs of the satellite in addition to the cost of launching the replacement satellite. As the policy responds to a loss on an agreed value basis, the fact that the sum insured may depreciate over time following launch is irrelevant in terms of its operational capability. Moreover, if triggered, the policy would permit the insured operator to order a new satellite immediately and subsequent launch service.

### Insurers' subrogation rights

When an insurer pays or indemnifies the insured for the satellite loss, the insurer acquires rights of subrogation whereby the "insurer steps into the shoes" of the insured and seeks recovery from any third party or parties who were considered to be responsible or liable to the insured for the loss. This right of subrogation acquired by the insured is considered an important avenue of redress available to insurers who are attempting to mitigate their loss in terms of the claim brought by the insured against the policy. Subrogation rights and any restrictions attached to the acquisition of those rights are detailed in the conditions section of the policy wording.

It is conceivable, assuming ALPHA-5 had been insured, that the loss recovered under a policy then concurrently in force would have prompted Alpha's insurers to evaluate Omega's fault and consider whether to exercise their rights of subrogation acquired under the policy against Omega.



Source: C. Kunstadter, XL Insurance

Figure 13. Distribution of insured values by orbital location

### The launch and in-orbit insurance market

The launch and in-orbit insurance markets are considered to be the preserve of specialist underwriters. That said, the market is both global and competitive, and in common with other lines of insurance, the availability of underwriting capacity will significantly influence the rating of the policies. Consistent with policies of such large financial magnitude in terms of potential property damage, the policy is written by numerous insurers acting in a coinsurance capacity – the idea being that the risk is spread and ultimately absorbed by more than one insurer.

### 4.2 Third party liability

Apart from insurance designed to protect the satellite operator against the loss of the property (referred to above), the satellite operator may also consider purchasing or will be protected by third party liability insurance designed to address liability arising for:

- Damage from space debris to persons and property on the ground – more specifically from third party liability occasioned as a result of a launch failure damage;
- Damage from a re-entering satellite or relevant to the above scenario;
- Damage occasioned in space – such as debris impact to, or collision with, another satellite in-orbit.

In our hypothetical scenario, Omega could have benefited from such insurance if it were considered legally liable to Alpha. We have assumed that Omega did not purchase such coverage for its satellite OMEGA-1. Such third party coverage for satellites is not widely purchased, at least in GEO.

#### Launch

The most common form of third party liability insurance provides protection during the launch phase. Indeed, international launch services providers may be required by domestic law or industry practice to obtain such coverage. For example, in the United States, the Commercial Space Launch Act of 1984, as amended, and associated regulations require any person licensed to operate a launch vehicle to obtain third party insurance; or demonstrate financial responsibility in amounts to compensate for the maximum probable loss from claims by a third party for death, bodily injury, or property damage or loss resulting from an activity carried out under the licence.<sup>1</sup>

In addition, national law may – and typically does – require that the satellite owner, respective national governments and certain other parties be named as additional insureds under the third party liability policy.<sup>2</sup>

The policy protects the launch providers and the other parties involved in the launch against liability in the event of third party property damage or bodily injury, either on the ground, at the launch site or down range, during the mission flight or in orbit, or following an unexpected re-entry.

Coverage is, however, limited in terms of duration, that is it may be specific to launch only or may extend to the end of the first year of the satellite's life.

In addition, the launch policy would not respond in the event that debris from the launch vehicle impacted the satellite/payload. This absence of policy response is the result of including a waiver of liability (or hold harmless) having been previously entered into between a launch provider and the satellite operator/insured and forming part of the terms of the launch services agreement between the two parties.<sup>3</sup>

Under U.S. law, coverage is designed to cover the “maximum probable loss” (not to exceed USD 500 million) to third parties from a launch accident. In the US policy, limits are anywhere between USD 10 million and USD 261 million.

### **In-orbit**

After expiry of the launch providers' coverage, there is generally no obligation for the satellite operator to purchase liability insurance. At present, the main exception to this rule is for UK satellite providers, who have been required to secure liability insurance for GBP 100m, adding the UK government as an insured party.

GEO satellite operators do not typically carry or purchase third party liability insurance for orbital related damage/liability. The rationale is that, historically at least, they assess the risk of collision and resulting liability to other operational satellites as very low. Nevertheless, at least one major operator is known to purchase such cover and interest is slowly building elsewhere.

Satellite operators in LEO planning to re-enter their satellite constellations at end-of-life may be required by the US Government, say, to carry third party liability insurance.<sup>4</sup> For example, one LEO satellite constellation operator at about 800 km, which plans to re-enter the satellites at end of life is required to maintain an in-orbit liability insurance policy with a de-orbiting endorsement to cover the de-orbiting of the satellite constellation up to a maximum sum insured of USD 500 million. The requirement by the US Government is actually in response to the threat of liability being assumed by a government in its role or capacity as a launching state which it acquires under the terms of the Liability Convention.<sup>5</sup> (See Section 3).

The launch and in-orbit insurance markets are considered to be the preserve of specialist underwriters. That said, the market is both global and competitive, and in common with other lines of insurance, the availability of underwriting capacity will significantly influence the rating of the policies.

## 5. Conclusion

This publication is designed to stimulate debate around the previously unanswered question whether space debris poses a threat to insurers. In an attempt to address this issue, we drew on expert insights from three different perspectives and disciplines: technical, legal and insurance.

From a technical viewpoint, the potential for damage or destruction of high-value operational satellites with resulting revenue losses does exist. That said, it can be argued – and indeed concluded from this publication – that the statistical probability of such a collision in GEO remains comparatively low.

Nevertheless, we acknowledge explicitly that projections are difficult to make because of our limited ability to observe small objects in GEO and the associated uncertainty surrounding past and future debris-generating events in this sector. More importantly, it was also recognised that the likelihood of a collision in GEO is increasing. This is because there is a sustained demand for deploying more satellites in GEO and no natural debris-removal mechanism.

### **How can insurers respond to this challenge?**

The products that the specialised space insurance market delivers for first-party property damage, provide an acceptable level of financial protection and security for their policyholders. Nevertheless, insurers are constantly reassessing their potential exposure and formulating their policies accordingly. In the past, exclusions or standalone policies tailored to address specific exposures have frequently been employed to respond to emerging risks and dynamic environments.

**On their own, insurers cannot respond to the challenge space debris poses to their insured operators. The more logical and pragmatic approach is for insurers to work with insureds in promoting mitigation efforts.**

The fundamental issue of liability remains shrouded in legal uncertainty. Notwithstanding relevant treaties and debris mitigation standards, there are very few legal precedents either at an international or national level. Procedural issues alone, both of a legal-standing and jurisdictional nature, currently hinder a speedy resolution of a dispute arising from a debris collision or impact. Moreover the legal duty to mitigate may not yet be sufficiently firm to provide a basis for liability. While this may change as debris mitigation becomes more uniform and the legal norms firm-up, procedural issues will likely remain an obstacle. A new, standalone international convention addressing debris is premature and its value as a solution is debatable.

What is patently clear from this publication is that, on their own, insurers cannot respond to the challenge space debris poses to their insured operators. The more logical and pragmatic approach is for insurers to work with insureds in, for example, promoting mitigation efforts. This could take the form of fostering a regime of legal certainty, be it at a national or international level, or collaborating with the scientific community to address this daunting issue. This publication is a first attempt by one insurer to move in that direction.

# Appendix (Sources)

## 2 What is happening up there: A technical perspective:

### Acknowledgments

Nicholas Johnson, NASA/JSC, contributed significant data and insights into the GEO graveyard manoeuvres and GEO object characterisation.

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#### Endnotes

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- 5 Convention on the International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389 ("Liability Convention"). The Liability Convention supplements Article 7 of the Outer Space Treaty.
- 6 Liability Convention, art. 3 ("In the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching state ... by a space object of another launching state, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible); Outer Space Treaty, art. 7 ("Each State Party to the Treaty that launches or procures the launching of an object into outer space ... 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 ...").
- 7 Liability Convention, art. 1(d) ("The term 'space object' includes component parts of a space object as well as its launch vehicle and parts thereof.").
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- 35 Liability Convention, art. 11(2).
- 36 See supra note 6.
- 37 Jurisdiction consists of personal jurisdiction and subject matter jurisdiction. "Personal jurisdiction is the court's power to bring a person into its adjudicative process and render a valid judgment over that person." *Kucik v. Yamaha Motor Corp.*, 2010 U.S. Dist. LEXIS 66535, \*29 n.6 (N.D. Ind. July 2, 2010). "Subject-matter jurisdiction is 'the courts' statutory or constitutional power to adjudicate the case.'" *United States v. Lawrence*, 535 F.3d 631, 636 (7th Cir. 2008) (citations omitted).
- 38 Defendant's domicile in the forum satisfies due process requirements and establishes personal jurisdiction. *International Shoe Corp. v. state of Washington*, 326 U.S. 310,316 (1945)
- 39 See supra note 34.
- 40 The doctrine of forum non conveniens is an inherent power of a court to root out cases where venue is technically proper, but where an alternative forum would be plainly superior. *American Dredging Co. v. Miller*, 510 U.S. 443, 448-49 (1994). A forum non conveniens dismissal is appropriate when "a foreign plaintiff chooses the home forum of an American defendant in an action that has little or no relation to the United States in order to take advantage of more favorable American procedural or substantive rules." *Monegro v. Rosa*, 211 F.3d 509, 512 (9th Cir. 2000) (citations omitted).

- 41 The defendant must establish: (1) “existence of an adequate alternative forum;” (2) private interest factors favor dismissal; and (3) public interests favor dismissal. *Leetsch v. Freedman*, 260 F.3d 1100, 1103 (9th Cir. 2001). Moreover, unique to cases brought in the United States against American defendants by a foreign plaintiff – such as Alpha’s action against Omega – (1) the possibility of law less favorable to the plaintiff in its home forum “should ordinarily not be given conclusive or even substantial weight” in the analysis; and (2) the plaintiff’s choice of forum merits less deference than a domestic plaintiff’s forum election. *Piper Aircraft Co. v. Reyno*, 454 U.S. 235, 247, 256 (1981).
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## 4 Insurance considerations

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Space debris: On collision course for insurers?

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