Preparing for the Worst: The Space Insurance Market's Realistic Disaster Scenarios

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ABSTRACT

Approximately 30 satellite launches are insured each year, and insurance coverage is provided for about 200 in-orbit satellites. The total insured exposure for these risks is currently in excess of US$25 billion. Commercial communications satellites in geostationary Earth orbit represent the majority of these, although a larger number of commercial imaging satellites, as well as the second-generation communication constellations, will see the insurance exposure in low Earth orbit start to increase in the years ahead, from its current level of US$1.5 billion. Regulations covering Lloyd's of London syndicates require that each syndicate reserves funds to cover potential losses and to remain solvent. New regulations under the European Union's Solvency II directive now require each syndicate to develop models for the classes of insurance provided to determine their own solvency capital requirements. Solvency II is expected to come into force in 2016 to ensure improved consumer protection, modernized supervision, deepened EU market integration, and increased international competitiveness of EU insurers. For each class of business, the inputs to the solvency capital requirements are determined not just on previous results, but also to reflect extreme cases where an unusual event or sequence of events exposes the syndicate to its theoretical worst-case loss. To assist syndicates covering satellites to reserve funds for such extreme space events, a series of realistic disaster scenarios (RDSs) has been developed that all Lloyd's syndicates insuring space risks must report upon on a quarterly basis. The RDSs are regularly reviewed for their applicability and were recently updated to reflect changes within the space industry to incorporate such factors as consolidation in the supply chain and the greater exploitation of low Earth orbit. The development of these theoretical RDSs will be overviewed along with the limitations of such scenarios. Changes in the industry that have warranted the recent update of the RDS, and the impact such changes have had will also be outlined. Finally, a look toward future industry developments that may require further amendments to the RDSs will also be covered by the article.

INTRODUCTION

Lloyd's of London

Lloyd's is well known as the place to go to insure just about anything.[1] It began as a syndicate of merchants and shipping owners meeting in Edward Lloyd's coffee house in the late 17th century to arrange mutual indemnification against loss, and expanded into other areas of transportation as technology developed. Lloyd's is not an insurance company as such; it is an insurance market of members, a corporate body governed by the Lloyd's Act of 1871. Nowadays, insurance covers a very wide spectrum, still including shipping, but also everything from property to livestock. Some of the more unusual items insured in recent years have been Egon Ronay's taste buds, Michael Flatley's legs, and Celine Dion's vocal chords. In 2013, Lloyd's wrote £26.1 billion of premiums. Space insurance, now in its fifth decade, has become a key market sector.

Atrium Space Insurance Consortium

The Atrium Space Insurance Consortium (ASIC) was founded at the beginning of 2007, to focus solely on the expanding space insurance market. In 2014 the consortium consisted of nine members, the main ones being Aegis, Canopius, Talbot, and Travelers. ASIC is managed by Atrium Insurance Agency Limited (AIAL), a wholly owned subsidiary of Atrium Underwriting Group Limited, a Lloyd's approved coverholder. AIAL is authorized and regulated by the Financial Conduct Authority. The ASIC team consists of the underwriting team in Atrium's offices at Lloyd's in London, and an engineering team based in Ottawa, Canada.

The Space Insurance Market

As of mid-2014, the total number of insured satellites in orbit was approximately 200. This represents about 50% of all commercial satellites in orbit and only about 20% of all active satellites in orbit, since government and military satellites are

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not normally insured. The total value of the insurance policies on these insured satellites is US$25.7 billion. Approximately US$1.5 billion of that is represented by low Earth orbit (LEO) satellites, and aside from a small exposure in medium Earth orbit (MEO), the remainder relates to satellites in geosynchronous Earth orbit (GEO).

Satellite Insurance Basics

A satellite's operational life breaks down into two main parts: the launch, and in-orbit operation. The launch risk, which is the highest risk portion, exists for a relatively short period of time compared to the in-orbit life, which may be more than 15 years. Consequently, insurance rates for launch are around an order of magnitude higher than in-orbit rates. A launch policy normally covers the launch, orbit-raising, in-orbit testing, and commissioning into service, plus anything that might go wrong in the first year of life of the satellite. After the launch policy expires, satellite owners/operators purchase in-orbit coverage, covering a satellite for the remainder of the satellite's life, usually on the basis of one year at a time.

Insurance is intended to cover only unforeseen and unforeseeable occurrences (*e.g.,* random failures). Coverage is provided for just about anything that can go wrong with the satellite—"all perils" is the traditional expression. As well as launch failures, mechanical or electrical failures, debris or meteoroid strikes, and the effects of space weather are all covered under a typical space insurance policy. The only things excluded are acts of terrorism, civil unrest, and war, including the use of antisatellite weapons.

Insurers must be able to feel reasonably confident that satellites will work in the space environment; suitable design margins are implicit, as is a comprehensive ground test including the launch dynamics and all space environments.

The Insured Value and the Relationship Between Losses and Claims

The insured value of the satellite is set by the owner. For launch insurance, it is usually the replacement cost, but may include an amount representing anticipated revenue lost during the time to ready a replacement satellite. A launch failure is most often catastrophic, but can sometimes result in the satellite being placed into orbit with reduced life, or with compromised performance in some other way.

Failures in orbit typically result in a reduction of the worth of the satellite as a commercial commodity. For a simple communications relay satellite, this will be in terms of transponder-years. For something like an imaging satellite, the process of establishing the loss quantum is not so straightforward, but will involve the evaluation of possibly a dozen or more performance parameters relating to image quality and/or quantity. Each claim requires a proof of loss showing how the failure is related to the reduction in capacity. The claim amount is basically a function of the loss in commercial value.

Over the last 20-odd years, the space insurance market has paid nearly $11B in claims. Failure investigations are generally able to identify a cause, whatever it might be. The largest contributors have been launch failures and power system failures, with propulsion and payload anomalies representing smaller, but still significant claims. Approximately 3% of these claims were attributed to space weather.

The Origin of Realistic Disaster Scenarios

An exceptional number of major catastrophes (not space related) in a relatively short space of time in the early 1990s resulted in Lloyd's suffering huge losses (around £8B between 1988 and 1992). This was attributed largely to the reinsurance spiral that developed when many syndicates underwrote again the very risks they had transferred, sometimes without knowing it, leaving insufficient capital in reserve to pay for losses, bankrupting many underwriting members, and bringing Lloyd's close to insolvency.[2]

Regulations were subsequently introduced requiring Lloyd's syndicates to maintain sufficient reserve funds to cover potential worst-case losses and still remain solvent. To achieve this, realistic disaster scenarios (RDSs) were established for each major line of insurance. The resultant losses from these RDSs, along with the anticipated frequency of such events across all lines of insurance, are used to determine a reserve that syndicates must maintain. Rating of each individual risk needs to include a factor to ensure that the reserve is maintained.

New regulations under the European Union's Solvency II directive[3] now require all insurers to develop worst-case models for all classes of insurance provided to determine their own solvency capital requirements. Solvency II is expected to come into force in 2016 to ensure improved consumer protection, improved supervision, deepened EU market integration, and increased international competitiveness of EU insurers. For each class of business, the inputs to the solvency capital requirements are not just based on previous results, but must also reflect extreme cases where an unusual event or sequence of events exposes the syndicate to its theoretical worst-case loss. The first space RDS to be used by Lloyd's of London syndicates assumed the total loss or destruction of all satellites within a five-degree segment of geostationary orbit. This RDS was devised at a time when geostationary communication satellites were starting to be co-located. By the early 2000s, with a greater number of commercial satellites in operation, and as greater experience was

gained with co-located satellites, the total loss of all satellites within a specific segment of arc was no longer deemed realistic, and a review of the space RDS was performed. An article introducing a new concept of space market RDSs was presented at the International Union of Aviation Insurers Annual General Meeting, Lisbon, Portugal, in May 2002.[4] Following analysis and review by Lloyd's, the article formed the basis of a new RDS that was introduced in January 2004.

Initially, only two RDSs were required to be considered by Lloyd's managing agents for space/satellite risks:

1. A very energetic solar proton flare
2. A generic defect affecting a class of satellites

Other scenarios that were initially considered during the development of the space RDS were

3. LEO/MEO satellite break-up leading to large-scale destruction of co-orbiting satellites (space debris)
4. Meteoroid storm
5. Ground station outage
6. Launch failure with multiple payloads
7. Terrorist action, possibly involving the use of antisatellite weapons

These other five RDSs were subsequently discounted based on the analysis of probabilities and associated losses (note that scenario 7 is excluded in any case as it is classed as an act of war; which is typically excluded in insurance policies).

In 2010 Lloyd's published an article outlining and discussing adverse effects of space weather on a number of Earth infrastructures such as the power grid, pipelines, telecommunications, rail transport, navigation, and aviation.[5] Around the same time, the Space Risks Study Group of the International Union of Aerospace Insurers and the newly created Lloyd's Market Association Satellite Risks Committee decided that a review of the space RDSs should once again be performed to assess the continuing applicability of the existing scenarios and analyze potential new scenarios that may exist due to changes in the commercial space sector since the previous exercise. A review of the space market RDS was undertaken in 2013 and a new edition issued. Lloyd's managing agents for space/satellite risks were asked to report on four new RDSs on a trial basis for 2014, although following the first quarter results it was decided that the four new RDSs would be adopted from January 1, 2015. The four new RDSs are

1. An anomalously large solar energetic particle event affecting many satellites
2. A generic defect causing undue space weather sensitivity in a class or classes of satellites
3. A generic defect causing unforeseen failures in a class or classes of satellites
4. Collision with orbiting space debris

DISCUSSION OF REALISTIC DISASTER SCENARIOS

Large Solar Energetic Particle Event Leading to Widespread Partial Losses

As the peculiarities of the space environment are understood to a greater degree, increased survivability is being built into satellites. In general, today's satellites are able to cope quite well with the vagaries of the space environment without serious problems. Experience has shown that reactions to adverse space weather conditions vary enormously among the satellite population; two virtually identical satellites can respond quite differently to a given event, to the extent that one will fail completely and the other will be completely unaffected. Furthermore, repetitions of the same space weather signature may cause an anomaly on a particular satellite on some occasions but not others. In general, space weather-attributable anomalies result in relatively few claims because in the majority of cases the anomaly is temporary and has no permanent effect on the operation of the satellite. In other cases, equipment redundancy and performance margins mitigate the effect.

The one exception is solar proton flares, which are known to universally degrade solar cell efficiency. An anomalously large proton flare similar to that shown in *Figure 1*, but several orders of magnitude more energetic, could result in a relatively large number of satellites losing a portion of their power generating capability, and hence insured capacity. During the

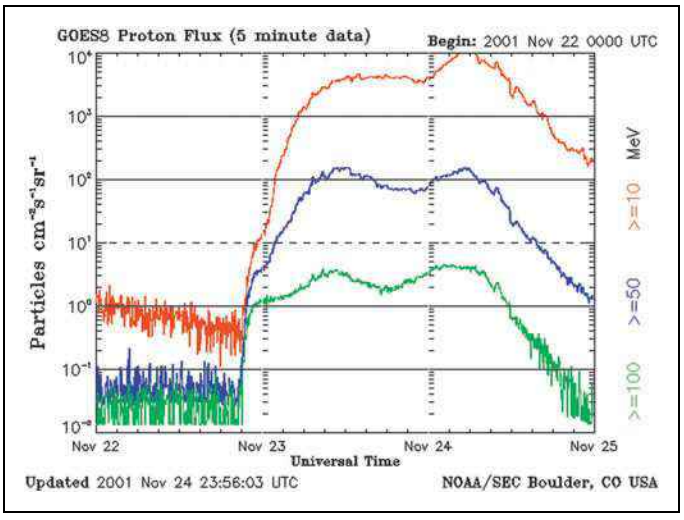

Fig. 1. GOES proton flux plot.

design process the solar array is designed so as to be able to withstand a certain number (typically 3 for a 15-year life) of large proton flares equivalent to some of the largest ever measured. It must be noted that accurate records have been maintained only for the past 5 solar cycles (55 years), a relatively short period. However, it seems extremely unlikely that a significantly higher number of proton flares will be seen within a typical satellite's lifetime. That said, a single anomalously large proton flare (or a number of smaller flares in close succession) could potentially affect all geostationary satellites, although the specific effect will also be a function of the satellite's age and technology. However, it is considered that such a flare could result in a loss of power of as much as 5% on average. Note, however, that this does not necessarily always translate directly into an equivalent loss of communications capacity, or insured value, as power margins need to be taken into account, as well as the flexibility that some operators may have to back-off (reduce the output power) of their transponders. In addition, should such an event occur, the losses would be spread over a number of accounting years, as the resultant loss of power would have the effect of bringing forward the end-of-life date of the satellite.

The 2013 RDS assumes that either a single anomalously large proton flare or a number of flares in quick succession result in a loss of power to all satellites in geosynchronous orbit. All exposures in this orbit are assumed to be affected by the proton flare(s). Managing agents assume a 5% insurance loss to all affected policies. Based on the current insured fleet, and today's values, it is estimated that this kind of event could lead to a loss to insurers of the order of $1B.

Generic Defect in New Satellite Series Causing Space Weather Anomalies

This kind of generic defect could be regarded as a subset of the Undetected Generic Defect in New Satellite Series (see next page); however, the relationship to space weather susceptibility makes it appropriate to put it in a class of its own. Although space weather is undoubtedly foreseeable, up to a point (in other words, we know it will continue to happen), and is reasonably well characterized as regard to average mission exposure (radiation dose/damage, particle flux, *etc.*), short-term variations and particularly worst-case peak levels are less well defined. This class of RDS is intended to cover the case where a design change or design deficiency creates an unexpected sensitivity to one or more kinds of space weather signature, leaving the satellite prone to certain anomalies such as uncommanded operating mode changes or equipment turn-off or failure that induces loss of control or capacity. The specific type of space weather susceptibility may change with advances in technology (*e.g.,* from surface discharge to internal discharge), so that the introduction of new technology often produces new and unforeseen susceptibilities and anomalies. The present limitations of ground simulation capabilities make it impossible to test for all possible interactions, and particularly combinations of space environments. However, space weather susceptibilities can generally be isolated, characterized, and designed out, if enough satellites of one type are built with a consistent configuration.

Table 1 shows the breakdown of anomalies by subsystem and those that were believed to be attributable to space weather, taken from ASIC's in-house satellite anomaly database. Multiple anomalies on a given satellite are treated as separate anomalies. Bus subsystem anomalies are undifferentiated by payload type. With in-orbit policies typically limited to one year, generic defects can generally be identified via regular in-orbit health reports, and the magnitude of downstream claims can be limited by applying appropriate subjectivities. Likewise, when unforeseen space weather susceptibilities appear, the risk can be reset to baseline level via exclusions, subjectivities, or by revising policy margins.

To calculate loss under this RDS, managing agents consider all live policies covering geosynchronous satellites. The following specific satellite types are considered individually:

Astrium Eurostar 3000 (all variants)
Boeing Space Systems 702 and GEM (all variants)
Lockheed Martin A2100 (all variants)
Mitsubishi Electric DS2000 (all variants)

Table 1. Satellite Anomalies by Subsystem and Attribution as of January 2014 (© ASIC)

Subsystem	All Anomalies		Space Environment	
Communications payloads	866	26.27%	274	32.5%
Optical/imaging payloads	17	0.52%	4	0.48%
ACS including computer	765	23.20%	187	22.18%
Power	735	22.29%	169	20.05%
T&C/data handling	379	11.50%	173	20.52%
Propulsion	318	9.65%	9	1.07%
Thermal	165	5.00%	27	3.20%
Mechanisms	14	0.42%	0	0.00%
Structure	1	0.03%	0	0.00%
Unattributed	37	1.12%	0	0.00%
Total	3244	100%	843 (25.57%)	100%

Orbital Sciences Corporation Star 2 (all variants)
Space Systems Loral LS1300 (all variants)
Thales Alenia Space Spacebus 4000 (all variants)

The four largest lines for each satellite type taken from the types listed are summed and the largest of these figures reported as the Space Weather Design Deficiency RDS figure.

Undetected Generic Defect in New Satellite Series

This class of RDS is intended to cover an undetected generic design-related or component defect that affects a number of satellites already launched. It often takes a year or more for such a defect to come to light and be identified.

During this time the manufacturer will continue launching similar models, so that by the time a generic defect has been identified a number of satellites may have been launched. Although the impact can vary widely, depending on the size of the satellite and the nature of the defect, this could result in significant losses in capability. In the period 2000–2005, insurers were hit hard by fleet-wide failures due to satellites being launched with undetected generic defects. The upside is that a generic defect is considered unlikely to appear after a satellite has been five years in orbit, which sets an upper bound on exposure.

In the early years of the satellite industry, it was typical for generic defects to be isolated to a particular manufacturer/bus type. Nowadays, with the consolidations in the supplier chain (see *Fig. 2*), a defect in a component can show up in more than one bus type. It is more useful to look at the issue in terms of commonality within different subsystems, power, propulsion, and so on.

Taking power as an example, there is the increasingly limited selection of suppliers of battery cells, especially since the advent of Li-ion cells. On the other hand, because of the lot production method of manufacturing battery cells, a generic defect in a production lot that goes undetected until the satellite is in orbit is unlikely to affect more than one or two satellites at most, although these may well come from different manufacturers.

Generic defects in solar arrays seem to occur more in the upstream manufacturing process, and have involved items such as cover glass adhesive, or harness fabrication, which again seldom affect more than two or three satellites. In some cases, although a large number of satellites were affected, numerous causes and contributory factors were identified, making the classification as a generic defect questionable.

Considering propulsion, there have been various kinds of chemical thruster defects, and various problems with ion and plasma thrusters, with both the electronics as well as with the actual thrusters. In electronics, we have seen a tin-whisker problem, and some capacitor issues, but on the whole, not a lot of generic issues are associated with

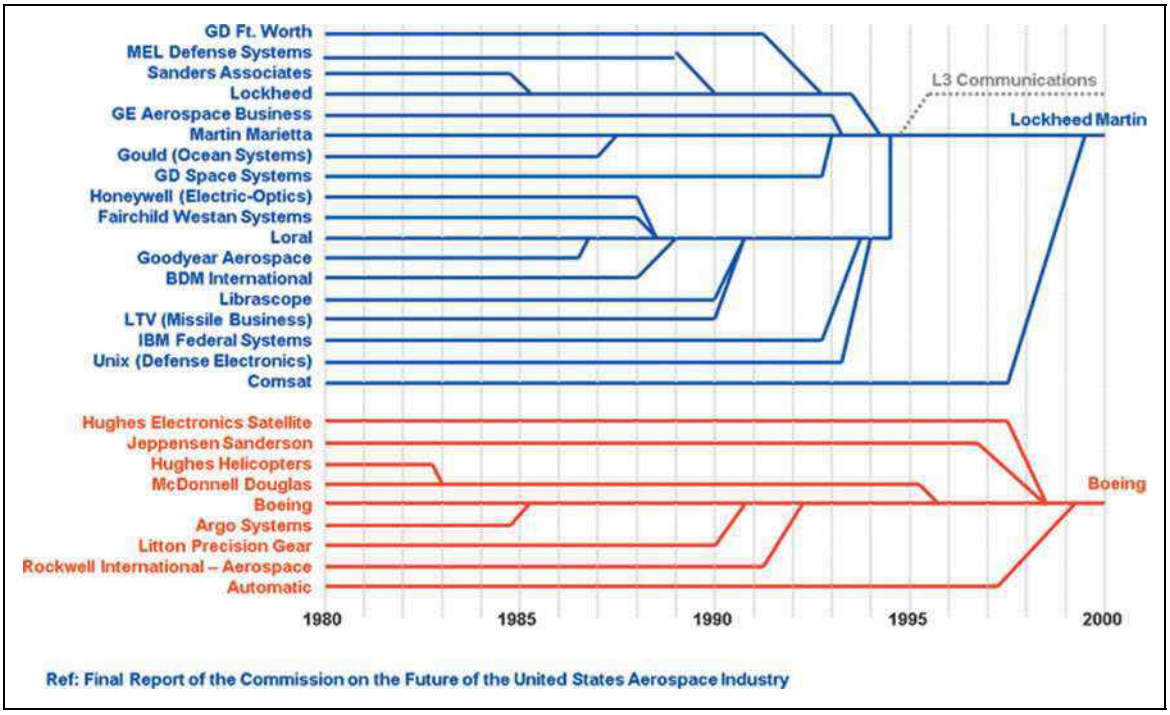

Fig. 2. Supply chain consolidation.

electronics. A number of generic problems have arisen in electromechanical devices such as solar array drives, momentum wheels, and gyros.

Several factors mitigate the impact of generic failures:

- Nearly everything comes in lots, and generic defects are very often confined to a single lot.
- No one manufacturer builds more than a handful of satellites each year.
- Generic defects hardly ever cause a catastrophic failure, although there have been some notable exceptions.
- Generic failures hardly ever cause a constructive total loss when they first become apparent, although the cumulative effect (*e.g.*, battery cells) may ultimately produce one.

Considering the above points, the following boundary conditions were initially established for this RDS:

- Maximum time on orbit before the defect becomes apparent: 5 years
- Maximum number of satellites that could be affected by a single defect: 10
- Effect on capacity/life on an individual basis: between 10% and 90%

The 2013 RDS requires that for all live policies covering each of the satellite types listed under the Generic Defect in New Satellite Series Causing Space Weather Anomalies RDS Class 2 above, and which have not surpassed the 5th anniversary of their launch date, managing agents must calculate a generic defect loss as follows and sum the 10 largest resultant figures:

Loss = Insured Satellite Value × Risk Period Factor × 50%

The Risk Period Factor is calculated as a function of the period remaining on the policy.

Multiple Losses from Space Debris Impact

The Space Debris RDS was initially discarded, as the probabilities of collision at that time (c. 2005) were considered to be not high enough to be of significant concern in comparison with other more realistic possibilities. This conclusion had to be reconsidered following the sudden and radical increase in orbiting objects following the Chinese experiment with an anti-satellite weapon on January 11, 2007, causing destruction of the Fengyun-1C (FY-1C) weather satellite, followed slightly more than 2 years later by the accidental collision between Cosmos 2251 and the operational Iridium 33 on February 10, 2009. These two events represent the worst satellite breakups in history. A total of 5,579 fragments from these two events were cataloged by the U.S. Space Surveillance Network (SSN) and almost 5,000 of them still remained in orbit as of January 2013.

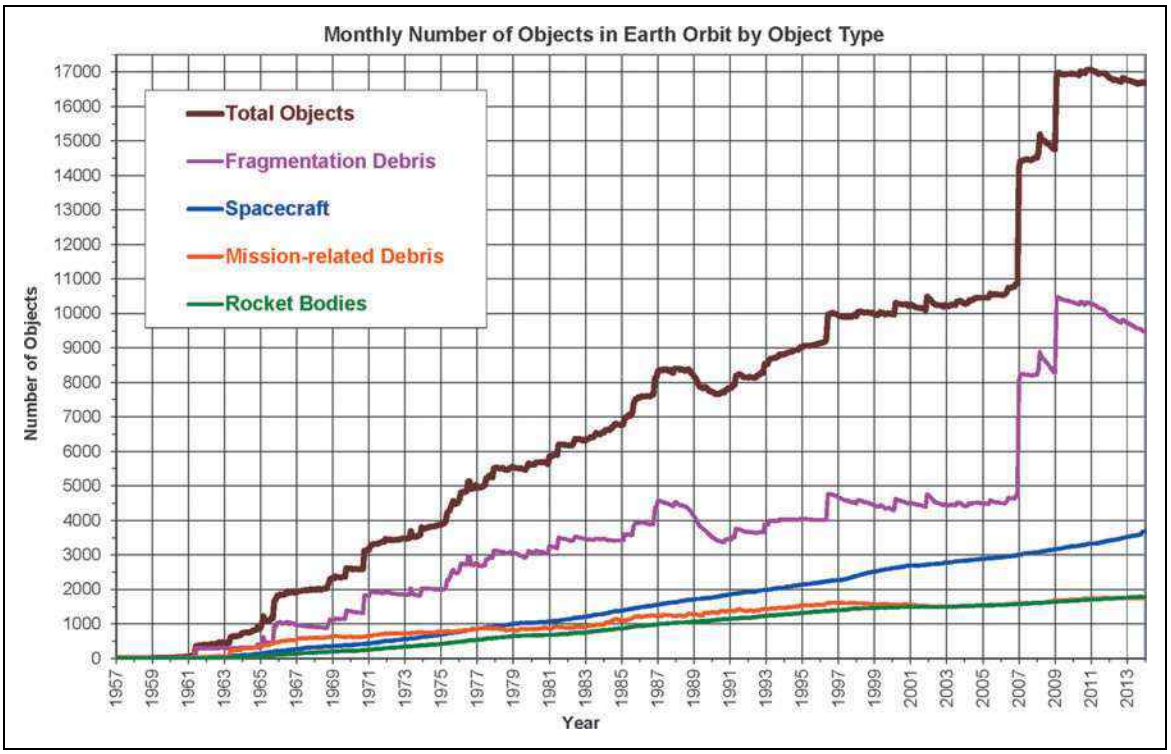

Fig. 3. Monthly number of objects in Earth orbit by object type.[6]

The combined FY-1C, Iridium 33, and Cosmos 2251 fragments account for about 35% of the cataloged population (*Fig. 3*).

In addition to these cataloged objects, hundreds of thousands (or more) of fragments down to millimeter size were also generated during the breakups. These fragments are too small to be tracked by the SSN, but still large enough to be a safety concern for human space activities and robotic missions in LEO (commonly taken as the region below 2,000 km altitude). As with their cataloged siblings, most of them are still in orbit.

Since the mid-1970s, specific measures have been taken to reduce or eliminate debris from space operations, by designing all deployment devices, frangible nuts, tie-down bolts, restraint bands, and so on, to be retained after activation. In August 2007, NASA issued Technical Standard 8719.14 to facilitate uniform processes for limiting orbital debris, and in 2010 the United Nations Office for Outer Space Affairs published *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space*. An industry-wide protocol has existed for many years to place retired GEO satellites into a "graveyard" orbit such that the subsequent orbit decay will not encroach on the operational GEO band. In both LEO and geosynchronous transfer orbit, depleted rocket stages are vented to prevent the possibility of explosion, and put into a de-orbit trajectory so that the stage will re-enter the atmosphere and burn up within a reasonable time (typically hours or days). Nevertheless, the situation in LEO has deteriorated to the point where the amount of debris in that orbit is predicted to remain more or less constant for the foreseeable future, as the decaying debris population is replaced by higher altitude debris drifting down.

Orbiting debris is continuously tracked by the SSN, and this information is available to satellite operators. The Center for Space Standards & Innovation also offers a service, SOCRATES (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space), which provides information on pending conjunctions of orbiting objects up to a week in advance. Satellite operators routinely execute collision avoidance maneuvers based on this information. The number of such maneuvers has been increasing in recent years, but to date, operators have successfully avoided collisions.

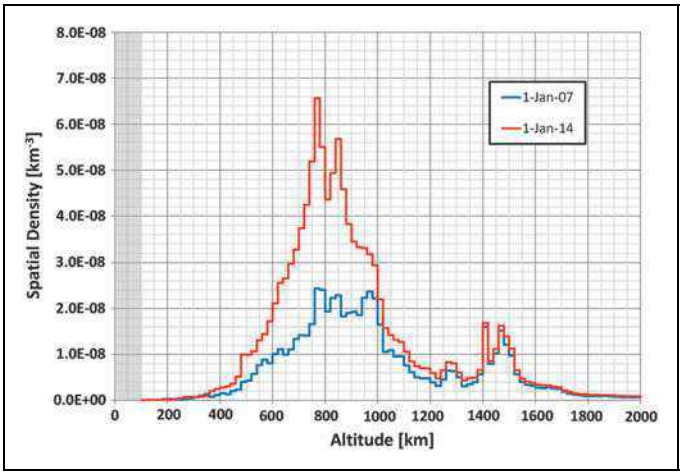

Fig. 4. Comparison of orbital debris spatial density distribution in low Earth orbit 2007–2014.[8]

Orbital debris tends to be scattered along specific orbit altitudes and inclinations (*Fig. 4*); thus, higher concentrations arise in the higher utilization orbits, particularly GEO and polar/sun-synchronous orbit. Debris also tends to be concentrated in certain transfer orbit inclinations, notably 25–32° and 62–90°, being a function of the most used launch sites. The probability of collision depends on the spatial density, and so the higher the orbit the lower the density, and therefore the lower the probability of collision. The risk of collision is also a function of the cross-sectional area of the satellite exposed to the debris; thus, the larger the satellite the higher the probability of collision. The risk of collision for a given satellite can be estimated from orbital debris models such as ORDEM 3.0, published by the NASA Orbital Debris Program Office at the Johnson Space Center. A method for estimating satellite-specific collision probability was published by D. Kessler in 1991.[7]

Studies have shown that the typical impact probabilities for a satellite in GEO, depending on the size of debris, are as follows[9]:

≤ 1 mm: 27 impacts/m^2/year
≤ 10 mm: up to 0.1 impacts/m^2/year
≤ 50 mm: up to 0.0007 impacts/m^2/year

However, it is important to understand that a collision will not necessarily cause catastrophic damage. Translation of impact probability into damage probability is difficult, but the variation of damage probability between geosynchronous and other orbits is not as significant as might be supposed, because, although the concentration of debris is higher in lower altitude orbits, the influence of satellite size and lifetime tends to offset the difference.

The 2013 Space Debris RDS currently considers only LEO satellites, since this region is where the significant debris-related incidents have been experienced to date. The RDS considers two separate groups, as a function of the orbit altitudes, as follows:

- Group 1: Satellites with orbit altitudes between 400 and 800 km (*i.e.*, 600 ± 200 km). This group encompasses all of the insured imaging satellites and the Iridium and the Orbcomm constellations of communication satellites. However, all other insured satellites known to orbit within this altitude range are included in the RDS calculation.

- Group 2: The Globalstar constellation of communication satellites with an altitude of 1,400 km. All other insured satellites known to orbit within ± 200 km of this altitude should also be included in the RDS calculation.

It is considered unlikely that a single debris event causing catastrophic loss within one of these groups would result in a debris cloud expanding sufficiently to affect the other group. Therefore, the RDS assumes 100% loss of all insured satellites in each group, multiplied by a Risk Period Factor as described under the Undetected Generic Defect in New Satellite Series, and takes the larger of the two amounts thus obtained.

FUTURE INDUSTRY DEVELOPMENTS AFFECTING RDSs

New Technology

We have noted above that the introduction of new technology into satellite design can be a factor in two RDSs; that is, it has the potential to affect sensitivity to space weather, and it can directly or indirectly cause unforeseen failure modes. Since the beginning of the satellite era, a number of technological innovations have produced step function increases in operating capability, for example,

Single-junction silicon solar cells to triple-junction gallium–arsenide

NiCd battery cells, through NiH_2, to Li ion

Microminiature integrated circuits

Ion/plasma propulsion engines

Microprocessor-based control systems

At one time or another, each of the above innovations has produced an epidemic of in-orbit anomalies, corresponding to the two Generic Defect RDS's, although perhaps not approaching disaster-level proportions. Fortunately, with experience, appropriate corrective actions were implemented, and all of the above have become standard features on most of today's satellites.

In recent years, although satellites have continued to increase in size and complexity, the pace of new technology development seems to have slowed somewhat, to the point where, at the present time, it is difficult to pinpoint any emerging technology that has the potential of causing a new failure epidemic. It is certainly considered extremely unlikely that any current new technology development could give rise to an entirely new RDS.

All-Electric Satellites

In the next few years, all-electric-propulsion satellites are expected to comprise a significant proportion of new GEO comsat orders. Eliminating the hypergolic propulsion system allows a much higher proportion of mass to be allocated to the payload. The major distinction of all-electric satellites is the time taken to transfer from a typical elliptical transfer orbit to geostationary orbit, which will typically be several months under nominal conditions, but could be a year or more under failure conditions. This has some serious implications for insurers. Nevertheless, the concept appears to be adequately enveloped by the current RDSs.

LEO Constellations

The launching of the Iridium constellation in the late 1990s, followed by the first-generation Globalstar, heralded a new era in LEO satellites. Some of these early constellations became classic examples of one of the above RDSs. Second-generation versions are now with us. Again, although this significant addition to the population of LEO satellites does potentially increase the risk of collision, debris, and the like, the existing RDS appears to cover the situation adequately.

SUMMARY & CONCLUSIONS

Four classes of RDSs have been identified for the space insurance market:

1. An anomalously large solar proton flare affecting many satellites
2. A generic defect causing undue space weather sensitivity in a class or classes of satellites
3. A generic defect causing unforeseen failures in a class or classes of satellites
4. Collision with orbiting space debris in a certain range of orbit altitude

The rationale for selecting these four categories and also the general assumptions for estimating worst-case claim scenarios in each category have been discussed.

Current and foreseen developments in technology and mission management that could potentially affect the current RDSs have also been outlined and reviewed. At the present time, it appears that the current RDS scenarios adequately cover all existing and foreseeable cases.

AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

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