Chapter 2
The Space Debris Threat and the Kessler Syndrome

The most beautiful thing we can experience is the mysterious.
It is the source of all true art and science.

–Albert Einstein

Why is the Problem Getting Worse?

One might logically ask this question. If we typically have less than a hundred launches into space each year—after discounting suborbital flights and sounding rockets—why can't we quickly bring the problem of space debris under rather quick control now that we have international guidelines in place? This is not really a mysterious problem, but it is certainly a complex one. The simplest answer is that debris begets debris.

There is a perhaps a somewhat useful metaphor here, which might be helpful to set the problem in context. Although this is certainly not a completely accurate picture it might help to visualize the problem and set the issues of orbital debris clean up in context.

It is not hard to shoot out a large number of street lights, but it can take a long time to clean up the broken glass, repair the sockets and wiring, and restore that which was rapidly destroyed. Further the streetlight, when first installed, consists of a lamp pole, a light bulb and a glass lamp cover. The streetlight that is destroyed may involve hundreds of pieces of debris to be cleaned up and carefully disposed. If just one light were to be shot out in outer space, the pieces would over time spread out over a huge area that would eventually encircle the entire planet. As a thought experiment think now what if one had allowed this sort of damage to continue in this manner for a half century many thousands of times with no effective repairs. It should be clear that a quick clean up and recovery may take quite a while to complete.

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The other thing to consider is that if two largest items collide in space at about 25,000 km an hour, the result is not four or six debris items, but perhaps more like 3,000 tracked objects and many more thousands of smaller, untrackable objects.

The collision in this case is more like an atomic explosion in terms of energy release than a stick of dynamite exploding. This type of incredibly high speed crash not only generates a huge new amount of debris elements, but the debris elements over time tend to widely disperse. Figure 1.4 above indicates the dispersal of the 3,000 debris elements from the missile destruction of the International Space Station which is clearly imperilled by this debris. We sincerely need to hope that no more such large collision events occur before we find a way of removing large debris elements from orbit to illustrate the point. The thin white line represents the orbit.

The very careful and rigorous study by J.-C. Liou and Nicolas Johnson indicated in 2006 that just the current amount of debris could generate a tripling of the space junk over the next 200 years. This is because space debris collides and generates more debris of smaller and smaller size. Since Liou's and Johnson's analysis there have been over 500 additional launches, and many of these had multiple payloads. The main problem is thus not cleaning up after new launches (although this is certainly part of the equation) but rather dealing with the current debris that is slowly grinding out additional debris elements. Even here there is a need for "triage" to address the most crucial problem first and then seek solutions to the rest of the problem later. This most urgent part of the debris mitigation process would be to remove from the low Earth Sun synchronous polar orbits the largest pieces of debris first. This is because these derelicts in space could generate the largest amounts of major new debris elements if there would be a major collision. This we know directly from experience.

There have been a number of studies conducted by various space agencies about space debris and its future potential increase. On one hand these studies are reassuring and on the other quite disturbing. At one level, these studies confirm there is a huge amount of open space around Earth relatively free of debris. Even in a so-called "congested area" such as the polar region in low Earth orbit, as depicted in Fig. 2.1, the likelihood of a collision remains extremely small. Figure 2.1 seems so frightening in large part because the scale depicted in this graphic is about 90 million to 1. The worst news of all is that more debris is forming than is returning to Earth due to gravitational effects. In fact there are now well over 6,000 tons of debris in orbit.

Space Debris in Orbit

The creation of additional space debris comes from a great variety of sources such as explosions of fuel tanks, launch vehicle upper stages and fairings as well as active and defunct satellites being bombarded by debris, and so on. Further micrometeorites from space are constantly raining down on the inner parts of the Solar System. These micro-meteorites are responsible for an estimated 12–15 % of the

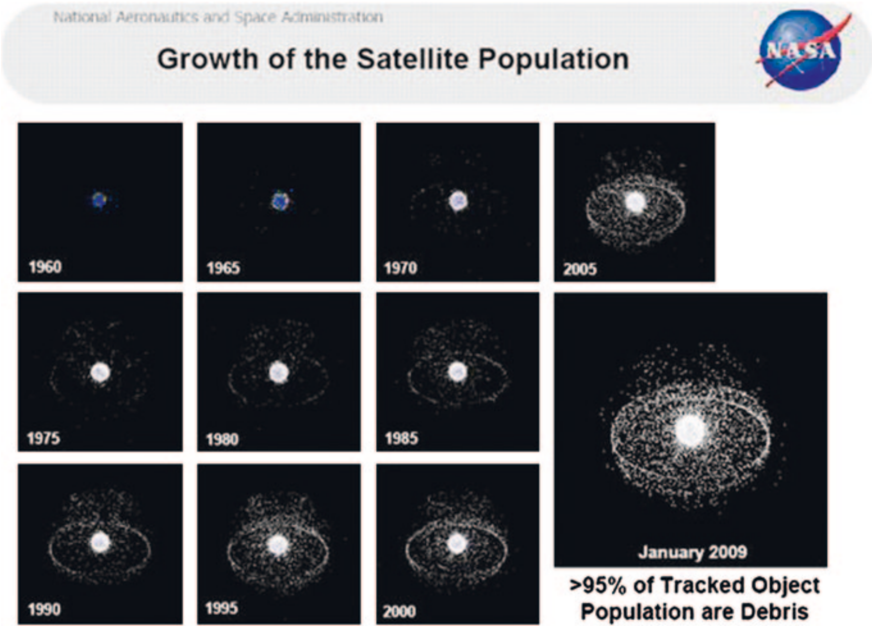

Fig. 2.1 Charting the significant increase in space debris that has occurred since 1960 (Graphic courtesy of NASA)

"hits" on spacecraft, based on the latest studies by various research institutes and researchers that monitor this activity.

Twenty-five years ago the cascade effect of debris crashing into other orbital objects produced a modest amount of new debris elements as can be seen in Fig. 2.1. But in time things began to change. Today this cascade effect is the largest source of new debris elements as the number of micro-debris elements that are less than 1 mm in size has climbed into the millions. There are perhaps enough of these various debris elements from the smallest chips of paint to the largest derelict satellites and upper stage rockets to increase the "number" of debris elements by a factor of four to six times over the next two centuries, even if there was to be a total moratorium on all future launches. This projection is based on the findings from the Liou and Johnson study in 2006 and factors in the number of new elements since that time including the Iridium-Kosmos collision and the Chinese anti-satellite missile test.

Orbital debris is not evenly distributed around Earth's orbit. There are particular bands where these orbital debris are currently concentrated. The worst congestion is in the LEO region and particularly the Sun-synchronous polar orbits. The depiction of the LEO region that is below the Van Allen Radiation Belt is clearly shown in Fig. 2.1 above. The other orbital region such as the MEO region above the Van Allen Belts and the GEO region still contain a number of satellites and debris elements, but relative speaking these are much less congested. This is because that not only are there far fewer debris elements, but also because the debris has a much larger volume in which to spread. Figure 2.1 shows the build up over time of the debris around Earth and how it has escalated in recent years. In 1980 the problem was hardly apparent, and even by 1985 it seemed almost trivial, but today it is clearly a larger and growing issue.

There are a number of other important aspects to note with regard to the orbits that are of importance. One aspect is that there are different disposal concepts that apply to these three different orbits. One logical disposal mode is to fire jets so that a satellite in LEO will simply de-orbit and burn up on its descent or splash down into the ocean. For geosynchronous satellites the disposal method is to push the spacecraft to a graveyard orbit that is higher than the geo orbit. When thus positioned there, these satellites can stay in super synchronous orbit for millions of years.

The greatest challenge is presented by the MEOs in terms of the disposal of satellites at end of life. Only a small amount of increment fuel is required to de-orbit a LEO satellite or to push a GEO satellite into a higher graveyard orbit. The disposal of MEO satellites is a problem in that a 40 % greater amount of fuel—beyond that used for orbital positioning—is needed to de-orbit a spacecraft launched into this orbit. This constitutes a very large economic penalty in terms of launch costs and increasing the size of propellant fuel tanks. Other options might be explored to move MEO satellites at end of life into some type of "graveyard or parking orbit", but this would not be an easy or permanent solution because the Sun, Earth and Moon would impact this type of orbit and thus it would not be stable.

Actually the problem and complexity of this final disposal issue only increases when probed further. Satellites can lose their ability to be commanded and thus be stranded in their orbits. Elements of the launch such as the upper stage rocket, fairings that served to protect the satellite from the atmosphere during launch and other extraneous parts can be launched and stranded in orbit with no mechanism to de-orbit them except for gravitational pull and atmospheric drag. Some satellite operators have claimed that they were requested not to de-orbit their failed satellites from operators of defense-related satellites because of possible collision with clandestine satellites uses for surveillance.

If the launch of a spacecraft is into LEO, these elements will eventually degrade, but this is not the case with MEO or GEO orbit. And, of course, not all satellites are launched into LEO, MEO or GEO orbit. Some satellites are launched into highly elliptical orbits such as the so-called "Molniya" orbit, named after the Russian satellite with this name. Or satellites can be launched into a somewhat similar highly elliptical "Loopus" orbit. There are also various other orbits such as the Quasi-Zenith or Figure 8 orbit (i.e., a geo orbit inclined 45 degrees), super-synchronous orbits and even unintended orbits. These last can result from a launch failure when the rocket fires too long or not enough, and thus the rocket is put on the wrong path.

Once a satellite or rocket motor becomes stranded in orbit, it can become a source of additional debris. Any of these stranded or even actively controlled space objects can be hit by another piece of debris at high speed and generate other debris. A fuel tank or a battery might explode and create additional elements of debris. The recommended procedure of venting fuel tanks for end of life satellites is considered an important procedure now widely practiced to help minimize space debris.

The uneven distribution of orbital debris creates problems with regard to those who perceive this as a serious issue and those willing to support in an active way the cleaning up of the mounting amounts of space junk. Those who operate satellites in GEO orbit are inclined to respond to concerns about rising debris by saying this is largely a LEO and polar orbit problem and not one that affects me. Those who operate MEO orbit systems might say much the same.

The increasing build up over time in orbital debris will, of course, be a problem for everyone who seeks to safety launch into orbit since launchers must travel through LEO on their way to a higher orbit. Further there is increasing debris in all orbits and unless the problem is addressed in the nearer term the longer term costs and difficulty of debris removal will exponential increase over time. Just as the issue of the sustainability of the Earth's environment is becoming exponentially worse and more difficult and expensive to address over time, the same type of problems exist with "kicking the can down the road" with regard to space debris.

The Urgency of Action and Orbital Priorities

The urgency of addressing the space debris problem is clearly perceived to be at different levels by those whose missions are related to LEO, MEO and GEO orbit systems. Thus if there are financial approaches devised to collect funds to address this problem, it is likely that contribution levels might well be different for those launching to LEO, MEO, GEO or points beyond. The discussion of orbital debris also often focuses on which countries are responsible for the creation of this problem in the first place. Clearly it is only a few spacefaring nations that were the prime cause of today's space junk. The primary countries in this regard are clearly the United States, China and Russia.

Although these three countries—or enterprises based in these countries—are the clear source of this debris, the source of secondary, tertiary, or even quandary debris that has come from subsequent collisions in space is much harder to assess. Instead of trying to assign specific responsibility to a particular country and thus looking backwards in time for a solution, it might be more appropriate to try to look forward to a more integrated global solution. The number of countries launching rockets and spacecraft into space is still only ten in number. The three primary launching countries plus Europe launch about 90 % of all rockets into space and well over 95 % of the total payload mass to orbit—and this will likely remain the case for some time to come.

Upgrading Debris Tracking Capabilities

A great deal of activity is now devoted to tracking space debris. Since 1961 the U. S. Air Force has been operating the Space Surveillance System that has been using increasingly outmoded Very High Frequency (VHF) radar tracking and in-orbit resources to track the mounting amount of space debris. As the amount and number of debris objects has increased exponentially, this system has become increasingly unable to keep up with the tracking requirements. This system, which was originally conceived as a means to detect a missile launch attack against the United States, is increasingly utilized to help protect key U. S. orbital assets. This includes anticipating possible collisions with the International Space Station (ISS) by a major debris element and indicating how raising the ISS orbit at the correct time could eliminate such risks.

The U.S. Air Force has contracted with Lockheed Martin to upgrade the existing radar systems and implement what is known as the "space fence" to have much more precise tracking capabilities. The first elements of this new capability were tested in February and March 2012 and successfully demonstrated orbital debris tracking capability. Based on these tests, the air force approved the design and an implementation plan. Steve Bruce, vice president of the Space Fence program for Lockheed Martin, said in a statement after the tests: "Our final system design incorporates scalable, solid-state S-band radar, with a higher wavelength frequency radar capable of detecting much smaller objects than the Air Force's current system [12]." This new space fence system will thus eventually be able to track object in LEO down 1 cm or 0.4 inches in diameter. This is more or less equivalent to the capability to track some 500,000 space debris elements [13].

The control center for this new Mark II space fence orbital tracking system is now operational, even though it will be several years before the new multi-billion dollar capability is fully installed and operational. (See Fig. 2.2)

Fig. 2.2 Mark II S-band radar space fence operations center (Graphic courtesy of Lockheed Martin Corporation)

Space Traffic Management

The space launch environment has clearly become more complex, with growing space launching capabilities and different sorts of commercial space activities. One thought that has arisen with the growth of interest in commercial spaceflight is that of Space Traffic Management. Today commercial spaceflight includes so-called space tourism, commercial cargo and human flight to orbit, commercial space stations and possibly hypersonic transportation systems. This diversity of activity and the increasing "mixture" of aviation, aerospace and space transportation systems suggest that public safety on the ground, in aviation space, in stratospheric operations and in outer space may only be systematically achieved through Space Traffic Management. The relevance here is that if an international body such as the International Civil Aviation Organization (ICAO) is charged with this responsibility, then they might also be able to help oversee this emerging complex aviation/aerospace/outer space environment and also administer processes to control space debris.

In this new role the newly designated international mechanism for Space Traffic Management might set safety and operational standards for many space and stratospheric missions and activities. This agency might coordinate international standards for spaceports, for hypersonic transportation systems and for commercial sub-orbital flights associated with "space tourism," for maximum altitudes for "cubesats," nanosats and microsatellites, for active de-orbit of satellites and upper stage rockets, etc. Even prior to the agreement on this new regulatory regime, which might take many years to achieve, there might be an international code of conduct for space that might suggest better practices, safety standards and debris mitigation standards than exist today.

The Next Steps Forward

The following chapters will address actions that might be taken to mitigate the further increase of orbital debris and processes that might be employed to remove debris from orbit. These mitigation efforts may involve legal, technical, operational or financial steps that can either help to stop the creation of new debris or carry out active removal of debris from orbit.

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