Launch Activity and Orbital Debris Mitigation

INTRODUCTION

Since the start of human space activity, the number of orbital debris, or artificial objects orbiting Earth that are no longer functional, has steadily increased. These debris make up 95 percent of all orbiting space objects and consist of spent satellites and upper stages, separation devices, bolts, paint chips, and still other spacecraft components. U.S. Space Command tracks more than 9,000 objects larger than ten centimeters wide with ground-based optical and radar telescopes; another 100,000 objects between one and ten centimeters are estimated to be orbiting Earth. Figure 1 shows computer-generated views of catalogued space objects, including debris, distributed in various Earth orbits.

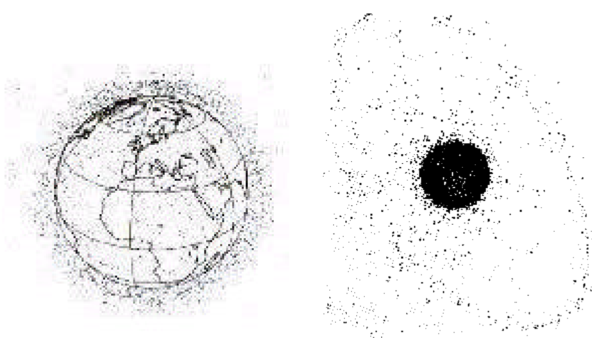

Figure 1: Space objects distributed in low-Earth (left) and geostationary, medium-Earth, and Molniya (right) orbits

While the risk of an orbital debris impact to an operational spacecraft is low, the debris population continues to grow at 175 metric tons per year and has caused damage to active spacecraft. Indeed, orbital debris' presence is apparent in the dings and dents observed on spacecraft such as the Space Shuttle, the Russian Mir space station, and the Hubble Space Telescope. As a result, efforts are underway in both the government and industry to mitigate orbital debris.

As indicated above, launch vehicle upper stages and their mechanisms and components have proven to be a considerable contributor to the orbital debris population. This report shows how launch vehicles and launch activity can create orbital debris and explains what the U.S. and foreign governments and the aerospace industry are doing to minimize the amount of orbital debris generated by launch activity.

LAUNCH ACTIVITY AND ORBITAL DEBRIS CREATION

Along with derelict spacecraft, upper stages comprise the greatest concentration of mass in Earth orbit. More than 1500 rocket bodies launched by the spacefaring nations of the world currently circle Earth, with nearly half of these in low orbits. The orbital stages of launch vehicles can create hazards to operational spacecraft in two main ways: through collisions and explosions.

Collisions involving launch vehicle orbital stages can occur if spent upper stages and their components remain in operational orbits after directly injecting their payloads. While rare, collisions can cause devastation to active spacecraft, as occurred when the Japanese ECS-1 (Ayame-1) satellite was incapacitated after colliding with the third stage of its own launch vehicle.

Accidental explosions of upper stages are the primary source of the approximately 2200 rocket body debris now in Earth orbit. Upper stages may explode when, after the upper stage successfully delivers satellites to orbit, stored energy, such as residual propellants and pressurants, undergoes thermal cycling or is over-pressurized due to solar heating. Such explosions can generate hundreds of fragments of orbital debris and, along with spacecraft explosions, account for almost 40 per-

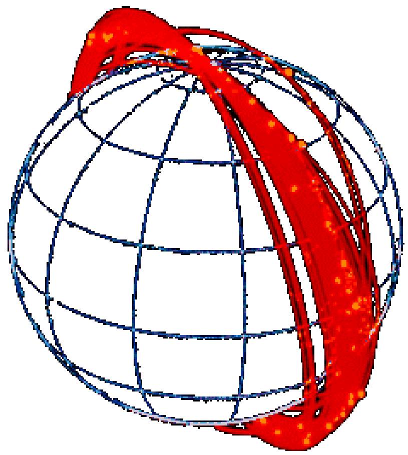

Figure 2: Notional spread of orbital debris after a spacecraft or upper stage explosion

cent of all orbiting objects tracked from the ground. Figures 2 and 3 depict how orbital debris can spread over time.

Upper stage explosions are considered to be the greatest source of the most hazardous debris in Earth orbit. The creation of more debris adds to the risk of collision with an active satellite. While Space Shuttle Discovery successfully avoided debris from an exploded Pegasus upper stage with an in-orbit maneuver in 1997, the less fortunate French military satellite CERISE was struck by a fragment of an exploded Ariane upper

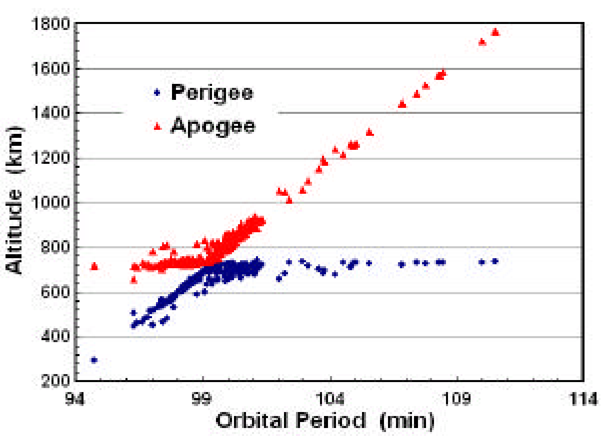

Figure 3: Gabbard diagram of the orbital debris distribution from a Long March upper stage explosion in March 2000

stage in 1996. Three upper stages and two upper stage components exploded in 2001.

The launch industry and U.S. government, along with governments around the world, have recognized the risks associated with upper stage collisions and explosions. The next section shares the efforts the U.S. government, international organizations, and the launch industry have made to minimize on-orbit collisions and explosions involving launch hardware, in turn mitigating orbital debris.

LAUNCH ACTIVITY AND ORBITAL DEBRIS MITIGATION

Recognizing that keeping the space environment clean is a common responsibility and desire, spacefaring governments and companies have worked to develop procedures and standards for minimizing the amount of orbital debris they produce in their launch activities. While some of the government procedures and standards developed pertain specifically to launch hardware, many are generally applicable to space activity. Though described in separate sections below, U.S. government, foreign and international, and launch industry orbital debris mitigation efforts have coincided in time and have influenced one another.

U.S. Government Efforts

In 1988, the Reagan Administration released the first national space policy that called for agencies to "seek to minimize the creation of orbital debris." The following year, the U.S. government issued a report on orbital debris. Noting the lack of good measurements on the orbital debris environment, the report called for the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) to develop a plan to monitor the debris environment. As a result, these agencies embarked on programs to address this recommendation. Figure 4 shows the Haystack radar, a facility operated by the

Massachusetts Institute of Technology's Lincoln Laboratory that NASA and the Air Force have used since 1990 to track small orbital debris.

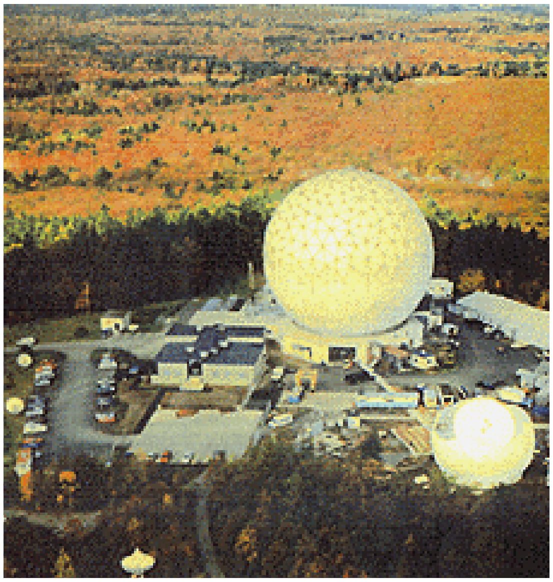

Figure 4: The Haystack radar

The Bush Administration took up orbital debris mitigation as a formal goal in its 1989 national space policy, adding that the United States would also encourage other nations to adopt debris mitigation policies and practices. Following the approval of that directive, NASA and DoD adopted policies concerning the mitigation of orbital debris in all of their space activities.

The government updated its orbital debris report in 1995, issuing five recommendations. These recommendations were to: (1) continue and enhance debris measurement, modeling, and monitoring capabilities; (2) conduct a focused study on debris and emerging low-Earth orbit (LEO) systems; (3) develop government/industry design guidelines on orbital debris; (4) develop a strategy for international discussion; and (5) review and update U.S. policy on debris. These recommendations have guided U.S. government activity regarding orbital debris mitigation since that time. Just one year after the issuance of this report, President Clinton's national space policy reaffirmed the earlier policy by calling for U.S. government agencies to minimize space debris. The 1996 policy also required NASA, DoD, the intelligence community and the private sector to develop design guidelines for U.S. government space hardware procurements and stressed a U.S. leadership role in urging other nations to adopt debris minimization practices and policies.

Shortly after the issuance of the report, a U.S. interagency working group led by NASA and DoD developed a work plan to study the debris environment and to work with U.S. government agencies and other spacefaring nations and international organizations to design and adopt guidelines to minimize orbital debris. In 1997, the working group created a set of "U.S. Government Orbital Debris Mitigation Standard Practices." Based on a NASA safety standard of procedures for limiting debris, the Standard Practices are intended for government-operated or -procured space systems, including satellites as well as launch vehicles. The interagency group has shared the guidelines with the aerospace industry to encourage voluntary compliance.

Now forming the foundation of U.S. government protocol regarding orbital debris, the Standard Practices support four objectives, presented below. All of the practices apply to launch vehicle components and upper stages.

1. *Control of debris released during normal operations.* Spacecraft as well as upper stages are to be designed to eliminate or minimize debris released under normal circumstances. Any planned release of debris larger than five millimeters that remain on orbit for over 25 years should be evaluated and justified on the basis of cost effectiveness and mission requirements.

2. *Minimization of debris generated by accidental explosions, during and after mission operations.* During missions, spacecraft

and upper stages should not have any credible failure modes for accidental explosions, or the probability of a failure mode's occurrence should be limited. After missions, on-board stored energy should be depleted or safed.

3. *Selection of safe flight profile and operational configuration.* Spacecraft and upper stage design and mission profiles should estimate and limit the probability of collision with known objects during orbital lifetime. Tether systems should be analyzed for intact and severed conditions.

4. *Post-mission disposal of space structures.* Launch vehicle components, upper stages, spacecraft, and other payloads should be disposed of at the end of mission life by one of three methods: atmospheric re-entry, maneuver to a designated storage orbit, or direct retrieval. Tether systems should be analyzed for intact and severed conditions when performing trade-offs between various disposal strategies.

Several U.S. government agencies have worked in recent years to develop guidelines and regulations on orbital debris production and mitigation for their activities and the industries they oversee. NASA, DoD, and Air Force Space Command orbital debris directives and guidelines have applied broadly to their launch as well as on-orbit activities. Air Force Space Command's Eastern and Western Range Requirement 127-1, for example, states that launches from federal ranges must have completed collision avoidance analyses. Regulatory agencies such as the Federal Communications Commission and the National Oceanic and Atmospheric Administration have proposed and published rules, respectively, pertaining to orbital debris mitigation for communications and remote sensing satellites, respectively.

The Federal Aviation Administration (FAA) has developed orbital debris-related regulations for the U.S. launch industry. The FAA attempts to mitigate orbital debris generated by space transportation in several ways. In 14 Code of Federal Regulations (CFR) part 415.39, the FAA requires expendable launch vehicle (ELV) launch license applicants to demonstrate that: (1) there will be no unplanned contact between the vehicle, its components, and payload after payload separation; (2) no debris will be generated from the conversion of chemical, pressure, and kinetic energy sources into energy that fragments the vehicle or its components; and (3) stored energy must be removed by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in permanent discharge state, and removing any remaining source of stored energy.

While part 415.39 applies to ELVs, 14 CFR part 431.43 specifies that the first two of the above stipulations apply to reusable launch and re-entry vehicles. The latter regulation also requires a reusable vehicle operator to perform a collision avoidance analysis to ensure a 200-kilometer separation between the vehicle and an inhabitable orbiting object during launch and re-entry. Finally, 14 CFR part 440, Appendix A, requires launch license applicants seeking a maximum probable loss determination for their activities to share with the FAA an analysis of risks posed by launch vehicles to operational satellites on orbit.

Foreign and International Efforts

As Table 1 shows, all major spacefaring nations have been responsible for adding to the number of space objects and debris in Earth orbit. Several foreign space agencies and organizations have recognized the risks associated with orbital debris and have issued or are currently developing orbital debris mitigation guidelines that apply to launch as well as all types of space activities. Many of these standards bear strong similarities to U.S. standards and have been patterned after them. The Japanese, European, French, and Russian space agencies have all developed orbital debris mitigation standards.

Country/ organization	Payloads	Rocket bodies	Debris	Total
China	32	20	285	337
CIS	1336	820	1687	3843
ESA	32	100	185	317
India	22	6	226	254
Japan	71	30	16	117
USA	966	570	2226	3762
Total	2459	1546	4625	8630

Table 1: Orbiting space objects and debris by origin

The subject of orbital debris has been and is currently being addressed in international fora. In 1993, several of the world's space agencies formed the Inter-Agency Space Debris Coordinating Committee (IADC) to facilitate the exchange of technical research and information related to orbital debris, to facilitate opportunities for space debris research cooperation, and to identify debris mitigation options. The IADC has compiled orbital debris mitigation guidelines for the world's spacefaring governments to follow that draw heavily from standards the space-faring nations have developed. In 2003, the IADC will present its guidelines to the Scientific and Technical Subcommittee of the United Nations' Committee for the Peaceful Uses of Outer Space (COPUOS), which since 1994 has included orbital debris as an annual agenda item.

Industry Efforts

Even before governments began to develop orbital debris-related policies and guidelines, launch vehicle developers became aware of the risks associated with orbital debris and began to explore ways to mitigate this hazard. One of the earliest procedures U.S. vehicle manufacturers adopted was the passivation, or depletion of on-board energy sources, of upper stages to prevent them from exploding and fragmenting. Passivation includes the burning or venting of residual propellants, the release of pressurants, the discharge of batteries, and the spinning down of momentum wheels and devices with rotational energy. It is believed that more than 80 percent of all upper stage explosions could have been prevented by passivation. Moreover, no passivated upper stages are known to have exploded.

The passivation of U.S. launch vehicles started in the early 1960s, when Thor-Ablestar upper stages vented leftover fuels. Over time, as upper stages of U.S. and non-U.S. upper stages experienced explosions and fragmented, passivation caught on among the world's launch vehicle developers. By the 1980s and 1990s, passivation became a standard procedure on Delta, Pegasus, Atlas, and Titan orbital stages. Foreign upper stages, such as those of the Ariane, Long March, and Zenit, now also employ passivation measures. The cost of passivation can be relatively small if it is planned in a vehicle’s design phase.

U.S. launch vehicle manufacturers also have modified vehicle designs to reduce the amount of debris that upper stages can create. Catchers are now attached to explosive bolts to prevent these components from becoming orbital debris when they are used to separate launch vehicle stages from each other or from their payloads. In addition, spring-loaded payload release mechanisms and payload hold-down clamps are now retained with their upper stages.

Finally, some launch vehicle upper stages are now being removed from useful orbits at the end of their missions in order to avoid collisions with operational spacecraft. Although the FAA does not require post-mission disposal, several techniques can be and are being used to dispose of upper stages. Post-delivery burns can remove upper stages from payload delivery orbits and into lower orbits to accelerate re-entry. The Delta 2 and Long March upper stages both performed post-delivery maneuvers to lower their perigees after deploying Iridium satellites, accelerating their decay periods to under two years; the Russian Proton upper stages immediately performed de-orbit burns. The Pegasus Hydrazine

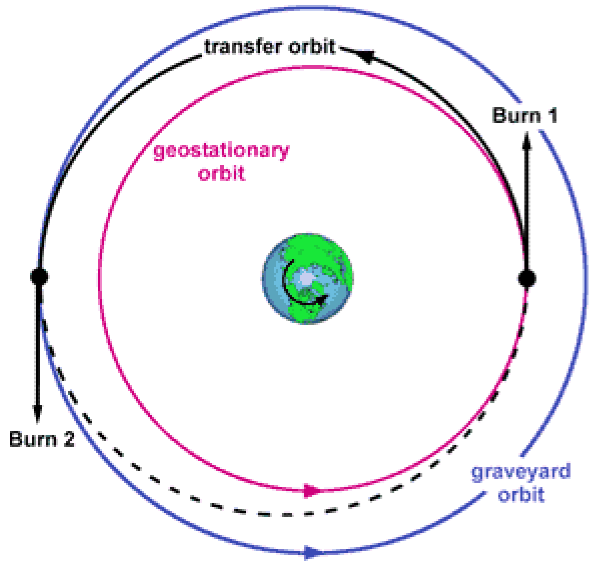

Figure 5: Movement of a space object from geostationary orbit to a graveyard orbit

Auxiliary Propulsion System (HAPS) also generally performs a depletion burn to move to a lower orbit shortly after payload delivery.

Extra burns can also remove upper stages from operational orbits and place them into "graveyard" orbits (see figure 5). In addition, upper stages can release their payloads early and leave the payloads to reach their final orbits using on-board thrusters. The U.S. Air Force is considering these various options for disposal of spent upper stages of the two Evolved Expendable Launch Vehicles, the Atlas 5 and Delta 4, from operational orbits after these vehicles deploy payloads into high-altitude orbits.

CONCLUSION

Although launch activity historically has been a major generator of orbital debris, the U.S. government, foreign governments, and the launch industry have become increasingly responsive to this issue over the decades since the beginning of the Space Age. The measures being taken by the launch industry, combined with the present creation of orbital debris mitigation standards and guidelines by national governments and international organizations, will help ensure that Earth orbit remains usable by the world's current and future spacecraft with minimal risk.