AN OVERVIEW OF REVISED NASA SAFETY STANDARD 1740.14

Robert Reynolds and Peter Eichler
Lockheed Martin Space Mission Systems & Services, 2400 NASA Road 1, Mail Code C23, Houston, Texas 77058, USA
and
Nicholas Johnson
NASA Johnson Space Center, SN3, Houston, Texas 77058, USA

ABSTRACT

The NASA Policy to limit the generation of orbital debris on NASA missions was stated in NASA Management Instruction 1700.8. This policy was implemented in the form of a NASA Safety Standard (NSS 1740.14) in August of 1995. Since the publication of this standard, all new NASA programs have begun to perform orbital debris assessments as a part of their design development activity and to provide debris assessment reports to the NASA Associate Administrator supporting their program for review and approval and to the NASA Office of Safety and Mission Assurance (Code Q) for review and concurrence. Established programs and programs far enough into their development so that the costs for redesign to meet the guidelines would be excessive and which were, therefore, grandfathered from having to meet the guidelines have been asked to review their operations procedures to determine if there are low-cost measures that should be taken to reduce their potential generation of orbital debris.

The experience gained in evaluating program responses and responding to program queries has led to the preparation of an update to NSS 1740.14. There have been some revisions to the guidelines, although the intent of the guidelines remains the same. In particular, no revisions of the 25-year rule for low Earth orbit postmission disposal or in the guideline for disposal orbits for geosynchronous missions were made. Tethers, which were treated within the guidelines in the first version of the standard, are now afforded a separate guideline. Finally, the process of providing the assessment of the upper stage for a payload program is clarified.

1. INTRODUCTION

Orbital debris environment modeling has been a subject of special interest at NASA Johnson Space Center (JSC) for a number of years, beginning with the work of Kessler and Cour-Palais. As these models became more sophisticated and the data that supported them became more extensive, the models were used to evaluate concepts for debris mitigation measures. In 1993 a set of models was run with the NASA EVOLVE code to predict future debris environment conditions under several scenarios (Ref. 1). These scenarios included orbital debris environment projections for both constant and increased future launch rates, and with and without debris mitigation measures.

At the time EVOLVE was being upgraded and the scenarios were being defined, NASA was also proceeding to implement its policy to limit orbital debris generation, as stated in NASA Management Instruction (NMI) 1700.8 (Ref. 2), by creating NASA Safety Standard 1740.14 (Ref. 3). This safety standard provided guidelines for debris control to be used by NASA Program Managers to implement debris mitigation measures as a part of the program development process. Since the release of the safety standard in August, 1995, the guidelines, rationale, and evaluation procedures have been disseminated and reviewed outside of NASA. In response to comments received as a result of this review process and because of our changing understanding of debris mitigation issues, NASA is currently preparing a revision to the safety standard as will be discussed in this paper.

One of the issues addressed in implementing the debris control policy was that of cost-effectiveness of debris mitigation measures. Since orbital debris is more of an impending problem rather than a near-term critical problem and since debris mitigation is not being practiced uniformly in all space programs, NASA has directed its Program Managers to adopt mitigation measures when they are cost-effective and do not conflict with mission objectives. Because of potential cost impacts, the one guideline area that has caused the greatest concern has been the guideline for postmission disposal of systems in or passing through low Earth orbit (LEO - that region of space up to 2000 km altitude) which specifies one of three options: (1) restricting the postmission orbit lifetime to be no more than 25 years, (2) re-orbiting systems to altitudes above LEO, or (3) planning for retrieval and deorbit. The first option is the most feasible for most affected programs, and it effectively requires most programs with space systems left in low eccentricity orbit at altitudes above 700 km or in highly eccentric orbit with perigee altitudes above 350 km to perform some sort of postmission disposal activity. For most programs, this option requires modifying designs or operational procedures and has the potential for significant cost impact. Consequently, one of the activities that was initiated after release of the safety standard was an effort to survey a wide spectrum of options that might be considered by NASA program managers to respond to this guideline.

2. DISCUSSION

As the understanding of the orbital debris environment has matured, the orbital debris community has accepted the responsibility for suggesting measures that might be taken to prevent the debris environment from becoming a significant problem. Discussions of debris control guidelines and debris mitigation measures have been an important part of the deliberations of national aerospace organizations, such as the American Institute of Aeronautics and Astronautics, and of international organizations, such as the Inter-Agency Space Debris Coordination Committee, an international technical committee having members from all of the major space-faring nations. In addition to the NASA effort in sponsoring the development of Safety Standard 1740.14, the Japanese government has also sponsored a similar effort on the part of NASDA which has produced its own set of guidelines (Ref. 4). The European Space Agency is in the process of developing a similar document. Debris modeling and mitigation are topics on the agenda of the Scientific and Technical Subcommittee of the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS). In short, the review and refinement of the NASA guidelines is an important and timely activity.

In the past year two general changes have made in NASA orbital debris control policy and policy implementation. First, NMI 1700.8 has been revised and is currently being reviewed within NASA. The revised policy statement is more specific than the original and clarifies the responsibilities for programs grandfathered from the guidelines. Under the revised policy grandfathered programs will be responsible for evaluating and implementing changes in operational procedures to reduce debris generation if this can be done with minimal cost impact. Second, the revised standard states that the NASA Program Manager has the responsibility to perform a debris assessment which includes the upper stage(s) and associated debris such as staging components.

2.1 Changes in Standard

An important part of the revision of Safety Standard 1740.14 was the modification of the guidelines. A summary of the revised guidelines is presented in Table 1. As seen in this table one of the revisions is to create a separate section for tether missions. In addition to the guideline revisions, the evaluation procedures have also been reviewed and, in some cases, clarified. These changes were influenced by queries from various NASA and non-NASA program offices. Also, two appendices have been added. The first of these new appendices provides background on the 25-year postmission orbit lifetime guideline, and the second provides background on the guideline for debris surviving atmospheric reentry. The minimum size of debris considered in the revised standard remains 1 mm in diameter.

2.1.1 Guidelines on Debris Released During Normal Operations (Guideline 3)

The guidelines for LEO operational debris were revised to link the criteria more closely to conditions for postmission disposal. The revised guidelines on debris released in or passing through LEO during normal operations include:

1. the orbit lifetime of any such debris should be limited to less than 25 years, and
2. the total object-time product should be no larger than 100 object-years for objects larger than 1 mm in diameter

The most significant change to the guidelines on controlling debris released during normal operations is to replace the limit on large operational debris from being less than 0.1 m^2-years to all debris being limited to a maximum lifetime, and to increase the object-time product for all debris from 50 object-years to 100 object-years. These changes limit the number of debris larger than 1 mm to be no more than 4 if the orbit lifetime is to be 25 years; if there are more than 4 pieces released, at least some of these pieces must have lifetimes less than 25 years.

The guideline for operational debris passing near geosynchronous Earth orbit (GEO) is essentially unchanged. That is, debris must not be left in a long-life orbit that would pass within 300 km of the GEO regime.

Table 1. Debris Assessment Issues and Corresponding Guideline Descriptions

Debris Assessment Areas	Guideline	Guideline Description	Comments
Release of debris during normal mission operations	3-1 3-2	• Limit number and orbit lifetime of debris • Limit lifetime of objects passing through GEO	Guideline includes staging components, deployment hardware, or other objects that are known to be released during normal operations.
Accidental explosions	4-1 4-2	• Limit probability of accidental explosion during mission operations • Deplete on-board stored energy at end of mission life	Guideline includes systems and components such as range safety systems, pressurized volumes, residual propellants, and batteries.
Intentional breakups	4-3 4-4	• Limit number, size, and orbit lifetime of debris larger than 1 mm and 10 cm • Assess risk to other programs for times immediately after a test when the debris cloud contains regions of high debris density	Intentional breakups include tests involving collisions or explosions of flight systems and intentional breakup during space system reentry to reduce the amount of debris reaching the surface of the Earth.
Collisions with large objects during orbital lifetime	5-1	• Assess probability of collision with intact space systems or large debris	Collisions with intact space systems or large debris may create a large number of debris fragments that pose a risk to other operating spacecraft. A significant probability of collision may necessitate design or operational changes.
Collisions with small debris during mission operations	5-2	• Assess and limit the probability of damage to critical components as a result of impact with small debris	Damage by small debris impacts can result in both mission failure and failure to perform postmission disposal. A significant probability of damage may necessitate shielding, use of redundant systems, or other design or operational options.
Postmission disposal	6-1 6-2 6-3	• Remove spacecraft and upper stages from LEO to reduce collision threat to future space operations • Remove spacecraft and upper stages from GEO to reduce collision threat to future space operations • Assess reliability of postmission disposal	Options are to transfer to a disposal orbit or to transfer to an orbit where the space system will reenter within 25 years. Disposal orbits are defined away from LEO and GEO.
Debris surviving reentry and impacting in populated areas	7-1	• Limit number and size of debris fragments that survive uncontrolled reentry	This guideline limits human casualty expectation.
Collision hazards posed by tether systems	8-1 8-2	• Assess the probability of collision with resident space objects and limit orbital lifetime • Mitigate the effects of severed tether systems	Tether systems may pose special collision hazards with other objects in orbit. Severed tethers may create additional hazards and hinder disposal plans.

2.1.2 Guidelines on Debris Generated by Explosions and Intentional Breakups (Guideline 4)

The guidelines on control of debris generated by accidental explosions remains essentially unchanged, with an accidental explosion probability of 10^{-4} being a design objective; this guideline is directed primarily at upper stages. The guideline on depletion of on-board stored energy after completion of mission has been revised to specifically suggest that propellant depletion burns should be designed to reduce orbit lifetime to the maximum extent possible.

The guidelines on intentional breakups were revised to limit the object-time product of 10 cm and larger debris from such events, rather than for 1 mm and larger debris in the initial version of the guidelines. The guideline that no debris larger than 1 mm remain in orbit longer than 1 year remains in effect. The guideline on debris generated by breakup as a planned reentry event was deleted since this activity is covered under the intentional breakup guideline.

2.1.3 Guidelines to Limit the Generation of Orbital Debris from On-Orbit Collisions (Guideline 5)

In general, the guidelines in this area did not change in their intent, with the design goals of limiting the probability of collision with large objects in orbit to 10^{-3} and the probability of collisions with small debris causing loss of control being 10^{-2}. However, the guideline on limiting the probability of collision with large debris was modified to include the entire orbit lifetime, rather than the mission lifetime as previously stated, since the generation of substantial amounts of secondary debris should be avoided.

2.1.4 Guidelines on Postmission Disposal of Space Structures (Guideline 6)

The primary change in these guidelines is the elimination of the near-circular 12-hour orbit altitude regime as a region to be avoided in considering postmission disposal orbits since the current spatial densities do not warrant special attention. The other guidelines remain essentially intact.

For systems in or passing through LEO, the postmission disposal options are:

a. Atmospheric reentry option: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit.

b. Maneuvering to a storage orbit between LEO and GEO: Maneuver to an orbit with perigee altitude above 2500 km and apogee altitude below 35,288 km (500 km below GEO altitude).

c. Direct retrieval: Retrieve the structure and remove it from orbit within 10 years after completion of mission.

For systems above LEO, disposal should occur either by maneuvering to a storage orbit at least 300 km above GEO altitude or maneuvering to a storage orbit at least 500 km below GEO altitude.

2.1.5 Guideline on Limiting Risk from Debris Surviving Uncontrolled Reentry (Guideline 7)

This guideline remains unchanged. The guideline is derived from the calculation of human casualty expectation resulting from reentering systems and is stated in terms of a maximum debris casualty area of 8 m^2. The total debris casualty area is the area on the ground within which an unprotected human being would be hit by a piece of reentering debris. The 8 m^2 guideline value limits the probability of human casualty to 10^{-4} for that reentry event.

2.1.6 Guideline on Control of Collision Hazard Posed by Tether Systems (Guideline 8)

This is a new section in the revised standard. Tethers were removed from consideration under the guidelines for operational debris. The tether guidelines are presented in Table 2. The rationale for giving tethers their own set of guidelines is two-fold: (1) extended tethers can have a large cross-section for collision with large objects in orbit and, therefore, may represent a significant hazard to spacecraft operating in the same altitude regime and (2) simple tether designs can have a high probability of being severed, with the fragments being left in orbit, and the fragments may have the same large collision cross-section as do the intact tethers.

From an orbital debris perspective, there is much still to be learned about tethers, and research is underway at JSC in this area. One issue is to understand under what conditions would tether fragments remain extended. There are indications from tether research that tethers longer than a critical length, determined by the tether design and material composition, will remain extended, while tethers shorter than this length will not. Tethers fragments which do not remain extended will be less likely to collide with other large objects in orbit.

2.2 Postmission Disposal Options for Upper Stages

Since the guideline limiting postmission orbit lifetime is a new and applicable constraint on many LEO payloads and upper stages, a study has been conducted at JSC on options for satisfying this guideline. This study is in progress and these results are not complete. Attention has first been directed to upper stages, and a summary of options for upper stages is presented in Table 3. Some of these options will apply to payloads also, but the ease

Table 2. Guideline Block for Tether Systems

GENERAL POLICY OBJECTIVE

CONTROL OF COLLISION HAZARD POSED BY TETHER SYSTEMS

NASA programs and projects will assess and limit the collision hazard posed by tether systems on other users of space.

GUIDELINE

8-1. *Tether systems deployed in LEO or HEO:* Intact tether systems should meet the guidelines limiting the generation of orbital debris from on-orbit collision (Guidelines 5-1 and 5-2) and the guidelines governing postmission disposal (Guidelines 6-1, 6-2, and 6-3).

8-2. *Mitigating the effects of severed tether systems*: Due to the high probability of tether systems being severed, either by meteoroids or by orbital debris, the projected remnants of a severed tether system should be evaluated for compliance with Guidelines 5 and 6 as noted above.

of implementation may vary for the two types of systems. For example, propulsive options may be more attractive to liquid propellant upper stages than options requiring long-term attitude control, whereas propulsive options might be very unattractive for a payload having no appreciable propulsive capability but an option requiring long-term attitude control might not be so.

3. CONCLUSIONS

After receiving a broad review of the debris control guidelines outside of NASA and having gotten additional feedback on the guidelines from within NASA, JSC has made revisions to NASA Safety Standard 1740.14. The overall direction of the guidelines has remained, but details in many of the guideline have changed. Notable changes to the guidelines have occurred for tether programs and for the control of operational debris. NASA will continue to review the guidelines as new measurements of the environment are obtained, as debris environment models are improved, and as we learn more about the impact of the guidelines on space system design processes and options to reduce the cost of implementation.

4. REFERENCES

1. Reynolds, R. C., Loftus, J. P. and Kessler, D. J., Assessing the Effectiveness of Techniques to Limit Orbital Debris Generation, *Proc. of the SPIE/Aerospace Science and Remote Sensing Conf.*, Paper No. 1951-34, April, 1993.

2. The NASA Policy to Limit Orbital Debris Generation, *NASA Management Instruction 1700.8*, April, 1992.

3. Guidelines and Assessment Procedures for Limiting Orbital Debris, *NASA Safety Standard 1740.14*. Office of Safety and Mission Assurance, August, 1995.

4. Space Debris Mitigation Standard, *NASDA-STD-18*, March, 1996.

Table 3. Postmission Disposal Options for Upper Stages

OPTION	CONSEQUENCES
USE NATURAL FORCES	
Reduce perigee altitude of orbit	Increase the fuel requirement for delivery of the payload to the mission orbit; may decrease the maximum deliverable payload mass
Use lunar and solar gravitational perturbations to reduce lifetime	Restricts allowed time of launch which may conflict with launch window requirements for payload or upper stage; only an option if the initial orbit has an apogee altitude above ~5,000 km; depending on orbit inclination, may only be effective for a range of perigee altitudes (e.g., for perigee altitudes below ~400 km for a 27.5° GTO); no changes necessary for hardware or software
USE EXISTING HARDWARE	
Restart engines to perform the disposal burn	May require hardware or software modifications in existing systems; only an option for liquid propellant upper stages; for planning purposes propellant cannot be taken from flight performance reserves; mass penalty from adding the required propellant; in some cases might be effective if additional tank capacity could be added to system; requires attitude control after completion of mission burn; typical propellant requirement for 25 year lifetime is 2-5% of the dry mass of the upper stage
Perform idle mode disposal burn	May require hardware or software modifications in existing systems; only an option for liquid propellant upper stages; for planning purposes, propellant cannot be taken from flight performance reserves; mass penalty from adding the required propellant; in some cases might be effective if additional tank capacity could be added to system; requires attitude control after completion of mission burn; typical propellant requirement for 25 year lifetime is 2-5% of the dry mass of the upper stage
Use attitude control expendables	Mass penalty from adding the required propellant; in some cases might be effective if additional tank capacity could be added to system; may require design changes to extend life of power system, attitude control
ADD NEW HARDWARE	
Addition of a small solid rocket motor for the disposal burn	Extensive experience using small SRMs to perform maneuvers (ullage motors); added mass for motor plus support equipment will come out of deliverable payload; requires attitude control for a short time after completion of mission
Use of aerodynamic drag augmentation	Simple and passive; need to limit the risk of operating spacecraft or large debris hitting the drag device (area-time product remains constant); useful only if orbital altitude is below ~1000 km circular or GTO with perigee below ~400 km; requires technology development
Use of a tether for momentum transfer	Only option that combines postmission disposal maneuver of the upper stage with an increased payload capacity; effect of momentum tether verified in general by on-orbit experiment (SEDS)
Use of electric propulsion system	Low thrust level may require long burn times (months); onboard power requirement of 500 to 1500 W; extensive space experience in use of these systems for attitude control and stationkeeping
Use of solar radiation pressure	Very low thrust level may require long time for effective orbit change; attitude control must be maintained while changing orbit; constant attitude changes necessary for thrust vector control; major technology development needed
Reduce orbit lifetimes using directed energy devices (lasers)	Very advanced technology concept; problem is to change orbit of system without causing the structure to disintegrate; thrust might be enhanced by adding a material to be evaporated by the laser, but this would add a mass penalty
Rendezvous and retrieval or deorbit	Orbit change and rendezvous is very expensive for most cases of multiple acquisitions by a single vehicle; viable option for a dedicated rendezvous mission; acquiring an uncontrolled structure could be challenging