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STEPS TAKEN BY SPACE AGENCIES FOR REDUCING THE GROWTH OR DAMAGE POTENTIAL OF SPACE DEBRIS

Report by the Secretariat

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INTRODUCTION

1. At its thirty-third session, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space noted with appreciation the report prepared by the Secretariat on various steps taken by space agencies for reducing the growth or damage potential of space debris (A/AC.105/620) and recommended that it should be updated annually (A/AC.105/637, para. 84).

2. That recommendation was endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-ninth session.[1]

3. The present report has been prepared by the Secretariat in response to that request and is based on new information provided by Member States, as well as by national and international space organizations.

I. GENERAL MITIGATION POLICIES

4. The National Aeronautics and Space Administration (NASA) of the United States of America, in its management instruction 1700.8, entitled "Policy for limiting orbital debris generation", identified its policy to employ design and operations practices limiting the generation of orbital debris consistent with mission requirements and cost-effectiveness and required each programme or project to conduct an assessment demonstrating compliance. To implement that policy, the NASA Office for Safety and Mission Assurance assigned the NASA Johnson Space Center at Houston, Texas, the task of developing specific guidelines. That resulted in the development of NASA safety standard 1740.14, entitled "Guidelines and assessment procedures for limiting orbital debris". All commercial activities subject to the authority of the United States Department of Transportation are subject to the regulations of the Office of Commercial Space Transportation. They require each applicant to address safety issues with respect to its launch, including the risks of associated orbital debris, on-orbit safety, and re-entry hazards.

5. The United States Department of Defense, in its "Space policy" dated February 1987, expressly addressed orbital debris as a factor in the planning of military space operations. The Department of Defense, in that space policy, stated that it would seek to minimize the impact of space debris on its military operations. Design and operations of its space tests, experiments and systems would strive to minimize or reduce accumulation of space debris consistent with mission requirements. Experience from its space experiments involving the creation of orbital debris has proved that that can be achieved by careful planning. For example, nearly all of the debris generated by the Delta 180 Space Defense Initiative test re-entered within six months because the test was conducted at low altitude to enhance orbital decay of the debris. Also, the United States Space Command, in its regulation 57.2, entitled "Minimization and mitigation of space debris", required the assessment of the impact of design and operations measures to minimize and mitigate debris on military space systems.

6. The United States further stressed the importance of the space debris issue in its national space policy released on 19 September 1996. It stated that the United States would seek to minimize the creation of space debris and that NASA, the intelligence community and the Department of Defense, in cooperation with the private sector, would develop design guidelines for future government procurement of spacecraft, launch vehicles and services. The design and operation of space tests, experiments and systems would minimize or reduce accumulation of space debris consistent with mission requirements and cost-effectiveness.

7. Measures to limit space debris generation must be developed and implemented on a multilateral basis by the spacefaring nations. The Japan Society for Aeronautical and Space Sciences (JSASS) committee on space debris prevention design standards published in March 1996 the final report for standards and design criteria of the National Space Development Agency (NASDA) of Japan. Based on that report, NASDA established the Space Debris Mitigation Standard (NASDA-STD-18) on 28 March 1996. A comparison of the guidelines and assessment procedures developed in NASA safety standard 1740.14 and NASDA-STD-18 was discussed at the twentieth International Symposium on Space Technology and Science, held at Gifu, Japan, from 19 to 20 May 1996, and details of the standard were presented at the forty-seventh International Astronautical Congress, held at Beijing from 7 to 11 October 1996.

8. The NASDA Standard includes the following mitigation measures:

(a) Passivation of the spacecraft and the upper stages at the end of the mission;

(b) Re-orbiting of the spacecraft and the upper stages at the end of the mission;

(c) Disposition of the objects on geostationary transfer orbit so as not to pose a risk to the geostationary orbit;

(d) Minimization of the debris released during normal operation;

(e) Post-mission disposal of spacecraft from low-Earth orbit (LEO).

9. According to the current NASDA Standard, a plan for space debris mitigation control should be tailored for each programme, but each NASDA project manager is requested to prepare a space debris mitigation plan, including an adequate rationale for items for which an exception is requested. Manufacturers are also requested to present a similar plan. Each plan will subsequently be reviewed by the NASDA safety review committee. An exception will be granted only under certain conditions; some projects currently well into their development cycle may be allowed to violate some requirement of NASDA-STD-18. The procedures for these assessment activities should be standardized by 1997. A handbook explaining each requirement and providing technical data and guidelines for satisfying the intent of the space debris control policy is scheduled for publication by the end of 1996.

10. According to information received from the British National Space Centre, the following provisions were proposed for inclusion into European Space Agency safety standards in order to prevent the creation of space debris, their fallout or impact on the ground:

(a) Means should be provided to prevent the hazardous descent of debris as the result of launch vehicle stage descent, a launch abort, or the uncontrolled de-orbiting or orbital decay of spacecraft, or space system elements, which are likely to survive re-entry;

(b) The creation of space debris in orbits that repeatedly intersect orbital paths used by space systems should be avoided;

(c) Normal operations should not result in the creation of orbital space debris through the jettison or release of items, or the ejection of fragments;

(d) Propellant, pressurized fluids and stored electrical and mechanical energy that remain in orbital systems and elements at the end of mission should be safely dissipated. It should be ensured that released liquids do not form droplets;

(e) Space systems and space system elements, including launch vehicle stages, in orbits with perigee altitude below 2,000 km should remain in orbit for no longer than 25 years after completion of the operational mission. The post-operational orbital lifetime of space systems and space system elements, including launch vehicle stages, in orbits with perigee altitude below 2,000 km should be limited to 25 years. This can be achieved by de-orbiting immediately after mission completion or transferring to an orbit with a maximum orbital lifetime of 25 years. The end-of-life manoeuvrability must be established in accordance with rules and regulations of launch and mission operation authorities;

(f) At the end of operational life, geostationary spacecraft should be placed in a disposal orbit that has a perigee at least 300 km above the geostationary orbit;

(g) If separation of the apogee boost motor from a geostationary satellite is necessary, separation should occur in a super-synchronous orbit with a perigee at least 300 km above the geostationary orbit;

(h) Upper stages used to transfer geostationary spacecraft from geostationary transfer orbit to geostationary orbit should, on completion of the mission, be inserted into a disposal orbit that has a perigee at least 300 km above the geostationary orbit;

(i) Launch vehicle sub-orbital stages should be equipped with tracking aids to permit monitoring of trajectories and prediction of impact points;

(j) Launch vehicle sub-orbital stages should be equipped with a remotely controlled engine shut-off and/or stage destruction capability, as appropriate, in order to prevent the descent of stages/or stage debris outside pre-defined safety limits;

(k) The design of orbital stages should support the capability of being safely de-orbited or moved to a disposal orbit, as appropriate;

(l) Launch vehicles should be designed to be insensitive to lightning strike when on the launch pad and during atmospheric flight;

(m) The design should prevent re-contact or impact of separated spacecraft or launch vehicle stages due to cold thrusting, tumbling or attitude changes.

11. In order to minimize the creation of space debris, the Canadian RADARSAT programme undertook two specific preventative measures:*

(a) The first consisted of establishing a system-level requirement that any solid debris resulting from the operation of a restraint/release mechanism should be contained. That is, all contractors were required to design a system so that no debris would be released by the spacecraft during deployments;

(b) The second preventative measure consisted of protecting the RADARSAT spacecraft from the existing space debris environment. That measure was undertaken in order to ensure, to the best extent possible, that the RADARSAT spacecraft did not prematurely become space debris as a result of a space debris impact.

II. DEBRIS MITIGATION TECHNIQUES USED IN LAUNCH VEHICLES

12. Launch vehicles and spacecraft can be designed so that they are litter-free, that is, so that they dispose of separation devices, payload shrouds and other expendable hardware (other than upper-stage rocket bodies) at a low enough altitude and velocity that they do not become orbital. This is more difficult to do when two spacecraft have a common launch vehicle. In addition, stage-to-stage separation devices and spacecraft protective devices such as lens covers and other potential debris can be kept captive to the stage or spacecraft with lanyards or other provisions to minimize debris. This is being done in some cases as existing or new designs allow. These practices should be continued and expanded when possible.

13. Litter-free operations should combine design and operational practices, thereby contributing to the achievement of the goal of limiting further orbital debris created by any space operations. As a result of such efforts, the growth rate of orbital debris will decline, although the overall debris population will continue to increase.

14. Perhaps the most significant debris-reduction policy has been the NASA requirement instituted in 1982 for the venting of the unspent propellants and gases from Delta upper stages to prevent explosions caused by the mixing of fuel residues. That practice was continued when the United States Air Force began direct acquisition of Delta launch vehicles and several private companies initiated commercial launch services. No United States hypergolic stages following this procedure have inadvertently exploded.

15. The United States launch planning is also affected by projections of the Collision Avoidance on Launch Program, which warns of potential collisions or near misses for manned or man-capable vehicles before they are launched. Some launches have been momentarily delayed during their countdowns to avoid flying in close proximity

*The details of these measures have already been provided in the report of the Secretariat on various steps taken by space agencies for reducing the growth or damage potential of space debris (A/AC.105/620).

to orbiting objects. However, it should be noted that sensor limitations affect the accuracy of any predictions. In addition, the Computation of Miss Between Orbits Program provides information regarding the proximity of payloads to debris objects in orbit and has been used during manned missions. Since 1986, the Shuttle has manoeuvred three times for collision avoidance.

16. Recently, the modernization of operative, and development of new, space and rocket technology led space-related enterprises in the Russian Federation to undertake a number of preventive measures for reducing the level of space debris pollution, namely:

(a) A new DM upper stage of the Proton launcher is under development, incorporating provisions to eliminate the separation of the engine starting system (SOZ motor) from the stage during its powered ascent into orbit, so that no additional debris is created. Special measures are also being developed to prevent explosion of this stage after its injection into orbit;

(b) It is anticipated that the modernized Soyuz-2 launcher will be equipped with a passive decelerator to prevent accumulation of spent rocket stages on working orbits;

(c) On-board electric power supply systems are being modernized to increase the safety of their operation in both active and passive modes.

17. During the launchings of the Zenit launch vehicle, developed by the Yuzhnoye Design Office at Dnepropetrovsk, Ukraine, its second stage is injected into orbit. After injection, up to 4 tonnes of the oxidizer and its vapours, up to 2 tonnes of the fuel and up to 60 kg of gaseous helium can still remain in tanks. To date, there have been 2 cases of second-stage destruction in orbit out of 21 successful launches. Post-flight analysis has shown that in the two cases, rocket stages were under conditions of solar illumination for almost the entire time before the destruction occurred (17-18 revolutions around Earth). This condition had apparently promoted more intensive oxygen evaporation, which subsequently saturated the standard safety valve. In case of slow or no drain of evaporating oxygen through a safety valve, the remaining oxygen has enough energy for tank destruction.

18. Based on this analysis, a modified system of oxygen tank venting of the Zenit second stage has been developed. In addition, in order to reduce the thermal flows of oxygen at the initial period in orbit, the vehicle launching time is selected to avoid long periods of solar illumination. Six Zenit vehicles were launched after implementation of these important improvements and no last stage destruction has occurred. For future launches of the Globalstar programme, an additional pyrotechnic valve will be installed on the upper part of the second-stage oxidizer tank. This valve will be activated after orbital injection by a special command from the on-board control system. The venting nozzles will be installed at different angles to provide for proper spinning of the stage along its longitudinal axis. Furthermore, a quantity of the remaining working reserve of oxygen in the tank is reduced by careful selection of the ascent trajectory.

19. The Japanese space agency NASDA has implemented the draining of residual propellants (LOX, LH_2, N_2H_4) and residual helium gas of the second stage of the H-I/H-II launcher. The release of mechanical devices at satellite separation and solar panel deployment has been avoided except in some particular missions, such as the separation of spent apogee motors for the geostationary meteorological satellite. In order to prevent the unintended destruction in space of the second stage of the H-II launcher, the command destruct system is disabled immediately after injection into orbit and its pyrotechnics are thermally insulated to preclude spontaneous initiation.

III. PREVENTION OF ACCIDENTAL DEBRIS CREATION

20. The most urgent activities in the Russian Federation regarding space debris mitigation technology are directed towards the prevention of explosions of used spacecraft and rocket stages caused by chemical energy accumulated on board. It is well known that such explosions are currently the main sources of the most dangerous small-sized debris. With the gradual accumulation of used spacecraft in orbits, their collisions with space debris (kinetic

explosions) will soon become the main sources of new debris. Therefore, a long-term programme of space debris level control should also include an item on removing such objects from working orbits.

21. For some missions, the performance of the launch vehicle has a sufficient margin so that the stage has propellant available to do a de-orbit burn. The stage needs to be modified to provide the guidance and control capabilities required for a controlled de-orbit after fulfilling its primary mission (which is the delivery of the payload into orbit).

22. When the mission requires delivery of a spacecraft which itself has manoeuvre capability, two alternatives are possible. One is to leave the upper stage attached for delivery of the spacecraft to orbit in order to maximize its manoeuvre capability. The second is to separate the spacecraft at sub-orbital velocity so that the stage decays naturally and the spacecraft uses its on-board propulsion to establish its orbit. From a cost-penalty perspective, the first alternative results in a greater mass in orbit - a potential debris hazard -while the second alternative increases the complexity of the spacecraft. Assessing which alternative is more appropriate requires further study.

23. An alternative to entry and ocean disposal is relocation to a disposal orbit. In LEO, this is not an advantageous strategy because it generally requires a two-burn manoeuvre that is more costly in terms of fuel than the single burn that is required for entry. During the 1980s and early 1990s, the former Union of Soviet Socialist Republics used such an orbit in LEO to dispose of 31 of its nuclear power sources.

24. Another alternative to a controlled direct entry is a manoeuvre that lowers the perigee so that the inertial orbital lifetime is constrained to a period of 25 years. Such a manoeuvre removes the object from the region of high hazard quickly and removes the mass and cross section from orbit in a small fraction of the orbital lifetime required without such a manoeuvre. This is significantly less costly than a targeted entry. It makes the eventual re-entry happen earlier, but raises questions regarding liability issues.

25. To be in accord with the NASA standard of the United States, the Japanese space agency NASDA also adopted 25 years as an allowable lifetime until mission-terminated space systems re-enter by natural force into the atmosphere. For most systems, this occurs if the orbit is lower than 750 km. In the case of higher orbits and if the re-entry risk is allowable, the most feasible measure to avoid collision risk with other operating space systems is to reduce the orbital lifetime by reducing the perigee height of the orbit. However, this manoeuvring may require a propulsion system that might complicate the design of the system.

26. In case the re-entry risk is not allowable, the desirable solution may be the controlled re-entry over an empty oceanic region. NASDA does not have any experience with controlled re-entry of spacecraft from a high altitude, but the tropical rainfall measuring mission (TRMM) is supposed to re-enter over an oceanic region from an altitude of 380 km to provide this kind of data. However, to minimize the casualty area where the surviving fragments would be scattered, the structure should be strong enough to withstand break-up caused by aerodynamic force at an altitude of 70-80 km. This condition is contradictory to required small re-entry survivability. Another problem is the selection of a really safe oceanic region for such a manoeuvre.

27. According to NASDA, if the operational orbit is too high to perform a lifetime reduction, the space system should be reboosted into a disposal orbit region. In planning to reboost into higher orbit, care must be taken to increase both perigee and apogee heights to avoid any interference with the operational orbit. Altitude ranges from 1,300 km to 1,400 km may be candidates for tentative disposal orbit. If such a manoeuvre requires an unacceptable amount of propellant, a limited corrective impulse could be used to move the object a small distance above the operational orbit until some additional mitigation measures become available (e.g. orbital retrieval by the Space Shuttle).

28. The removal of large, inert objects requires an active manoeuvre vehicle with the capability to rendezvous with and grapple an inert, tumbling and uncooperative target and the ability to properly and accurately apply the required

velocity increment to move the object to a desired orbit. These capabilities have been demonstrated by the Space Shuttle, but no unmanned system has these capabilities for higher altitudes and inclinations.

29. The multiplicity of small objects makes it impossible to actively acquire and enter each object individually. There are two classes of schemes that have been proposed for the removal of such debris. One is the use of active or passive devices to intercept particles with a medium, such as a large foam balloon, that absorbs kinetic energy from the particles. This causes the objects' perigee to fall to regions where aerodynamic drag induces entry. The other is an active device that illuminates the particle with a beam of directed energy, causing the particle either to lose velocity or to be dissipated into fragments that are no longer of significant mass.

IV. ENVIRONMENTAL PROTECTION OF THE GEOSTATIONARY ORBIT

30. For missions to the geostationary orbit (GSO), the pertinent considerations for disposal of the upper rocket stage are the launch date, launch azimuth and the perigee of the transfer stage. For multi-burn systems, positive ocean disposal can be achieved with an apogee burn of a few metres per second if the stage has sufficient battery lifetime and contains an attitude reference and control system.

31. In addition, there are sets of launch times to GSO aligning the orbit of the transfer stage so that natural forces (properties of the Sun, Moon, Earth etc.) act to lower or raise the perigee of the stage. Consideration of the effect of these forces can minimize the cost of active control of liquid propellant stages and is a low-cost technique for the disposal of solid rocket motor stages. The only alternative strategy for the disposal of solid rocket motors is to orient the thrust vector of the rocket in a direction so that the perigee of the transfer orbit resulting from the burn is at a low enough altitude to cause the stage to eventually re-enter (sometimes referred to as an off-axis burn). This strategy results in a performance penalty of about a l5 per cent for the stage.

32. The measures adopted for the NASDA programmes seem to be relatively inexpensive and have proved to be very effective. For example, the orbital life of the ETS-VI H-II second stage (1994-056B) was reduced to about seven months as a result of de-orbiting. The stage re-entered into the Earth atmosphere on 31 March 1995.

33. The use of disposal orbits is a technically feasible strategy for clearing the GSO region, but it is not the only available strategy. The cost-effectiveness of a disposal orbit strategy compared with other strategies has not been examined. If raising the orbit is to be the technique of choice, then it requires planning and reserving the necessary propellant resources to effect the manoeuvre. Preliminary studies indicate that the orbit needs to be raised on the order of 300 km to serve the intended purpose, not the 40-70 km that has been used by some operators. The performance cost to reboost is 3.64 m/s for each 100 km or 1.69 kg of propellant for each 1,000 kg of spacecraft mass. To reboost for 300 km is comparable to three months' station-keeping.

34. Study Group 4 of the International Telecommunication Union (ITU) Radiocommunication Bureau, in which the United States is a participant, has already endorsed the recommendation that all geosynchronous orbit satellites should be boosted not less than 300 km above the geosynchronous orbit at their end of life and that the spacecraft should then be made inert by discharging any residual propellants and gases and "safing" the batteries.

35. The National Oceanic and Atmospheric Administration (NOAA) of the United States, NASA and several programmes of the United States Department of Defense regularly boost their satellites that are no longer functional into orbits above GSO to prevent the creation of additional debris by inadvertent collisions with other drifting satellites and to free valuable orbital slots.

36. The technology for removing Russian spacecraft from GSO at the end of their active lifetime is based on the use of remaining fuel (for satellites of the Statsionar-D, Ekran-M and Gorizont series) and on the provision of the necessary amount of additional fuel to ensure the increase of the mean altitude of the orbit by 200 km (for new types of spacecraft).

37. To evaluate the adequate distance for disposal of the GSO spacecraft, the effect of long-term orbital perturbations was studied in Japan. The resulting value of the minimal distance is almost the same as that recommended by both ITU and NASA Code-Q, namely about 300 km. The current minimum requested by NASDA is 150 km and the target is 500 km. Actual re-orbit is often more than required to eliminate the influence of possible measuring system errors.

Notes

[1]Official Records of the General Assembly, Fifty-first Session, Supplement No. 20 (A/51/20), para 86.