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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-second session, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space agreed that it would be desirable to compile information on various steps taken by space agencies for reducing the growth or damage potential of space debris and to encourage common acceptance of those steps by the international community, on a voluntary basis (A/AC.105/605, para. 80).

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

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

I. DEBRIS MITIGATION TECHNIQUES USED IN LAUNCH VEHICLES

4. The National Aeronautics and Space Administration (NASA) of the United States of America established debris mitigation strategies in the early 1980s after observing that hypergolic upper stages would often explode some time after they had completed their mission. The latent period would range from several weeks to as long as 16-27 years. Examination of the design of the stages led to the identification of a number of potential failure modes, modes that could have led to the observed explosions. In each case, the event occurred because of the stored energy in the flight performance residuals that had been on board at the termination of the launcher stage mission. Since then, a number of different techniques have been used to burn or vent the stored propellants and pressurants and to open electrical circuits and batteries.

5. All United States launch systems execute some form of contamination and collision avoidance manoeuvres shortly after spacecraft separation. In general, the components of the system for releasing the spacecraft remain with the upper stage. The initial procedures to deplete stored energy were developed in 1981, when it was observed that second stages of the Delta launcher would explode some time after completion of payload delivery. Analysis indicated that with residual propellants, the nitrogen tetroxide and helium could be heated to temperatures that would generate pressure exceeding the strength of the material. When the tank structure failed, the propellants ignited and the stage exploded. The fragmentation of the second stage of Delta-111 on 1 May 1991, after 16 years in orbit, supports this conclusion. The second stage depletion burn was first implemented in September 1981, just four months after the investigation had started. No Delta stage that has followed stored energy depletion procedures has exploded since then.

6. In the case of the Centaur launcher, used on the Titan and the Atlas boosters for geosynchronous orbit missions, a collision avoidance manoeuvre is conducted so that the Centaur stage is boosted into a graveyard orbit above the geostationary arc. In all cases, the engines are burned to depletion to preclude stored energy from inducing overpressure explosions. After completion of the depletion burn, the pressurants are vented.

7. The last stage of the Titan launcher is normally disposed of by leaving it on a ballistic re-entry trajectory. When the stage has a limited orbital lifetime, the commercial Titan-2 stage is modified so that it will not overpressurize during the period before atmospheric re-entry. To date, this has been done by thermal control paints. In more powerful versions of Titan-2, which augment the lift capability by an array of solid rocket motor boosters on the first stage, procedures similar to those used by Delta will be adopted.

[1] *Official Records of the General Assembly, Fiftieth Session, Supplement No. 20* (A/50/20), para. 76.

8. In the case of Titan-3 and Titan-4, the second stage is burned to depletion after payload separation and the collision contamination avoidance manoeuvre is conducted, generally to de-orbit the stage. The upper stage then has to take measures to minimize debris. The predominant upper stage is the Centaur mentioned above.

9. The other United States upper stages that can be used, the payload assist module (PAM-D2), Transtage, inertial upper stage (IUS) and transfer orbit stage (TOS), have not flown, or been scheduled to fly, since debris avoidance manoeuvres have been required, so no explicit procedures have been defined. Transtage has restart capability, so it could use procedures similar to Delta or Centaur stages. The others are all solid rocket motors and have limited capability to manoeuvre with attitude control system after payload separation.

10. The French space agency Centre national d'études spatiales (CNES), together with Arianespace, started residual fuel venting from the upper stage of the Ariane launcher in the case of launches into low-altitude circular orbits (e.g. the satellite pour l'observation de la Terre (SPOT-2), the European Remote Sensing Satellite (ERS-1) and Topex/Poseidon satellites) to prevent explosions. Since flight V-59, fuel venting of the third stage is routinely carried out regardless of the type of the target orbit.

11. Future CNES debris mitigation policies include the following:

(a) The launcher may leave in orbit a maximum of one inert object (debris) per satellite launched;

(b) All objects left in orbit (whatever the orbit may be) must be made fully passive to prevent any further explosions after the end of the mission. Active elements such as batteries or tanks containing residual propellant must reach a fully inert state after delivering the satellites to orbit;

(c) Last stage separations must be clean and explosive bolts and clamps must be trapped to avoid operational debris;

(d) Solid propellant perigee kick motors that release aluminium particles are to be avoided;

(e) All other stages must naturally re-enter the atmosphere or be de-orbited.

12. A special release system has been developed for the upper stage of the Chinese Long March 4 launcher. This system is designed to release, after separation of the satellite, the residual propellant from the tank and the residual gas from the high-pressure container in the booster, in order to avert the danger of in-orbit disintegration of the upper stage. The de-orbiting technology will be used on the improved Long March 2 launcher to make possible the earlier re-entry of its upper stage.

II. PREVENTION OF ACCIDENTAL DEBRIS CREATION

13. There are different types of orbital objects; the largest number of such objects are fragment debris created by explosions. In order to avoid significant accidental debris creation, the National Space Development Agency (NASDA) of Japan has implemented provisions for the draining of residual propellants (liquid oxygen (LOX), liquid hydrogen (LH_2), N_2H_4) and the residual helium gas of the H-I and H-II second stage. The release of mechanical devices at satellite separation and solar paddle deployment has been avoided except in certain missions, such as the separation of spent apogee motor for the geostationary meteorological satellite. For the purpose of the prevention of unintended destruction of the H-II second stage in space, the command destruct system is disabled immediately after injection into orbit and its pyrotechnics are thermally insulated to preclude spontaneous initiation.

14. NASA has been conducting studies to determine how a requirement to de-orbit objects might be implemented in a cost-effective manner. In general, lowering the perigee of the orbit, so that the orbital life is 25 years or less, is adequate to protect the future environment. Such a manoeuvre is effective because, with the lower perigee subject

to drag, the apogee quickly migrates out of the region of greatest risk and the risk during the prolonged decay is minimal. For flight planning and mission management purposes, it is proposed to integrate this requirement with the other variables used in calculating the current flight performance reserve. Because of variance in the actual flight performance, the residuals available for the manoeuvre may not achieve the desired reduction in every instance, but on average the goal will be met. Clearly it is necessary for all operators to adopt such a practice concurrently because there is no significant effect if it is adopted only by one operator.

15. A large company in the United States that is responsible for development of the Iridium constellation of 66 small communications satellites has included provisions for debris mitigation in the very first phases of its programme. In the original operations concept, the most important provision was the de-orbiting of spent spacecraft. The concept also called for selection of orbits that minimized the collision hazard both with the company's own spacecraft and with other objects, while minimizing debris associated with insertion and deployment. Subsequent updates of the concept have dealt with the explosion hazard and the need for the spacecraft itself to be implementing mitigation techniques autonomously. In particular, the nominal orbits of satellites in the constellation have been adjusted to provide for miss distances greater than 100 km at the polar region (where all orbits are intersecting). Also, based on input from various suppliers, nickel-hydrogen batteries and hydrazine fuel have been identified as the only explosion hazards, and provisions have been made to minimize that kind of failure.

16. The procedures for the operational phase of the Iridium project include supporting software that will direct (under specific conditions) the spacecraft to execute fuel-depleting and perigee-lowering burns with whatever capability it can use. The procedures emphasize the need for ailing spacecraft to be taken out of the operational orbit and "safed" with regard to explosion hazard. The operator of the Iridium system has agreed to the de-orbiting philosophy, which can occasionally result in de-orbiting perfectly healthy spacecraft because the fuel remaining is only enough for de-orbiting.

17. Debris removal options have been used on a few occasions to date, such as retrieval via the United States Space Shuttle or de-orbiting. In the manned space programme of the Russian Federation, as in the manned space programme of the former Union of Soviet Socialist Republics, debris removal has been used consistently through the de-orbiting of the Progress supply vehicles and ageing orbital stations into oceanic areas (except Cosmos 557, Salyut 2 and the Salyut 7/Cosmos 1686 stations). Most re-entering spacecraft and upper stages have been destroyed by entry heating. In rare cases (Skylab, Cosmos 954 and the Salyut 7/Cosmos 1686 stations), some solid pieces have reached the surface of Earth.

18. According to a debris mitigation study conducted in China, no measures are required at the design stage for those parts and components of satellites and launcher stages that either do not enter into outer space orbit or are capable of returning to the atmosphere soon after their entry. For parts and components sent into an orbit with a longer orbital lifetime, it is necessary to take measures to tether them with the main object in order not to produce more debris. Whenever possible, China is using recoverable satellites for carrying out scientific experiments in outer space, thereby reducing the number of jettisoned satellites in orbit. Efforts are also being made to improve satellites and launchers in terms of design, launching technique and reliability.

19. In order to minimize the creation of space debris, the Canadian Radarsat programme has established a system-level requirement that any solid debris resulting from the operation of a restraint/release mechanism must be contained; that is, all contractors are required to design systems in which no debris is released by the spacecraft during its deployment in orbit.

20. During the operational lifetime of the planned Envisat spacecraft of the European Space Agency (ESA), the creation of mission-related objects will be precluded. At end-of-life, the controlled venting of pressure vessels and residual fuel, discharging of batteries and shutting down of the power system are foreseen.

III. ENVIRONMENTAL PROTECTION OF THE GEOSTATIONARY ORBIT

21. The International Telecommunications Satellite Organization (INTELSAT) has adopted the following practices to minimize the creation of space debris in the region of geostationary orbits (GSO):

(a) At the end of their operational lifetimes, INTELSAT will boost its communication satellites into an orbit at least 150 km above the geostationary arc. The intended increase in orbit will be 300 km for the INTELSAT-VI and all later satellite series;

(b) INTELSAT will discourage manufacturers of its spacecraft from using designs that jettison spacecraft parts, especially near GSO. For example, solid rocket motor casings and solar array cable wraps will stay attached to the spacecraft.

22. The United Kingdom of Great Britain and Northern Ireland recognizes the unique nature of the geosynchronous altitude and the need to preserve this global resource for future development and exploitation. Consequently, the Skynet family of geosynchronous communications satellites controlled by the United Kingdom have the following operational requirements:

(a) For all satellites that are currently in orbit, a fuel budget is allocated that is capable of performing a tri-impulse manoeuvre to a circular orbit with a minimum altitude of 150 km above the geostationary ring at the end of operational life;

(b) Design requirements for future series of satellites specify a capability to achieve a minimum altitude of 500 km above the geostationary ring using a similar tri-impulse manoeuvre at the end of operational life.

23. In all cases, in order to eliminate the potential for explosion, appropriate operational procedures will be established to make passive all energetic subsystems when the satellite has been placed in a graveyard orbit.

24. The following ESA geostationary satellites have been re-orbited: OTS-2 (orbiting 318 km above GSO), GEOS-2 (260 km), Meteosat-2 (334 km), ECS-2 (335 km) and Olympus-1 (due to a failure, this satellite has been left at orbit 213 km below GSO).

25. Similarly, the unusable meteorological satellites of the Geostationary Operational Environmental Satellite (GOES) series are put into disposal orbit and deactivated by their operator, the National Oceanic and Atmospheric Administration (NOAA) of the United States. The NOAA policy is to boost them into a "super-synchronous" orbit, at least 250 km above GSO, depleting all remaining fuel and minimizing the threat to other spacecraft in GSO. After the boost or disposal phase is complete, the spacecraft are then electronically deactivated by sending commands to turn off all communication down-links, battery under-voltage protection circuitry, and telemetry subsystems.

26. Using this procedure the SMS-1 satellite was put into disposal orbit 500 km above GSO, SMS-2 about 245 km above GSO and GOES-4 about 277 km above GSO. The GOES-1, GOES-5 and GOES-6 satellites were used operationally with no replacements available until they depleted their fuel in GSO. Those satellites have been left in the GSO region, but have also been deactivated. NOAA plans to conserve enough fuel on future operational meteorological GOES satellites to perform boost manoeuvres. The current GOES I-M spacecraft series includes a de-orbit fuel supply in addition to the nominal five-year operational fuel supply.

27. The number of objects in the geostationary transfer orbits (GTO) is increasing and is considered to be hazardous to future space activities because of their long orbital life. An effort is currently being made in Japan to decrease the orbital life of the second stage of the H-II launcher. The second stage (1994-056B) of the H-II second flight of 28 August 1994, for instance, was de-orbited from GTO with an apogee of 36,346 km and a perigee of 251 km to the orbit with an apogee of 32,298 km and a perigee of 150 km by performing idle mode burn and depleting residual propellants. It was observed that the second stage had, by 31 March 1995, fragmented into at least six new

objects, which have decayed since then. NASDA has, since 1985, also re-orbited GSO satellites after end-of-life at least 150 km upward, aiming at 300 km.

IV. DEBRIS PROTECTION OF ACTIVE SPACECRAFT

28. Measures were taken to protect the Canadian Radarsat spacecraft, successfully launched on 4 November 1995, from the existing space debris environment. Such measures were necessary in order to ensure, to the greatest extent possible, that the Radarsat spacecraft would not prematurely become space debris as a result of a space debris impact. The space debris environment to be encountered by Radarsat was defined using the ENVIRONET database of NASA. Individual spacecraft components were then examined to determine their vulnerability to that predicted environment. The vulnerability assessment included using hypervelocity impact equations, as well as actually subjecting spacecraft hardware to hypervelocity impact tests at the NASA Johnson Space Center. Where required, shielding was added to the spacecraft in order to bring the survivability of the spacecraft to an acceptable level. The shielding included adding Nextel (a ceramic fibre cloth) to thermal blankets, adding bumpers in front of exposed hydrazine lines and wire bundles, and thickening some component boxes in order to protect their enclosed circuits.

29. The planned ESA module of the International Space Station will be shielded in order to withstand the impact of particles of about 1 cm.

V. RECOMMENDATIONS OF THE INTERNATIONAL ACADEMY OF ASTRONAUTICS

30. The International Academy of Astronautics (IAA), which has observer status with the Committee on the Peaceful Uses of Outer Space, initiated a study on orbital debris, which was prepared by an ad hoc expert group of its Committee on Safety, Rescue and Quality. The objectives were to evaluate the need and urgency for action and to indicate ways to reduce the hazards posed by such debris. In the report on the study, which was approved in October 1993 as an official IAA position paper, it was recommended that the following action be taken immediately (A/AC.105/570):

(a) No deliberate breakup of spacecraft that produces debris in long-lived orbits;

(b) Minimization of mission-related debris;

(c) "Safing" (venting) procedures for all rocket bodies and spacecraft that remain in orbit after completion of their mission;

(d) Selection of transfer orbit parameters to ensure the rapid decay of transfer stages;

(e) Re-orbiting of geostationary satellites at end-of-life (minimum altitude increase of 300-400 km);

(f) Separated apogee boost motors used for geostationary satellites should be inserted into a disposal orbit at least 300 km above the geostationary orbit;

(g) Upper stages used to move geostationary satellites from GTO to GSO should be inserted into a disposal orbit at least 300 km above the geostationary orbit and freed of residual propellant.