SPACE DEBRIS RELATED ACTIVITIES IN JAPAN
- PAST, PRESENT, AND FUTURE -

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ABSTRACT

After introducing Japan's short history of space debris related activities, individual R&D activities conducted so far and future plans are presented according to the well accepted classification, that is, Observation/Modeling, Protection and Mitigation

1. INTRODUCTION AND SHORT HISTORY

One of the world's earliest warnings on the space debris problem was made in Japan in 1971 by Nagatomo and his colleagues of the Institute of Space and Astronautical Science (ISAS) /1/. Since that time, independent research on this topic has been carried out by various organizations in Japan. However, the quality and quantity of the research was kept rather low, and very limited significant international contributions were made.

In light of this situation and partly in response to the NASA initiatives, the Space Debris Study Group was founded by the Japan Society for Aeronautical and Space Sciences (JSASS) in September 1990. Its objectives were to promote overall space debris related research, to rouse public awareness of this issue and to provide guidelines to cope with it. The Interim and Final Report were published in January 1992 /2/ and March 1993/3/. To follow up some of the recommendations in those reports, two study groups of JSASS, "Study Group on Space Debris Prevention Design Standards" and "Study Group on Space Debris and Micrometeoroid Impact Detection" started their activities in July 1993. The former made a great contribution for NASDA to establish its Space Debris Mitigation Standard in March 1996 and the latter leaded us to actual promotion of SFU/PFA activity from 1996. On the other hand, NASDA, as the implementing organization of Japan's space development activities, formed in-house Space Debris Working Group in August 1993 and begun to tackle with the debris problem.

In response to the above mentioned activities, the Space Activities Commission (SAC) of Japan, which supervises the Japan's space activities, revised its Long Term Vision in the beginning of 1996 and recommended that Japan should aim to develop space systems that will leave as little space debris as possible. By this policy, space engineers and researchers responsible for the safety in space activities or having strong concerns about the space debris problem were encouraged to conduct their space debris related activities in various fields, some of which are to be introduced in this paper. In addition, international collaboration has been actively pursued in the framework of the Inter-Agency Space Debris Coordination Committee (IADC). In 1999, NASDA organized the Space Debris committee inviting space debris experts from inside and outside which is expected to work as a forum to exchange information and to coordinate domestic activities on space debris. The fundamental policy mentioned above has been just updated in February 2001 and also mentions the importance and immediacy of this issue. /4/

In the following chapter, individual activities conducted so far or planned are introduced according to the well accepted classification, that is, Observation/Modeling, Protection and Mitigation.

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2. OBSERVATION

2.1 Ground-based Observation

2.1.1 Pioneering observation efforts

There were two Japan's pioneering efforts to contribute to the knowledge of space debris environment in early 90s. Radar observations was started by Kyoto University utilizing the Middle and Upper atmosphere (MU) radar at Shigaraki, Shiga prefecture, Japan (34.85 ° N, 136.11 ° E). The radar is a monostatic pulse Doppler radar operating at 46.5 MHz with an active phased array antenna of 103 m in diameter, peak output power of 1 MW. The largest advantage of the MU radar is its fast beam steerability, which makes it possible to observe the radar scattering cross-section (RCS) variation of unknown objects for a period of 10-20 seconds. The antenna beam of the MU radar has an width of 3.7° , and can be pointed to any desired direction within the coverage of 30° from the zenith in 10 μsec. It is therefore possible to observe the passage of an object with multiple beams. It provided valuable information for RCS comparisons using radars with different frequencies. /5/

On the other hand, optical observations of geostationary objects was pursued by Communication Research Laboratory (CRL), utilizing an optical tracking system in Koganei, Tokyo (35.42° N, 139.29° E). It consists of a 1.5 m telescope, a liquid nitrogen cooled CCD camera, an image processing computer and other scientific and communication equipment. The system was originally constructed as a fixed ground station for space communication experiments using a geostationary satellite. Choosing an appropriate CCD detector, GEO objects which are as small as 50 cm are theoretically observable.

2.1.2 Bistatic observation

Prof. Takano and et al. conducted the study on the bistatic radar observation technique from the view point of utilization of world-wide existing facilities on the ground. Using the 10 m and 20 m antennas in KSC (Kagoshima Space Center) as a transmission station and the 64 m antenna in Usuda Deep Space Center as a reception station, they successfully demonstrated the applicability of this technique in the observation experiment of " Yokoh ", a scientific satellite in a circular orbit of 600 km altitude. It was shown that by means of the modern communication technology this kind of system could be sophisticated to have the capability to observe small size objects of 19 mm in diameter at 500 km altitude/6/.

2.1.3 NAO-NASDA observation efforts

As a part of the study for the ground-based observation system, NASDA requested National Astronomical Observatory (NAO) to conduct preliminary studies on optical observation of satellites. In October 1992, a trial was made to observe a spent geostationary meteorological satellite, GMS-4 (Himawari-4), using the 60 cm reflective telescope in Kagoshima Space Center (KSC) of the Institute of Space and Astronautical Sciences (31.13 ° N,131.04 ° E). The telescope was specially mounted with CCD camera for this study. Based on results of their continuing efforts, they studied the configuration of a new telescope dedicated to observation of rapidly moving space objects like space debris, which is bearing fruit as construction of Bisei Space Guard Center described below.

2.1.4 Bisei-, Kamisaibara- Space Guard Center

New optical telescopes to detect Near-Earth asteroids (NEAs) and Space Debris are under construction at Bisei-cho, Okayama, Japan. These systems consist of two telescopes with apertures of 0.5 m and 1.0 m and the 0.5 m one is already in operation from February 2000 and the 1.0 m one will be set up very soon. Although the telescope apertures are not so large as usual astronomical telescopes which was specifically designed for observations of pin point targets, there are several first grade technologies introduced for these telescopes. For example, fast f-ratio (F/3), wide field (3 degree), 10 times 2 x 4 k back-illuminated CCD camera, fast read-out (8 seconds), high position accuracy (0.2 arc seconds), and so on are expected to be achieved for the 1.0 m telescope/7/.

Fig.1 0.5m Optical Telescope
at Bisei Space Guard Center

A radar system to detect space debris is also under construction at Kamisaibara-mure, Okayama, Japan and is to be operational in 2003. The radar system is an active phased array antenna which includes radiators and transmitter/receiver/phase-shifter modules and employs S-band frequencies to minimize the effect of Rayleigh waves in order to observe very tiny objects, such as space debris of 2 to 3 cm in diameter in future, though at the beginning minimum detectable size is 1 m at a slant range of 600 km. The radar can simultaneously tracks 10 different objects within the area scanned by its antenna and can shift each beam electronically with a beam control subsystem, sending the phasing signal to the phase shifter. Observation will be performed for reentry prediction, collision warning between spacecraft and debris, and the analysis of space events, such as the explosion of a satellite.

2.2 In-situ Observation

2.2.1 Micro Particle Capturing missions (MPAC)

Intact capturing is one of the most promising methods to acquire the information of micro particulate environment in orbit. Japan's first measurement using such a device with Aerogel as capturing material was conducted on the JFD (Japanese Experimental Module Flight Demonstration) mission of the U.S. STS in 1997 but the exposure duration was limited to only 40 hours. With this preliminary experience, Japan is now developing two sets of MPAC instrument for measurement on the ISS, one of which is to be installed on the outside of the Russian Service Module in coming July and the other will be on the front side of JEM. Calibration data acquisition and related research are being promoted/8/.

2.2.2 SFU/PFA

Another way of measuring micro particle environment is the post flight analysis of the retrieved space system. So far, due to the lack of opportunity, such activities were limited to the cases of Solar Max, LDEF, EURECA and HST Solar Array. The Space Flyer Unit (SFU) was Japan's first reusable space platform dedicated to such space experiments as micro-G material processing, life science and other studies using the space environment. It was launched in March 18, 1995 by H-Ⅱlaunch vehicle and retrieved on Jan. 13, 1996 by the U.S. STS. On shipping back to Japan, extensive surface inspection on the particle impact sites was conducted by researchers of NAL and ISAS and more than 600 impact features were measured and photo-documented. In addition, more than 200 impact sites were chemically analyzed using SEM/EDX and all data are made open to the public through the Internet. Extensive calibration shots for converting impact damage data to particle data is now under way. The detailed analysis of the space debris impacts on SFU is believed to contribute to improve the knowledge of micro particle environment near the earth./9/

Fig.2 SFU Retrieval by the U.S. Space
Shuttle in Jan. 1996.

2.2.3 Feasibility study on on-orbit optical debris observation system

A feasibility study on the On-orbit Debris Observation System was started in 1995 jointly by NASDA and the Japan Society for Aeronautical and Space Sciences (JSASS) group with baseline requirements as follows, 1) debris observation in the GEO and near GEO, 2) optical observation, 3) detectable debris size of diameter 1cm, 4) observation from near GEO circular orbit or highly elliptic orbit, 5) mission life of 2 years or less, 6) dual mission launching by H-Ⅱ or equivalent, 7) low cost bus by applying the existing flight proven satellite system, 8) launch in 2004.

The study showed that debris observation with long enough time is feasible and that an elliptic orbit with large inclination is more suitable for determination of orbital parameters than a near GEO circular orbit/10/.

3. MODELING

Kyushu University group has been concentrating their effort on the environment evolution model in GEO since they started their activity. At first they developed a program, GEO-EVOL, to estimate population in GEO and its vicinity in future based on the present and projected space activities, assuming that only a half of the total fragments generated by explosion at the higher altitude than GEO should cross the GEO altitude. Recently they improved GEO-EVOL taking into account the dependency of this migration ratio on the breakup altitude and energy and renamed it as GEO space Debris Environment Evolution Model (GEODEEM). Their important findings are that the migration ratio shows a great influence on the future debris environment in the case of full realization of the ITU recommendation, and that, though re-orbiting strategy is very effective for environment preservation, GEO environment can easily reach at the level of the current LEO without taking some measure to suppress the explosion event rate/11/.

4. PROTECTION

4.1 Hypervelocity Launcher Development

4.1.1 NASDA: Two-stage Light gas gun

By necessity for verification of the JEM bumper system, NASDA developed a two-stage light gas gun which can accelerate a projectile of 1 g mass up to 6.8km/s with MHI. In the framework of IADC, NASDA participated in the international calibration campaign and confirmed that their gun has performance comparable to NASA's launching system. Using this facility, several series of hypervelocity impact tests have been conducted including hypervelocity test of JEM bumper, unzipping experiments under uni-axially stressed condition and crack durability test of the waffle and isogrid plate/12/.

4.1.2 TiTech: Three-stage light gas gun

The TiTec (Tokyo Institute of Technology) group is now developing a three-stage light gas gun with an additional compression stage to pump up the pressure of the second stage of a conventional two-stage light gas gun. The details are still not open to the public but it is said that they succeed in launching a projectile of 0.6 g mass at over 8 km/s.

4.1.3 NAL: Conical Shaped Charge

The average impact speed of space debris in LEO is estimated to be about 10km/s and the problem is that there exists no stable system to launch a projectile of 1g mass at this hypervelocity in the world. The Conical Shaped Charge (CSC) is believed to be one of the most promising ways to meet this requirement. Considering the need in JEM development by NASDA, NAL started R&D of CSC with MHI in 1992 and finally succeeded in launching an aluminum projectile of about 1g at 10.6km/s in 1998. But there still remain several issues to be solved for utilizing the CSC as a matured experimental tool. The authors believe that one is the effect of high internal energy imparted to the CSC projectile and that the other is the effect of the projectile irregular shape. Recently NAL is concentrating its efforts on these issues by developing the low speed CSC system/13/.

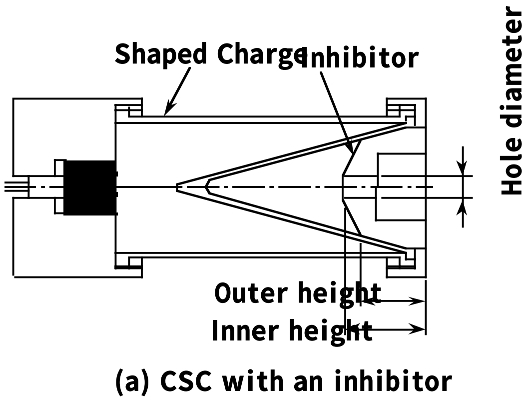

Fig.3 Inhibited Conical Shaped Charge

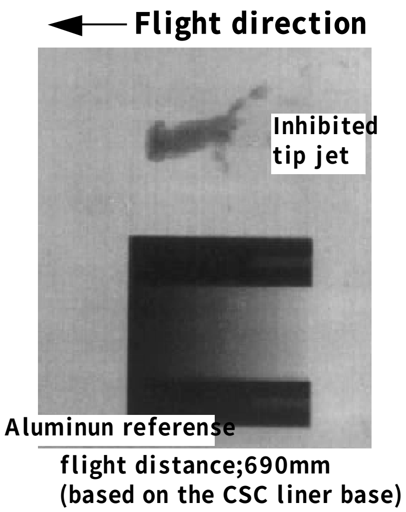

Fig. 4 Projectile Launched by CSC

4.2 Hypervelocity Impact Tests

4.2.1 JEM bumper verification test by NASDA

NASDA conducted a series of hypervelocity impact tests to investigate the shield design concept of JEM pressure module, i.e., bumper and isogrid pressure wall, against orbital debris impact. A two-stage light-gas gun had been newly developed for the purpose of improving test capability and the tests were carried out under the impact velocity of up to 6.8km/s with sphere aluminum projectiles of 3-9 mm diameters. Main purposes of the tests are to examine (1) penetration hole diameters, (2) unzipping failure (uncontrolled mode of crack propagation) of pressure wall, (3) failure tolerant performance of isogrid pressure wall, and (4) impact damage to pressure wall by inserting MLI. More than 120 impact tests were successfully performed and significant test results were obtained. Summaries of their results are followings: (1) penetration hole diameters are almost same size as ‘Goodwin’ prediction (2) critical crack length, which initiates unzipping failure of pressure wall, is much larger than that predicted by the Newman’s static equation, (3) crack propagation is slightly contained by the isogrid rib of pressure wall, and (4) penetration hole becomes smaller, while crack length becomes larger by installing MLI between bumper and pressure wall/14/.

4.2.2 Basic hypervelocity impact experiment in NAL

Besides technical support to NASDA’s JEM development activity, NAL has been conducting independently several series of basic hypervelocity impact tests using the powder gun at Kyoto University, the two-stage light gas gun and the rail gun at ISAS. It should be noted that, though the projectile mass and launching velocity are quite different with each other, projectiles of three launchers have almost the same kinetic energy. Using these launchers, the simple Whipple bumper of aluminum and CFRP was examined on their protection capability, which also provided invaluable calibration data to improve the accuracy of numerical simulation at the same time.

Recently, putting stress on the damage left in the CFRP plate as a structural member, NAL has just started a new series of CFRP impact tests using the two-stage light gas gun at ISAS which can accelerate an aluminum sphere of

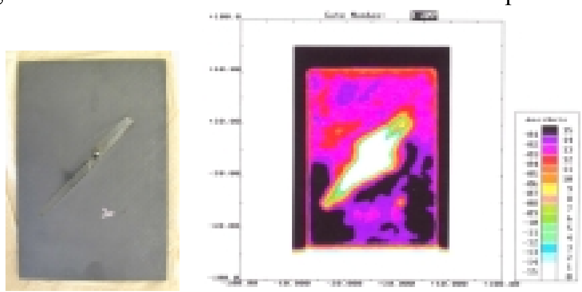

Fig.5 CFRP Impact Damage
Photo and Ultrasound Scanning Image

0.3 g up to about 4km/s. Dependency of the de-lamination area on the impact velocity is being investigated by the Non Destructive Inspection technique.

4.3 Numerical Simulation

NAL and CRC Research Institution have been continuing collaboration aiming at enhancement of applicability of the Hydrocode, AUTODYN-2D, to the space debris problem and improvement of simulation accuracy/15/. Findings and methodology established by NAL and CRC were actually applied to the design and analysis of the JEM bumper system. In addition to the simulation of hypervelosity impact phenomena, they also utilized that simulation code to design the CSC launcher described in 4.1.3 and to investigate the effects of high internal energy and irregular shape of its projectile/16/.

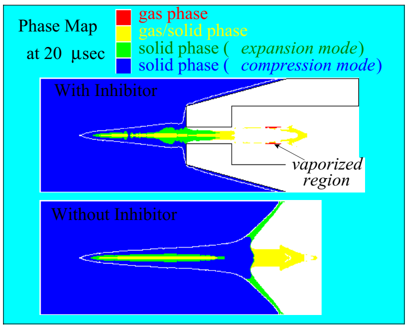

Fig.7 Numerical Simulation of Jet Formation Process by AUTODYN-2D

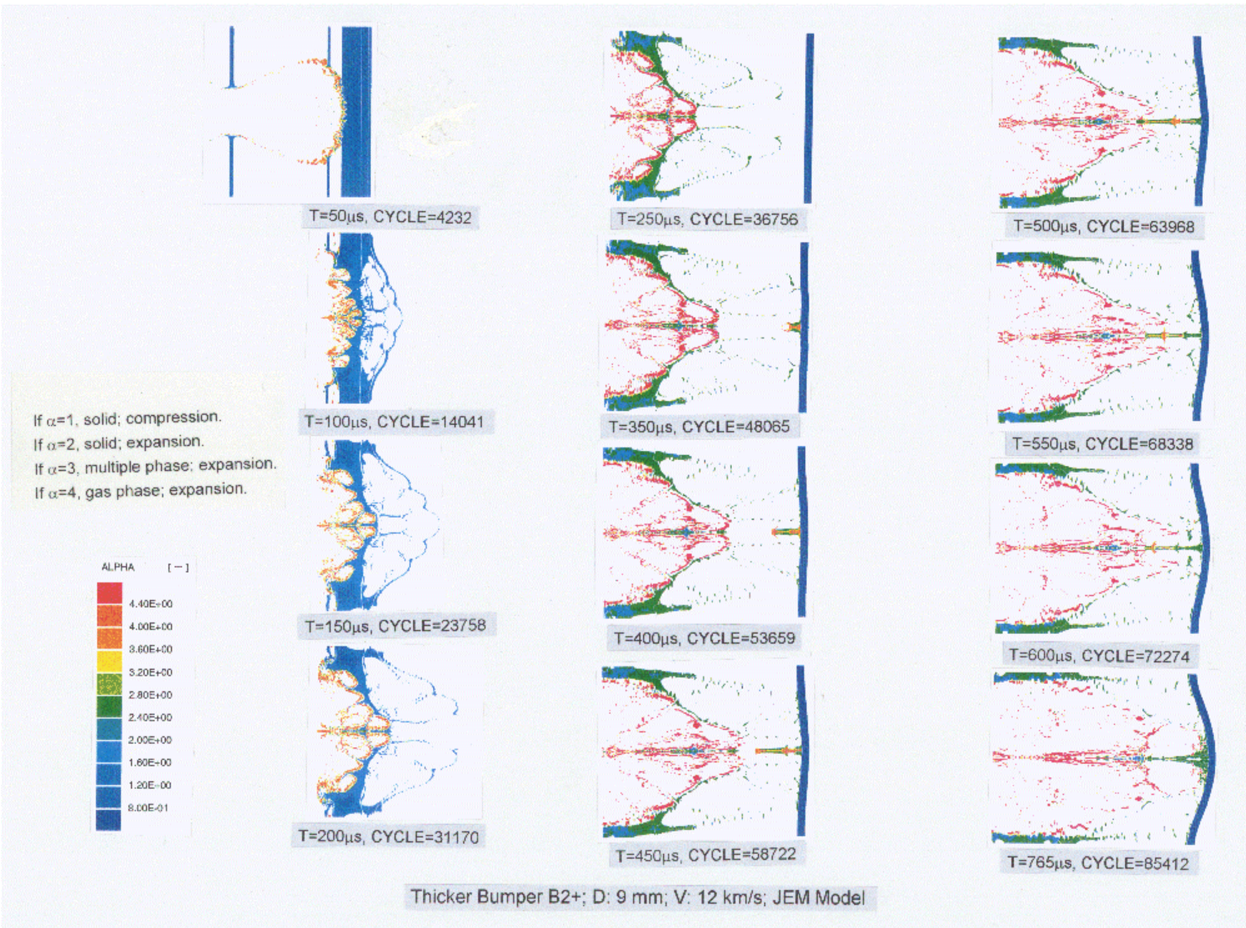

Fig.6 Numerical Simulation of Hypervelocity Impact against the Stuffed Bumper By AUTODYN-2D

5. MITIGATION

5.1 NASDA's Practices for Space Debris Mitigation

Based on full recognition of the space debris issue, NASDA took the lead in implementing the following general debris mitigation practices in its H-I program. Among them those well established in the actual operation have been also applied to the H-II program/17/.

1) Passivation of the second stage by draining the residual propellants (LOX, LH_2, N_2H_4) after separation of the payload,
2) Draining of residual helium gas,
3) Prevention of release of mechanical devices at spacecraft separation or solar paddle deployment,
4) Prevention of unintended, destruction of the second stage in space,
5) Reorbiting of the spent satellites in GEO,
6) Safety measures for separated apogee propulsion system,
7) Study of Minimization of Orbital Life of the GTO Objects.

5.2 NASDA Space Debris Mitigation Design Standard

On the request from NASDA, JSASS organized the "Study Group on Space Debris Prevention Design Standards" in September 1993 to discuss the contents to be involved in the "NASDA space debris mitigation design standards" which was actually issued in 1996. The study group consisted of members from major space faring companies, National Aerospace Laboratory (NAL), ISAS, and NASDA. As the first step (Sep.1993 ~ March 1994), possible or ever proposed mitigation measures were listed up and technological feasibility of them was discussed. And it also gathered information on the NASA and ESA activities for debris mitigation standards in order to keep the compatibility and harmony with those of other space faring nations. It was due to the understanding that space debris mitigation could not be realized without international cooperation and coordination. Through two years intensive study including the technical and economical feasibility discussion of each mitigation measure, the skeleton of the NASDA space debris mitigation design standards was summarized. After the review and check process in NASDA, the standard was finally enacted as NASDA-STD-18 in March 1996/18/.

5.3 Study for the Assessment Criteria for Reentry Safety of Space Debris

After enactment of the space debris mitigation design standard described above, in 1998, NASDA started preparation of the ground safety assessment criteria of space system reentry operation which is recommended to LEO spacecraft in the standard. This activity was conducted also with assistance from JSASS and included discussion on the allowable human casualty risk level as well as technical review of existing reentry survivability analysis tools. It leaded NASDA to the current in-house study for improvement of the survivability analysis tool and drafting of the criteria/19/.

5.4 Feasibility Study on the Active Removal System

Although the active removal operation of space debris is thought to be costly and unfeasible with the state of arts technology, it is still very attractive in the points that no costly requirements of self de-orbiting capability are imposed to the space system design and that it can be utilized for on orbit servicing operation, such as refueling, repairing. Encouraged by the success of ETS 7 mission in1999, feasibility study and related technology development are being promoted in National Aerospace Laboratory (NAL), Communications Research Laboratory (CRL) and NASDA. Status and details of these activities is also to be reported in this conference/20/.

6. CONCLUDING REMARKS

Japan’s space debris activities conducted so far and plans for the future were presented. More than ten years have passed since the Report on Orbital Space debris by U.S.

Inter Agency Group was issued in 1989, and our knowledge and technological basis related to the space debris issue has been enhanced fairly well. Some of the mitigation measures are voluntarily implemented by almost all space faring organizations in the world and discussion in the United Nations is proceeding steadily. The authors believe that it is the time to take one more step forward for future expansion of space activities.

In this context, the request from the organizer of this conference to survey the Japan's related activities provided authors with the opportunity to contemplate our direction to be taken from now on.

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