Research Paper
International Journal of Aerospace System Engineering
Vol.3, No.1, pp.5-9 (2016)

ISSN 2383-4986
http://dx.doi.org/10.20910/IJASE.2016.3.1.5

Towards A Better Understanding of Space Debris Environment

Toshiya Hanada†
Department of Aeronautics and Astronautics, Kyushu Uniersity
JAPAN
†E-mail: hanada.toshiya.293@m.kyushu-u.ac.jp

Abstract : This paper briefly introduces efforts into space debris modeling towards a better understanding of space debris environment. Space debris modeling mainly consists of debris generation and orbit propagation. Debris generation can characterize and predict physical properties of fragments originating from explosions or collisions. Orbit propagation can characterize, track, and predict the behavior of individual or groups of space objects. Therefore, space debris modeling can build evolutionary models as essential tools to predict the stability of the future space debris populations. Space debris modeling is also useful and effective to improve the efficiency of measurements to be aware of the present environment.

Key Words : Space Debris, Space Environment, Orbit Propagation, Future Projection

1. Introduction

This paper briefly introduces efforts into space debris modeling towards a better understanding of space debris environment. Space debris modeling mainly consists of debris generation and orbit propagation. Debris generation can characterize and predict physical properties of fragments originating from explosions or collisions. Orbit propagation can characterize, track, and predict the behavior of individual or groups of space objects. With collision flux estimation, therefore, space debris modeling can build evolutionary models, which predict the stability of the future space debris populations as in [1]. Such future projections can provide information necessary to specify when and how to do for space debris mitigation and environmental remediation. For examples, outcome of future projections would say that cleaning up space junks out there would be necessary for long-term sustainability of outer space activities as in Planetes the Japanese science fiction comics featuring space debris issues in 2075. Is it true? To figure out the right answer to the question we have to put more efforts into space debris modeling. Measurements are believed to be essential to properly conduct future projections because the stability of the future space debris populations may be subject to the initial population. Measurements are also essential to conjunction analysis to avoid accidental collisions and protection design to minimize damages due to impacts. Space debris modeling is also useful and effective to improve the efficiency of such measurements as in [2].

Received: March 23, 2016 Revised: April 26, 2016
Accepted: May 29, 2016
†Corresponding Author
Tel:+81-92-802-3047,
E-mail: hanada.toshiya.293@m.kyushu-u.ac.jp

2. Debris Generation

A key element of modeling space debris environment is the ability to predict the outcome of a typical satellite fragmentation. There are two important factors for long-term space debris environment studies: 1) fragment size, and 2) area-to-mass ratio distributions. The former defines the number of debris added to the environment after a breakup while the latter determines the orbital lifetimes of fragments with perigee altitudes below approximately 1,000km. Fragments from explosions or collisions can take any shape. Shape is important for improving the calculation of the average cross-sectional area of each fragment. Shape is also important for conducting a reliable assessment of the probability of non-penetration of spacecraft such as the International Space Station (ISS). Non-spherical projectiles can be more damaging than equal mass spherical projectiles under the same impact conditions.

As new satellite materials continue to be developed, there is a need for impact experiments based upon more modern light-weighted materials to better characterize the outcome of future on-orbit fragmentations. In addition, it is necessary to extend impact experiments to different velocity regimes to cover potential low-velocity collisions in the geostationary region. NASA Orbital Debris Program Office (NASA ODPO) and Kyushu University initiated impact experiments schematically illustrated in Fig. 1 (see also [3]). First, 15cm cubic microsatellites were prepared as targets to investigate the outcome of hypervelocity and low-velocity impacts. Then, 20cm cubic microsatellites were prepared as targets to investigate the effects of impact directions. Finally, multi-layer insulation (MLI) and a solar array panel (SAP) were added to the 20cm cubic microsatellites to investigate MLI and SAP pierces.

3. Orbit Propagation

The other key element of modeling space debris environment is the ability to characterize, track, and predict the behavior of individual or groups of space objects. First, Kyushu University has developed two different numerical orbit integrators. One integrates the rate of change of the classical orbital elements in the Gaussian form of the variation of parameter equations, whereas the other is based on the Cowell's formulation. Second, Kyushu University has developed an analytical orbit integrator, which calculates only the secular and long-term variations of the classical orbital elements to be used in evolutionary models as will be mentioned later. In addition to the spherically symmetric gravitational force of the Earth, a number of perturbing accelerations affect the orbit of an Earth-orbiting object. The orbit perturbations taken into account are: 1) the non-spherical part of the Earth's gravitational force, 2) atmospheric drag, 3) gravitational attractions due to the Sun and Moon, and 4) solar radiation pressure.

4. Evolutionary Models

With collision flux estimation, space debris modeling can build evolutionary models as essential tools to predict the current or future space debris environment, and also to discuss what and how to do for space debris mitigation and environmental remediation. First, Kyushu University developed GEODEEM, a Geostationary Earth Orbit Debris

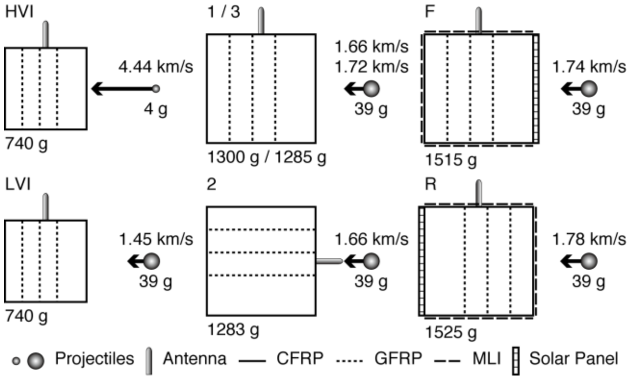


Fig. 1 Microsatellite impact experiments[3]

Environment Evolutionary Model, to track all objects which meet the following criteria: 1) eccentricity smaller than 0.2, 2) mean motion between 0.9 and 1.1 revolution per day, and 3) inclination lower than 30 degrees. Second, Japan Aerospace Exploration Agency (JAXA) and Kyushu University jointly developed LEODEEM, a Low Earth Orbit Debris Environment Evolutionary Model, to track all objects with perigee altitudes below 2,000km. Finally, both models have been merged into NEODEEM, a Near Earth Orbit Debris Environment Evolutionary Model, to track all Earth-orbiting objects. Now, future projections are being conducted using NEODEEM in Japan.

One of interesting results from future projections is that the current space debris population in the low Earth orbit region would continue to increase even with no new launches and no future explosions as in [4]. As demonstrated in Fig. 2, intact and mission-related objects in red, and explosion fragments in green decrease over time due to the atmospheric drag. Thus, the total number in black also decreases. This is true but only at the beginning of the projection. The total number increases as collision fragments in blue are newly generated. This result indicates that the volume of debris in the low Earth orbit region is so high that objects in orbit are frequently struck by debris, creating more debris and a greater risk of further impacts.

5. Measurements

One of further applications of space debris modeling is to improve the efficiency of measurements to be aware of the present environment as in [2]. Space debris modeling can characterize, track, and predict the behavior of groups of fragmentation debris. Such predictive analyses can devise a practical method for ground-based optical measurements. First, the population prediction of fragments from a single breakup event specifies effectively when and how to conduct ground-based optical measurements. Second, the motion prediction of fragments in a series of successive images clearly distinguishes between fragments originating from the target breakup event and the others. This practical method has been verified by applying for two confirmed breakups in the geostationary region. One is Russian Ekran 2 exploded on 23rd June 1978. The other is US Titan IIIC Transtage exploded on 21st February 1992.

Fig. 3 demonstrates observation planning to search fragments released from the aforementioned breakups. Fig. 3 provides time-integrated distribution of fragments to specify where most fragments will be detected as a function of geocentric right ascension and declination. Deep-colored area represents a region where detection rate is high. Fig. 3 also masks invisible region from a specific telescope, and overlays the Earth shadow at the nominal geostationary altitude. If a 1degree field-of-view telescope keeps looking at the point where most fragments will be detected, then a detection rate can be up to 14.7 fragments per hour.

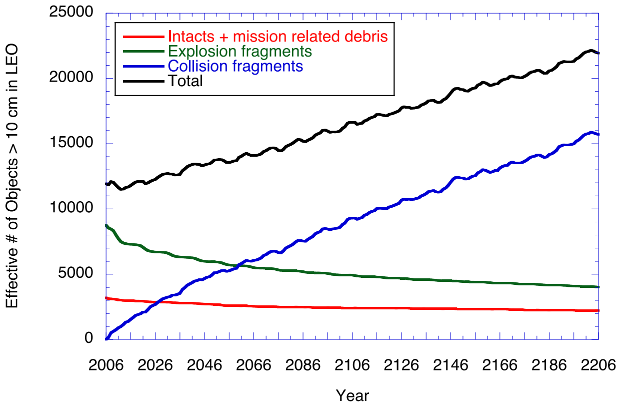


Fig. 2 Population growth in the low Earth orbit region [4]

Japan Aerospace Exploration Agency (JAXA) has developed Space Debris Monitor (SDM) based upon a patent jointly held by IHI Corporation and Institute for Q-shu Pioneers of Space [5]. SDM consists of approximately 3,500 conductive lines with a width of 50 µm, which are equally spaced on a non-conductive thin film with a gap of 50 µm. A piece of debris punches out a hole on the film at impact to break some conductive lines, so that an impact can be detected by periodically confirming the continuity of conductive lines on the film. Besides, the size of the hole on the film is substantially the same as the size of the debris impacted. One can estimate the size of the debris impacted by counting the number of the conductive lines without the continuity. Therefore, a satellite equipped with SDM can conduct in-situ measurement of sub-millimeter-size debris, not observable from the ground.

Space debris modeling can also characterize the nature of orbits on which debris may be detected through in-situ measurements. Fig. 4 plots the inclination vectors of catalogued objects which contribute to the collision flux into a measurement satellite. It may be noted that an inclination vector of $(i \times \cos\Omega,\ i \times \sin\Omega)$ where i and Ω represent inclination and right ascension of the ascending node, respectively identifies an orbital plane by its direction and magnitude. Fig. 4 clearly demonstrates that the pattern of inclination vector distribution is dependent on the position of the satellite along the orbit (i.e. argument of true latitude, u). In addition, there seems to be a constraint on orbital planes on which debris contribute to the collision flux into the satellite. Actually, solid thin lines represent a constraint derived from space debris modeling also. Applying this constraint to in-situ measurements, then one can properly estimate the orbital parameters of a broken-up object to identify the resulting environmental change as in [6].

6. Conclusions

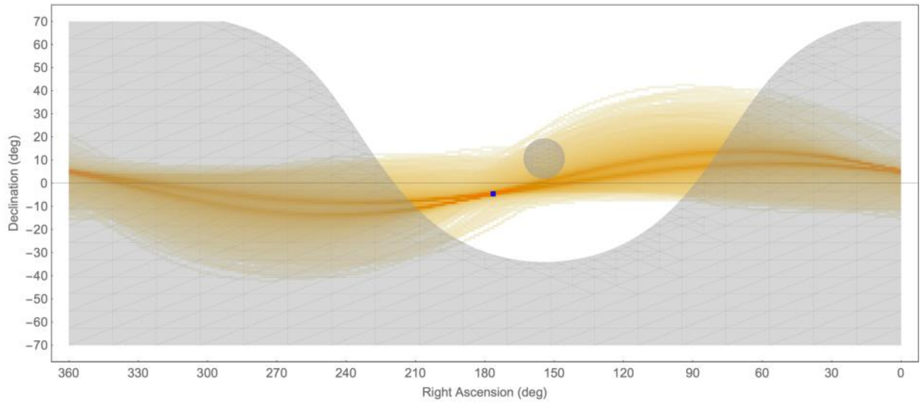
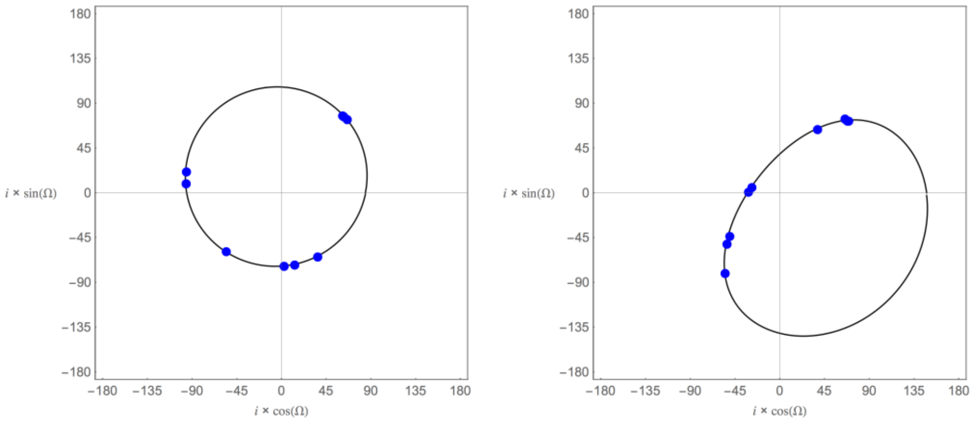


Fig. 3 Observation planning for fragments from the two known fragmentations in the geostationary region [2]



(a) $\boldsymbol{u = 75}[°]$ (b) $\boldsymbol{u = 153}[°]$

Fig. 4 Inclination vectors of objects which contribute to the collision flux

This paper briefly introduced efforts into space debris modeling towards a better understanding of space debris environment. Space debris modeling can predict the stability of the future space debris populations as demonstrated, and such future projections would say that space debris mitigation and environmental remediation would be necessary for the long-term sustainability of outer space activities. Space debris modeling is also useful and effective to improve the efficiency of measurements to be aware of the present environment. Optical measurements devised based on space debris modeling can achieve a higher detection rate to search unknown breakup fragments in orbits. In-situ measurements properly supported by space debris modeling can estimate the orbital parameters of a broken-up object to identify the resulting environmental change. Kyushu University is willing to pursue space debris modeling.

Acknowledgement

The author wishes to acknowledge students, alumnae, and alumni for their outstanding works on space debris modeling at Kyushu University. The author also wishes to acknowledge IHI Corporation, Japan Aerospace Exploration Agency, Japan Spaceguard Association, Mitsubishi Heavy Industries, Ltd., NASA Orbital Debris Program Office, and National Central University of Taiwan for their contributions and supports to space debris modeling at Kyushu University.

References

[1] Liou, J.-C., Anilkumar, A. K., Bastida Virgili, B., et al., "Stability of the Future LEO Environment - An IADC Comparison Study," *Proc. of the Sixth European Conference on Space Debris, 2013*.

[2] Uetsuhara, M., Hanada, T., Kitazawa, Y., "Effective Strategy to Identify Origins of Fragments from Breakups in GEO," *Proc. of the AAS/AIAA Astrodynamics Specialist Conference 2011*, pp.3047-3057, 2011.

[3] Hanada, T., Liou, J.-C., "Theoretical and Empirical Analysis of the Average Cross-sectional Areas of Breakup Fragments," *Advs Space Res.* 47, pp.1480-1489, 2011.

[4] Hanada, T., "Orbital Debris Modeling and Applications at Kyushu University," *Procedia Engineering* 67, pp.404-411, 2013.

[5] Nakamura, M., Kitazawa, Y., Matsumoto, H., et al., "Development of In-Situ Micro-Debris Measurement System," *Adv. Space Res.* 56, pp.436-448, 2015.

[6] Fujita, K., Furumoto, M., Tasaki, M., Hanada, T., "An Orbit Determination from Debris Impacts on Measurement Satellites," *Adv. Space Res.* 57, pp.620-626, 2016.

Authors

Toshiya Hanada
Studied Aeronautics and Applied Mechanics at Kyushu University in Japan, and graduated with the degree of Doctor of Engineering in 1994. His major field is astrodynamics.