ON SMALLER DEBRIS OF ORBITAL COLLISIONS

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Nowadays mutual collisions of spacecraft have become a disagreeable reality. And although such events are comparatively rare, they are making relevant contributions to the common pollution of near-Earth space, because the orbital collisions are characterized by high specific energies and multiple debris.

Until today there were four natural orbital collisions between cataloged objects and the last event (between active Iridium 22 and abandon Cosmos 2251) was the most spectacular. As a result of the collision there were created about 1785 catalogued fragments, which threaten many spacecraft and even the ISS. One can guess that there is still a lot of minor debris, which are invisible for radars, but dangerous for active spacecraft.

In the near-term outlook, the collisions of orbital objects shall be addressed as a main source of space debris due to their prolificacy. So it is important to have an adequate model for such events.

There are several known fragmentation models for hypervelocity collisions, but all these models were developed in great part using the analogy with high energy explosions, whose physics is very different. For the first time, the well known models could be tested by the Iridium-Cosmos event that is a full-scale space "experiment".

1-Introduction

The first collision between catalogued objects took place on July 24, 1996. The Cerise was damaged by a fragment of the Araine-5 rocket (Johnson, 1996), (Alby et al., 1997). The collision between IRIDIUM-33 and COSMOS-2251, that occurred on February 10, 2009 was the fourth “natural” collision (e.g. a chance event). In both events there was the impact of space debris separated from an active object, but the after-effects were quite different. In the first event there was debris only from the boom that was damaged. But in the second event there were created a lot of debris of the solar panels of both spacecraft. So, on January 12, 2012 the ISS was urged to maneuver to avoid problems from a 10 cm piece of IRIDIUM-33.

There are no conditions for full scale modeling of orbital collisions in on-ground laboratories, so it is important the made as full an analysis of orbital collisions data as possible.

Note that that there was an analogues event on January 11, 2007, when Fengyun-1C was crushed by a ballistic interceptor. It was an aimed impact, and it is interesting for modeling of hypervelocity collisions.

2- TLEs data

All the results mentioned below were learned from the TLEs data published on the http://www.celestrak.com site.
After the collision the fragments still ran along orbits near the orbits of the parent objects, so there is no collision between compact bodies. Thus, let’s assume preliminarily that the main part of the debris consists of splinters of solar panels. There were two types of objects: flat glass pieces and line circuitry and stiffening elements. The thickness of the flat elements can be assumed fixed for every spacecraft. The area-to-mass distribution for such objects depends on their rotation.

The [http://www.celestrak.com](http://www.celestrak.com) site gives drag terms, $B_{star}$ (Fig. 1). Such a term has the form of

$$B_{star} = \frac{1}{2} \rho_a C_x \cdot \frac{A}{m}.$$  

There are no data on the atmosphere density, $\rho_a$, at the altitude about 900 km, that can be used to calculate area-to-mass coefficients. Besides, the density has great variations. It is 500 times as high for high solar activity than for lower ones. It makes it impossible to calculate area-to-mass coefficients, and we can’t get absolute size values. But the altitude is about the same for all debris, and we can compare the terms with each other. You can see that the distributions for COSMOS-2251 and IRIDIUM-33 are similar, but in sum the drag terms of IRIDIUM-33 debris are essentially greater. Maybe, its solar panel elements were thinner (about ten times!).

I call your attention to the “tails” at the end of the distributions. It is something that doesn’t insert into the common frames, so it is interesting.

![Fig. 1. Drag terms of COSMOS-2251 debris (red curve) and IRIDIUM-33 (green curve).](http://www.celestrak.com)

Also the [http://www.celestrak.com](http://www.celestrak.com) site gives orbital data and consequently we have some hope to get velocity increment distributions. Fig.2 shows the increment distributions following from the altitude of the event (790 km). Note that the calculations were made using the data for 2011, so the perturbations (atmosphere drag, gravitational field moments) strongly pulled apart the orbits until this moment, so the distributions are very rough. It is essential that the velocity increments for the IRIDIUM-33 fragments are much lower. It can be due to the smaller thickness of the solar panel elements, that was
noted above, and also the mechanism of the mechanic impulse transfer from a “collision nucleus” to a “collision periphery”.

Fig. 2. Velocity increments of COSMOS-2251 debris (red curve) and IRIDIUM-33 (green curve).

-3- Fragmentation models for collisions

To compare the above data let us orient ourselves to the space debris model, MASTER-2005. The report on the model (Klinkrad et al., 2006) gives some breakup models. There are normal distributions to approximate the distributions of area-to-mass coefficients for collision events. These coefficients differ from the drag terms of TLEs only by about a constant multiplier. So we can write

$$p(B) = \frac{1}{\sigma_B \sqrt{2\pi}} e^{-\frac{(\log B - \log B_0)^2}{2\sigma_B^2}}$$

(1)

From Fig. 1 we could assume that this function is proper for the statistics of $B_{star}$ values in the event. Fig. 3 and 4 show the related approximations with the following parameters:

$B_0 = 0.000671, \sigma_B = 0.38$ for COSMOS-2251,
$B_0 = 0.00178, \sigma_B = 0.31$ and $\sigma_B = 0.33$ for IRIDIUM-33.

Fig. 3. Drag terms of COSMOS-2251 debris, rebuilding the TLEs data (red curve) and the normal law (green curve).
Fig. 4. Drag terms of IRIDIUM-33 debris, rebuilding the TLEs data (red curve) and the normal law (green curve).

You see that in the new frame the little tails of the distributions lead to large local leaks. We could estimate the significance of these peaks only relative to a particular application. But now we can assume that the normal distribution used in the MASTER-2005 is appropriate.

In the model, MASTER-2005, the same normal logarithmic distribution is also recommended for velocity distributions. Of course, we have very coarse results, but nevertheless the Poisson distribution (2) would be more appropriate as is seen from Fig.2.

\[ p(v) = \frac{1}{v_0} e^{-\frac{v}{v_0}} \]  

(2)

-4- Actual problems

1. The above analysis doesn’t concern the physics of a hypervelocity impact, that assumes the transition of a part of the materials into a quasi liquid state. Concurrently, the momentum transfer to the neighboring zones is essentially limited. So the visible debris mainly conserves the orbital parameters of the parent bodies, and it must be shown.

2. There are also a lot of microparticles, which are created as results of the decay or the release of the “collision nucleus”. Their parameters must be cleared up.

There are needed:
- additional data on the construction of solar panels,
- radar cross-section data on fragments,
- archive TLEs data in the vicinity of the moment of collision
- solution of the fundamental problem of the destruction of elements (rods, for instance), after an impulse loading on their ends,
- solution of the fundamental problem of decay of a “collision nucleus”.
- data base on spacecraft construction with detailed classification considering probable collisions.

-5- Conclusion
Comparing the fragmentation model by MASTER-2005 and the TLEs, there are a lot of unresolved problems. There are shortages both in size, and in velocity distributions of fragments after collisions.

A more accurate analysis of IRIDIUM-33 / COSMOS-2251 collision could enhance the estimations of safety for active spacecraft.

There are needed several models of fragmentation, according to different spacecraft constructions and impact conditions.

This is needed both in contingency planning for spacecraft constellations, and in the solution of protection problems for distinct spacecraft.

-6- References


http://www.celestrak.com

