軌道上デブリ除去対象指標とその低減効果の比較

Comparison of the mitigation effect of space debris by some removal indexes for orbital objects

長岡信明, 河本聡美(JAXA), 花田俊也, 阿部修司(九州大学)
Nobuaki Nagaoka, Satomi Kawamoto (JAXA), Toshiya Hanada and Shuji Abe (Kyusyu University)

After the long space activities, large numbers of fragments generated by explosions and collisions of space objects are gradually increasing. In recent, many research organizations have reported that as a result of self-proliferation of these space debris without some mitigation process, future space activities will be affected. Also, in the private sector, mega constellation with thousands of satellites are also planned as a continuous communication infrastructure, and it should be necessary to consider the influence on the space environments.

In this report, one guideline for improvement of future orbital environment after the result of space debris mitigation effect by some removal indexes for orbital objects with the propagation model of space debris created to predict the future debris distribution.
Preface

Purpose
This presentation denotes some effective guidelines for space debris mitigation and environmental remediation based on the outcome of future projections of debris population conducted with some removal scenarios.

Method
Devise removal scenarios which expect less debris generation and evaluate the outcome of future projections in terms of population growth and collision activities.

Point of Interest
Effect of ADR target selection on the future population. Effect of PMD success rate and/or ADR after PMD failure on the Mega-constellation.
Index for ADR Target Selection

- Select the index that expects less debris generation.
- The index of “collision probability x mass” is suitable for that purpose.

Debris evolutionary model (NEODEEM)

Initial Input:
- Set the scenario
- Initial population

Population Transfer: (Selectable)
- Traffic Model: New Launch (8-year cycle)
- Collision: NASA Std, BU Model 2001 Rev. (MC)
- Maneuver: PMD(MC), ADR(MC)
- Collision avoidance

Propagation:
- Earth Gravity (4 order and degree)
- Air Drug (Jacchia-Roberts)
- Lunisolar gravitational attraction
- Solar Radiation Pressure

Acknowledgement: Initial population are provided by ESA for IADC studies
ADR analysis by debris evolutionary model

Assumptions

I. Starting year of ADR: 2025
II. Number of ADR: 1/year, 5/year
III. Target selection considering the operation
   ① Eccentricity < 0.02,
   ② Limit of target mass
   ③ R/B entirely
IV. ADR target
   ① S/C and R/B
   ② R/B entirely
   ③ R/B entirely with maximum mass limit

Comment on ADR orbit height

Dependency of ADR orbit height and starting year

- Collision probability may change according to ADR height (original height ± 50km)
- Collision probability should change according to the start year of ADR
  ➢ Depend on debris distribution and target height
ADR effect (S/C and R/B)

Debris EN with ADR index

Distribution of ADR targets

ADR effect (R/B)

Debris EN with ADR index

Distribution of ADR targets

Target objects are less than 5
ADR effect (R/B < 4000kg)

Debris EN with ADR index

Distribution of ADR targets

Target objects are less than 5

ADR with 1 object/year

ADR with 5 objects/year

ADR effect (R/B < 8000kg)

Debris EN with ADR index

Distribution of ADR targets

Target objects are less than 5

ADR with 1 object/year

ADR with 5 objects/year
**Distribution of Collision Probability**

1. **Collision probability trend (ADR: 1 object per year)**

- Collision probability is absolutely small number, but number of collision objects is not so small.
- ADR should be effective for suppressing the debris generation.

---

**ADR effect (R/B < 8500kg)**

- **Debris EN with ADR index**
  - Number of objects (ADR/R/B max 8500kg kg=2.6/step=5.0)

- **Distribution of ADR targets**
  - ADR with 1 object/year
  - ADR with 5 objects/year
Effect of Fragment ADR

- ADR of intact debris objects rather than fragments can reduce future increases in the volume of debris objects.
- Fragments that are too small to be tracked for collision avoidance maneuvers should be reduced by ADR of intact.

Sample configuration of Mega-constellation

- Simulation of Mega-constellation should be dependent on the configuration.
- Simulations are carried out according to the following conditions.

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of satellites</td>
<td>1000</td>
</tr>
<tr>
<td>Altitude</td>
<td>1200km circular</td>
</tr>
<tr>
<td>Service duration</td>
<td>2020-2049 (30 years)</td>
</tr>
<tr>
<td>Launch duration</td>
<td>2016-2049 (34 years)</td>
</tr>
<tr>
<td>Mission lifetime</td>
<td>5 years</td>
</tr>
<tr>
<td>Yearly launch</td>
<td>200 satellites</td>
</tr>
<tr>
<td>Total launch</td>
<td>6800 satellites</td>
</tr>
<tr>
<td>PMD</td>
<td>Decay into circular orbit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>150 kg</td>
</tr>
<tr>
<td>Average cross-sectional area</td>
<td>3.0 m²</td>
</tr>
<tr>
<td>Semi-major-axis</td>
<td>7578.14 km</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.0001</td>
</tr>
<tr>
<td>Inclination</td>
<td>75 deg</td>
</tr>
<tr>
<td>Orbital plane</td>
<td>20</td>
</tr>
<tr>
<td>Right ascension of ascending node</td>
<td>360/20 = 18 deg / orbit plane</td>
</tr>
<tr>
<td>Argument of perigee</td>
<td>0.01 deg</td>
</tr>
<tr>
<td>Mean anomaly</td>
<td>360/50 = 7.2 deg / satellite</td>
</tr>
<tr>
<td>Phase difference angle</td>
<td>0.36 deg</td>
</tr>
</tbody>
</table>
Example of debris population on Mega-constellation

- More than 95% PMD may achieve stable debris increment.
- Longer system operation generate more debris according to the total number of satellites. Effective debris mitigation should be required.

ADR effect after PMD failure

- Positive effects of ADR for large constellations
  - ADR under five years after PMD failure is effective to remediate the environment.
  - Five years rather than 20 years after PMD failure is more effective, thus making the early implementation of ADR is quite important.
Effect of PMD Success

Baseline (Without Megacon)
PMD Success 90%
PMD Success 60%
PMD Success 30%

Debris EN with PMD Success rate

• Higher PMD success rate may be generated more debris around disposal orbit.
• For the long-span debris mitigation high PMD success rate is important index.

Conclusion

1. The index “Collision rate x mass” is useful for fragment/debris mitigation
   I. ADR of > 8000kg target is effective for debris mitigation.
   II. 5R/Bs per year ADR occur the lack of target R/B.
   III. ADR of intact debris objects rather than fragments can reduce future increases in the volume of debris objects.
   IV. Collision probability is absolutely small number, but number of collision objects is not so small, ADR should be effective for suppressing the debris generation.

2. PMD rate and ADR success
   I. ADR after PMD failure is effective to remediate the environment.
   II. Higher PMD success rate may be generated more debris around disposal orbit.
   III. For the long-term debris mitigation high PMD success rate is important.