B09

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

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長年の宇宙活動により軌道上には活動中や活動を終了した飛翔物体とともに、軌道上で爆発した物体の破片や飛翔物体同士の衝突による破片が徐々に増えている状況である。最近の研究ではこのまま放置するとこれら宇宙デブリの自己増殖による結果として、今後の宇宙活動に影響が出るとの結果が多くの研究機関から報告されている。また、民間では常時の通信インフラ構築として衛星数千機規模のメガコンステレーションの通信網の計画も提案されており、これらの宇宙環境への影響も検討する必要がある。
本報告では現状の宇宙環境をもとに将来のデブリの推移を予測するために作成した推移モデルをもちいて、将来のメガコンステレーションを含めた大型デブリ(運用を終了した衛星や最終段ロケット)に対する除去の指標を設定し、その効果を見ることで将来の軌道上環境の改善に対する一知見を示す。

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.

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第8回 スペースデブリワークショップ
2018/12/4

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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.

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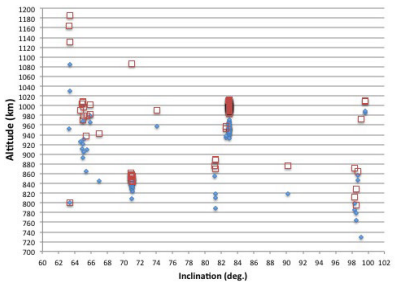
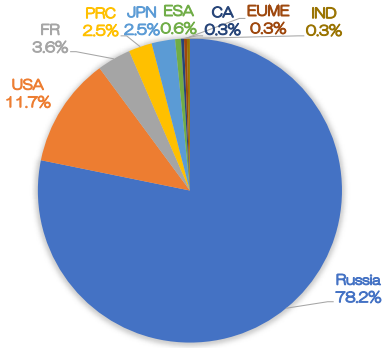
Index for ADR Target Selection

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

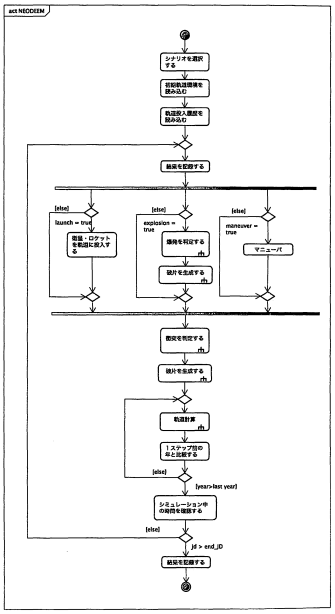


Orbital distribution of space debris
(LEO, Red: Apogee, Blue: Perigee)



Debris population by Nation

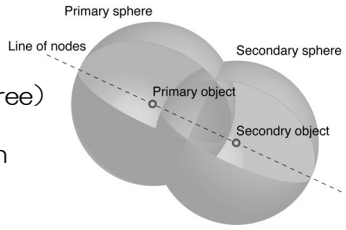
Debris evolutionary model (NEODEEM)



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

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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

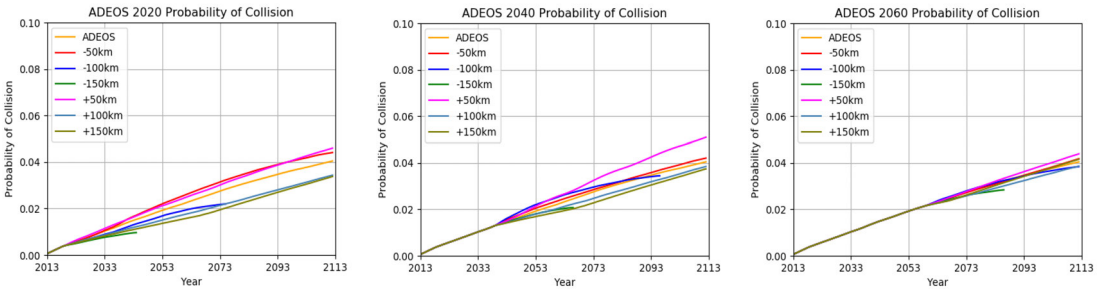
① S/C and R/B

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

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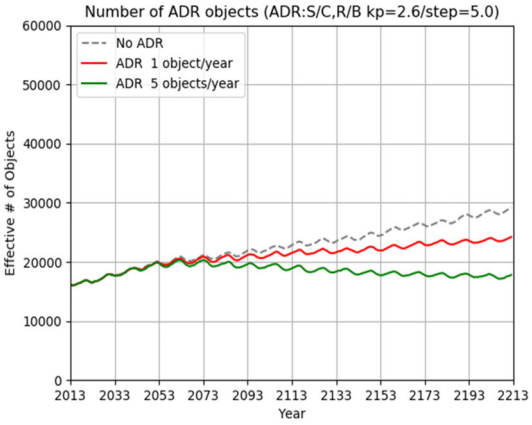
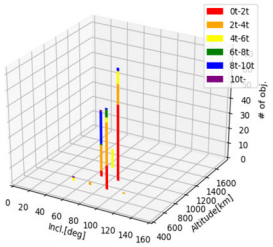
ADR effect (S/C and R/B)

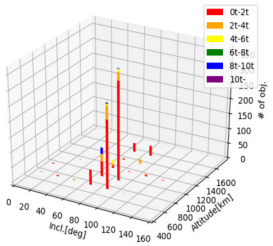


Debris EN with ADR index

Distribution of ADR targets

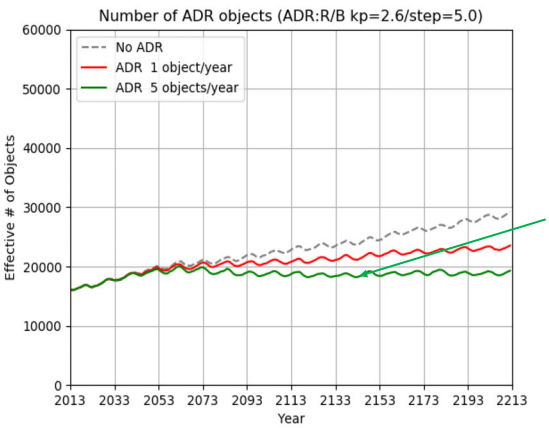


ADR with 1object/year



ADR with 5objects/year

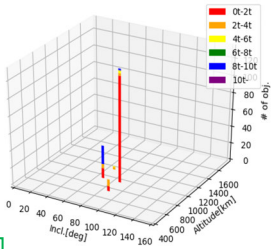
ADR effect (R/B)



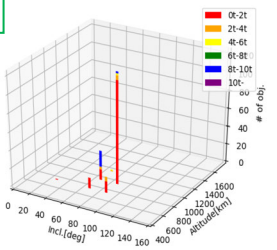
Debris EN with ADR index

Target objects are less than 5

Distribution of ADR targets



ADR with 1object/year



ADR with 5objects/year

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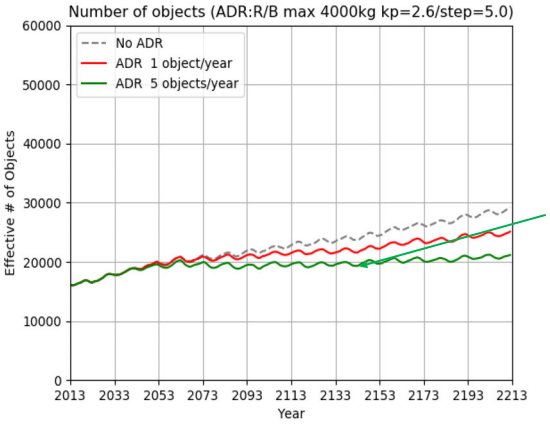
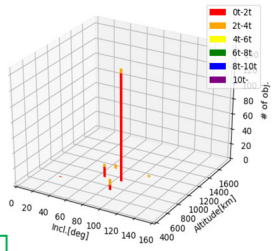
ADR effect (R/B < 4000kg)

Distribution of ADR targets

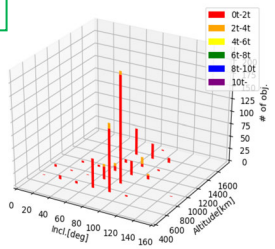


Debris EN with ADR index

Target objects are less than 5



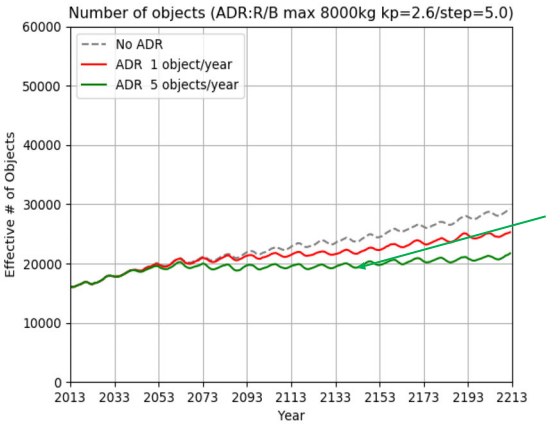
ADR with 1object/year



ADR with 5objects/year

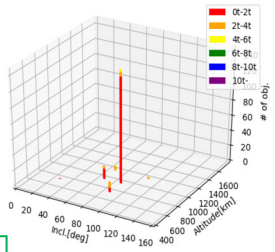
ADR effect (R/B < 8000kg)

Distribution of ADR targets

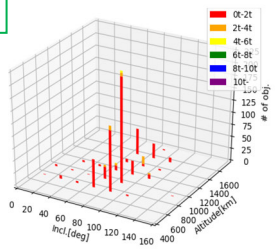


Debris EN with ADR index

Target objects are less than 5



ADR with 1object/year



ADR with 5objects/year

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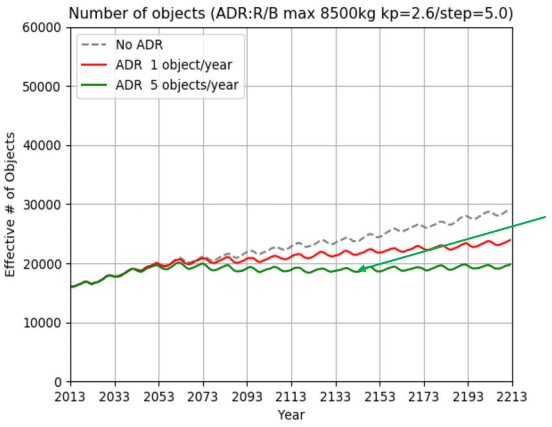
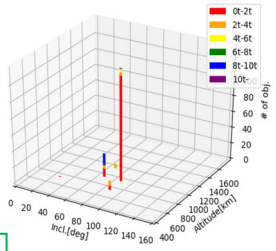
ADR effect (R/B < 8500kg)



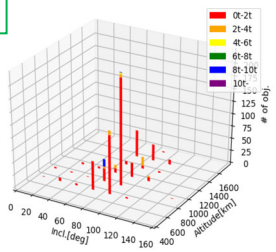
Debris EN with ADR index

Target objects are less than 5

Distribution of ADR targets



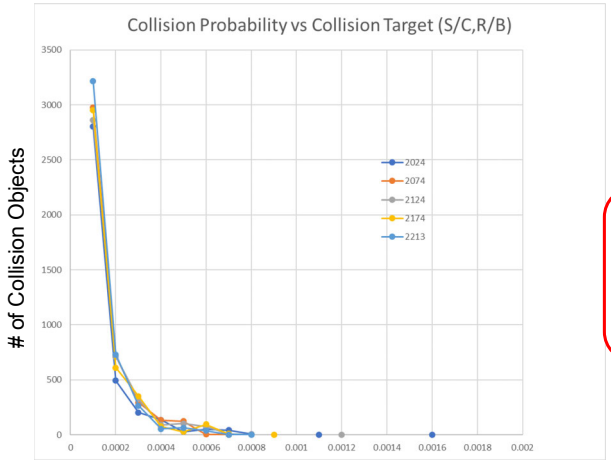
ADR with 1object/year



ADR with 5objects/year

Distribution of Collision Probability

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



Collision Probability (BIN)

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

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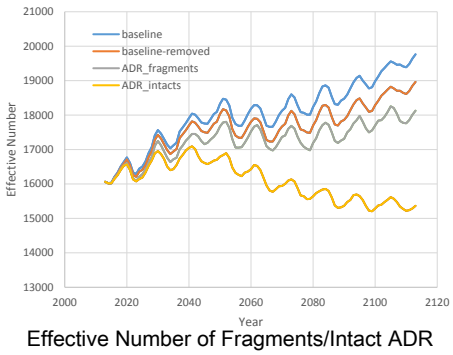
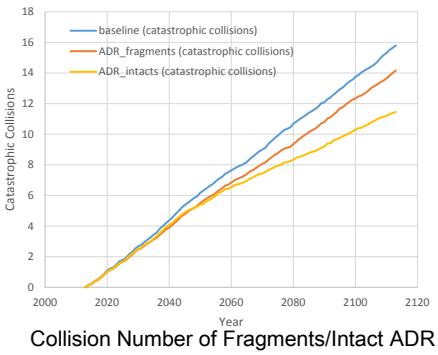
Effect of Fragment ADR



Effective Number of Fragments/Intact ADR

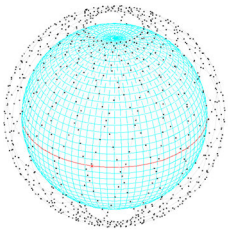


Collision Number of Fragments/Intact ADR

- 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.



1000 satellites @1200km alt.

Items	Values
Number of satellites	1000
Altitude	1200km circular
Service duration	2020-2049 (30 years)
Launch duration	2016-2049 (34 years)
Mission lifetime	5 years
Yearly launch	200 satellites
Total launch	6800 satellites
PMD	Decay into circular orbit

Items	Values
Mass	150 kg
Average cross-sectional area	3.0 m^2
Semi-major-axis	7578.14 km
Eccentricity	0.0001
Inclination	75 deg
Orbital plane	20
Right ascension of ascending node	360/20 = 18 deg / orbit plane
Argument of perigee	0.01 deg
Mean anomaly	360/50 = 7.2deg / satellite
Phase difference angle	0.36 deg

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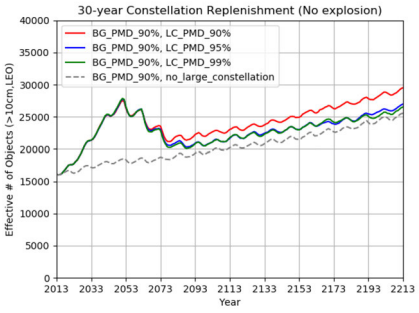
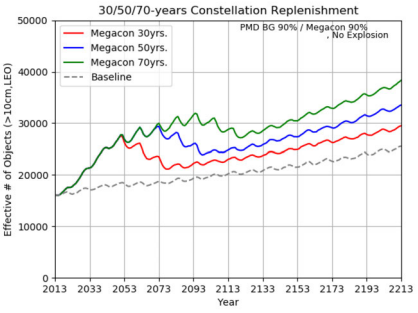
Example of debris population on Mega-constellation



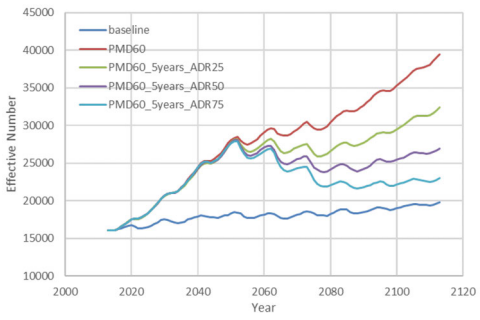
PMD rate effect on debris EN



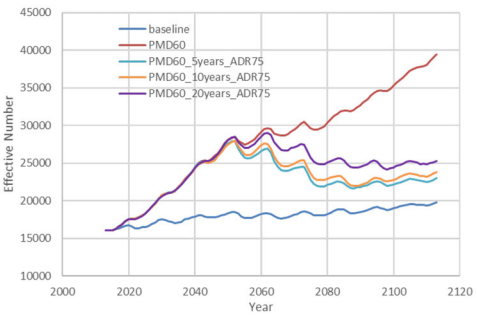
Operation duration effect on debris EN

- 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



ADR Effect after PMD Failure (ADR Failure ratio)



ADR Effect after PMD Failure (Start year of ADR)

- 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.

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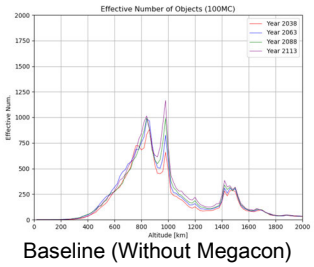
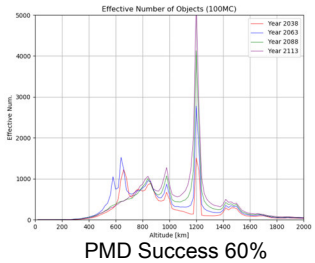
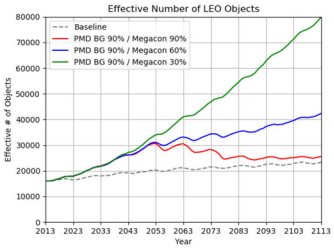
Effect of PMD Success



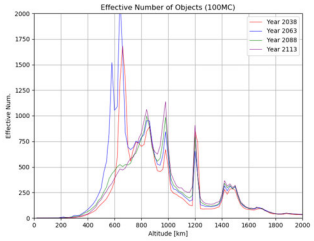
Baseline (Without Megacon)



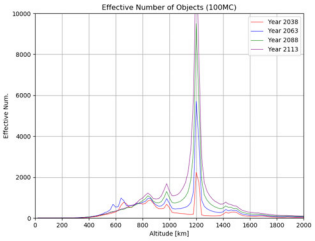
PMD Success 60%



Debris EN with PMD Success rate



PMD Success 90%



PMD Success 30%

- 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.

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