D2

デブリ除去衛星のミッションシナリオの検討

Study of the Demonstration and Practical Mission Scenarios for Active Debris Removal

○岡本博之、山元透、河本聡美、青山順一、
デブリ除去技術の研究チーム（JAXA）
○H. Okamoto, T. Yamamoto, S. Kawamoto, J. Aoyama,
and Debris removal technology research team (JAXA)

将来のデブリ除去実用ミッションと、実用につながる実証ミッションについて、それぞれのミッションシナリオを検討している。デブリ除去はデブリ環境改善、ひいては宇宙開発の持続的発展に必要な活動であり、デブリ対策の国際的な枠組みの中で各国の協力により行われることを想定している。国際的な除去活動を進めるには、まず可能なデブリ除去を実施することが重要であり、したがって段階的にデブリ除去が進められると想定している。①国産ロケット上段機の除去から始め、続いて②除去効果の大きい混雑軌道にある国内外ロケット上段機の除去を行うシナリオを検討している。③メガコンステレーションはデブリ環境に対して影響を与えるが、ロケット上段とは異なる性質の対象と考えている。合理的なコストでのデブリ除去実証を目的として、200kg 級の小型衛星による除去実証ミッションを検討している。実証ミッションは 2020 年度頃を目標に検討を進めている。

The mission scenarios for the practical active debris removal (ADR) and the ADR demonstration, that leads to the practical one, have been studied.
Since ADR is a necessary operation not only for the orbital debris environment, but also for the sustainable development of the global space activity, it is assumed to be conducted with a multi-national cooperation under the international framework of the space debris remediation which will be developed in the future. It is important to conduct actual ADR for advancing international ADR activity. So, the step by step phases are assumed in this scenario. In this scenario, starting from ① domestic inert rocket upper stages as a first ADR target, ② the large rocket upper stages in the crowded orbit region, which are thought to be most effective ADR targets, will be removed. ③ Mega constellation has some impact on the debris environment, but this target has the different nature from the rocket upper stage in terms of the ADR technology. We are studying the ADR demonstration mission of the 200kg class of small satellite by which we will show the ADR within a reasonable cost. The target schedule of the demonstration mission is in 2020 fiscal year preliminary.

Study of the Demonstration and Practical Mission Scenarios for Active Debris Removal

Hiroyuki OKAMOTO, Toru YAMAMOTO,
Satomi KAWAMOTO, Junichi AOYAMA,
Debris removal technology research team
JAXA

Agenda

- What is mission scenario? And Goal of this activity
- ADR Practical Scenario
- ADR Demonstration Scenario

What is mission scenario?

- Mission scenario clarifies the mission conducted by ADR satellites, i.e. mission sequence (timeline), mission objective, reference system, etc.
- Based on mission scenario, the mission definition will be specified.

Goal of this activity

- ADR demonstration mission scenario is the final output of this activity.
- To clarify the ADR demonstration mission scenario, the practical perspective of ADR activity has to be clarified.
- The demonstration scenario has been studied following to the practical ADR scenario study.

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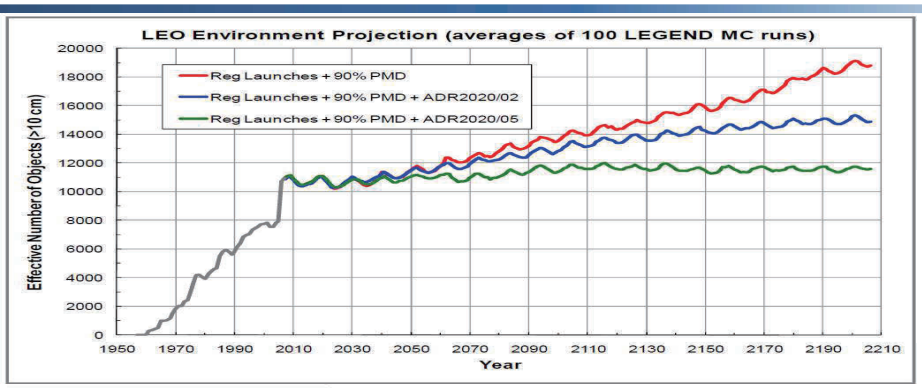
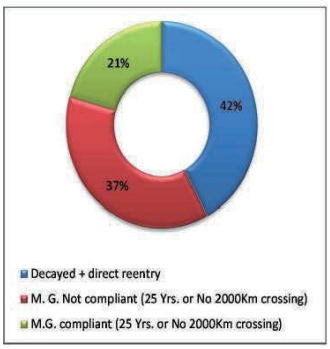
- ADR Demonstration Scenario

5

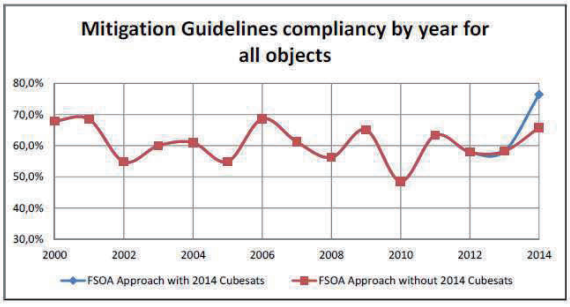
ADR Practical Scenario: Why ADR?



Liu, J. C. , An Active Debris Removal Parametric Study for LEO Environment Remediation, Advances in Space Research, 2011.



Global statistics for all objects between 2000 - 2014



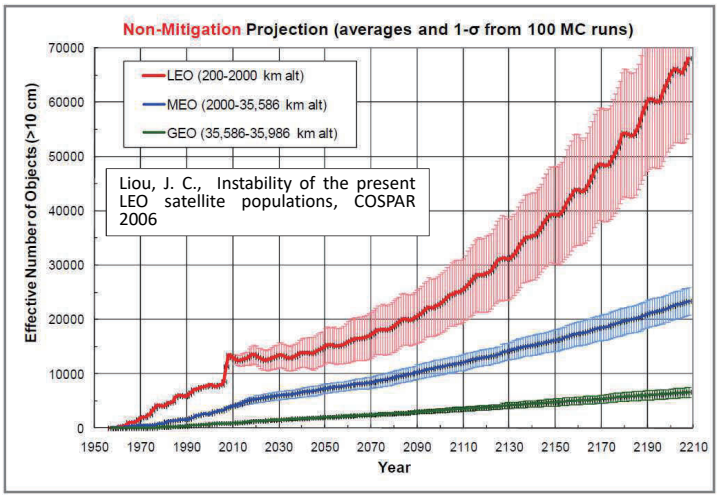
Cazaux, C., Overview on 2015 Space Debris Activities in France, COPUOS STSC, 2016

Yearly statistics for all objects between 2000 - 2014

6

ADR Practical Scenario

- Time flies
- LEO debris are priority target for ADR
  - LEO is getting worse faster than the other orbits



7

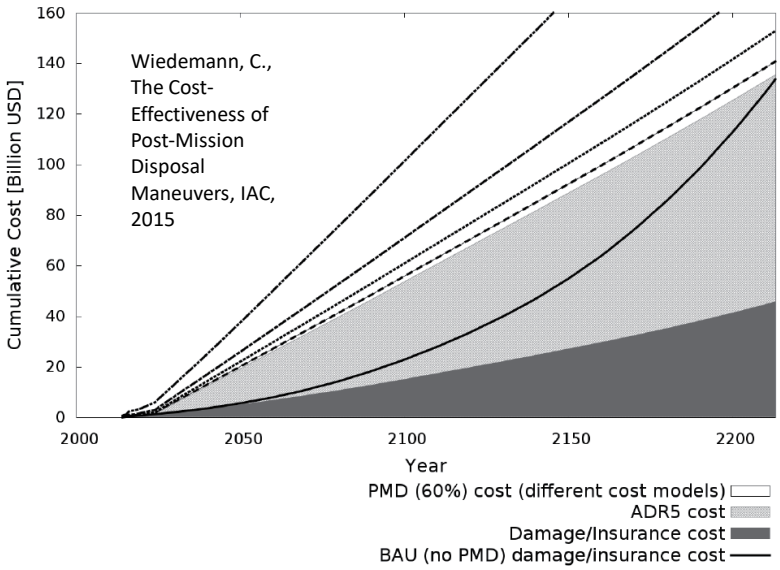
ADR Practical Scenario: Development

- How ADR will be started?
- Necessary to develop international framework of the orbital debris remediation
  - Stakeholders of ADR are across the globe
    - Space development segments, utilization segments, ..
  - Debris owner's country is different from ADR executor's one
  - Gradually developing the international consensus of ADR
  - To drive the international motivation to ADR, prove the cost effectiveness and technology of ADR is very important

8

ADR Practical Scenario

- ADR (should be) Economically reasonable.
  - BAU vs PMD vs ADR



9

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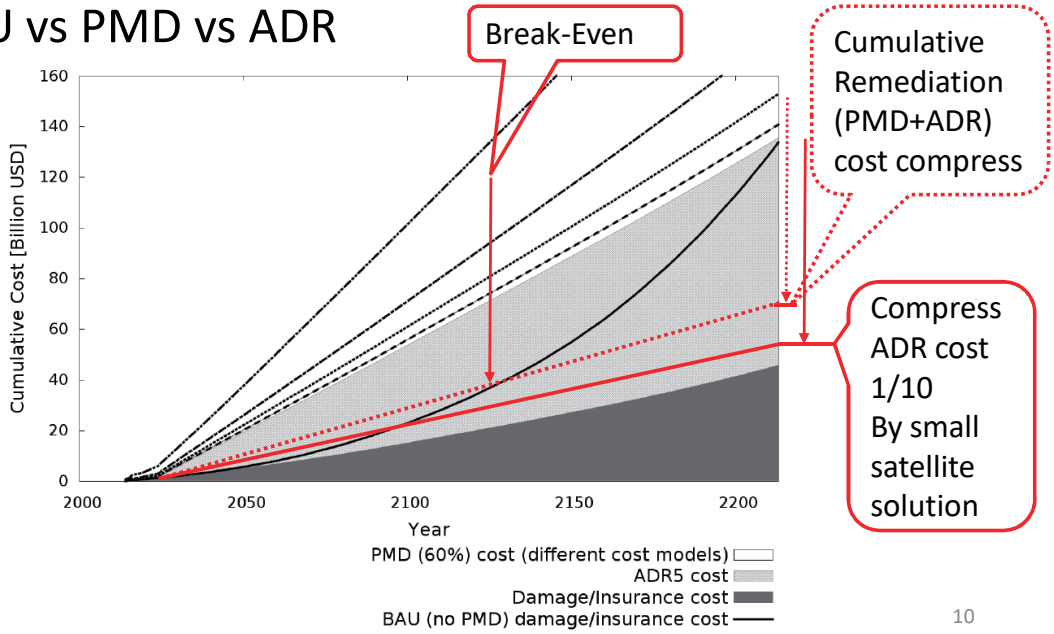


10

ADR Practical Scenario: Development

- 3 major phase of practical ADR will be developed
- Phase 1: Demonstration phase
- Phase 2: Keep technology and independent activity on ADR in each countries
- Phase 3: ADR is conducted under the international framework

11

ADR Practical Scenario: Concerning

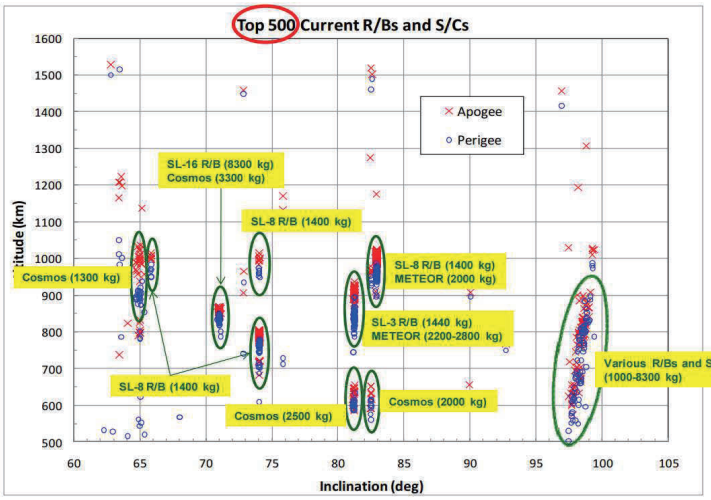
- Target Attitude
  - At beginning of ADR activity, ADR target attitude is assumed to be slow moving (<1deg./s). And the range of target attitude will be expanded gradually with the future technology development.
    - There exists slow moving R/B from the radar observation.
- Number of debris removed with one ADR spacecraft
  - Basically 1 by 1, with rideshare or multiple launch of ADR spacecrafts.
    - Mothership architecture is not excluded but need further technology development in some field, especially electric propulsion.
- Controlled Reentry
  - In this scenario, no controlled reentry will be required to ADR mission.
    - Each key technology required ADR mission in this scenario, i.e. Rendezvous, capture and EDT, can be adopted even if the controlled reentry is required.
    - Controlled Reentry requirement is still unknown to be applied to ADR mission, further discussion and arguments are consciously watched.

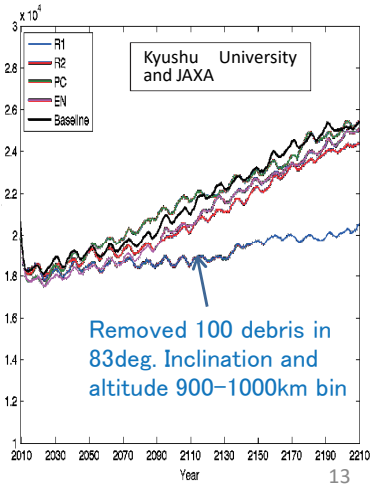
12

ADR Practical Scenario

- Effective but relatively easy target will be removed with cost effective technology
  - ADR Cost should be economically reasonable

Liou, J. C., Instability of the present LEO satellite populations, COSPAR 2006





13

ADR Practical Scenario: ADR targets

- 2 major target debris groups are considered.
- Large debris which will be the origin of the numerous small debris
  - Easier to get benefit by removing from the orbit comparing to small debris
    - One large debris removal is equal to thousands of future small debris removal.
    - Number of small debris are huge comparing to large debris, but spatial distribution of small debris are still sparse in terms of ADR spacecraft dimension.
  - Rocket body is simpler than satellites in terms of the shape and composition of the parts.
    - i.e. consisting of tank, engine, payload interface, etc.
    - Identical target to start ADR in cost effective way
- Mega-constellation satellites
  - After huge number of satellites operation, numbers of satellites will be malfunctioned and remained on the orbit causes debris problem severely.
  - Mega-constellation can have partial cooperative feature for rendezvous and docking.
    - Different from R/B debris

14

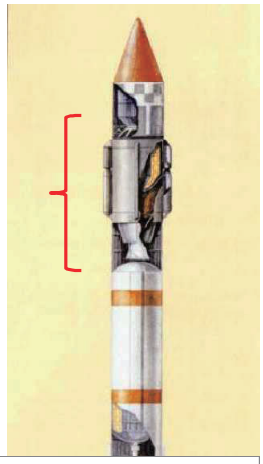
ADR Practical Scenario: Rocket Body (R/B)

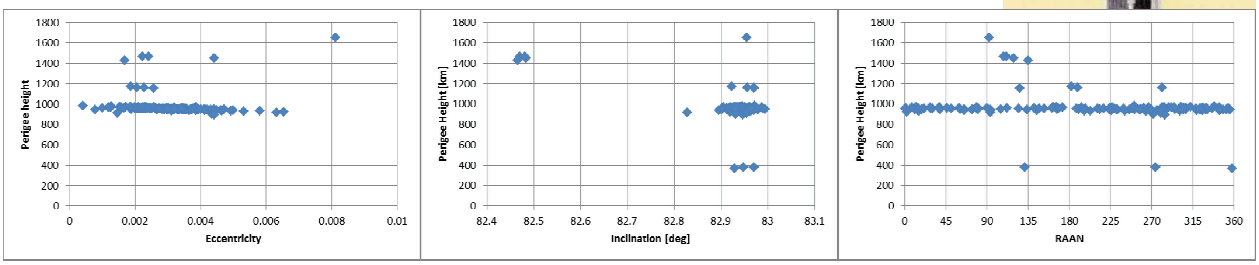
- For phase 1, debris from domestic rocket will be the target. (Scenario A)
  - H-2A upper stage for Japan
- For phase 2, R/B in the top 500 lists (domestic and foreign R/Bs) will be the target under the multi-national cooperation (Scenario B)
  - SL-16 R/B (Zenit upper statge), SL-8 R/B (Kosmos 3M), etc.

15

Scenario B:Example (SL-8 R/B case)

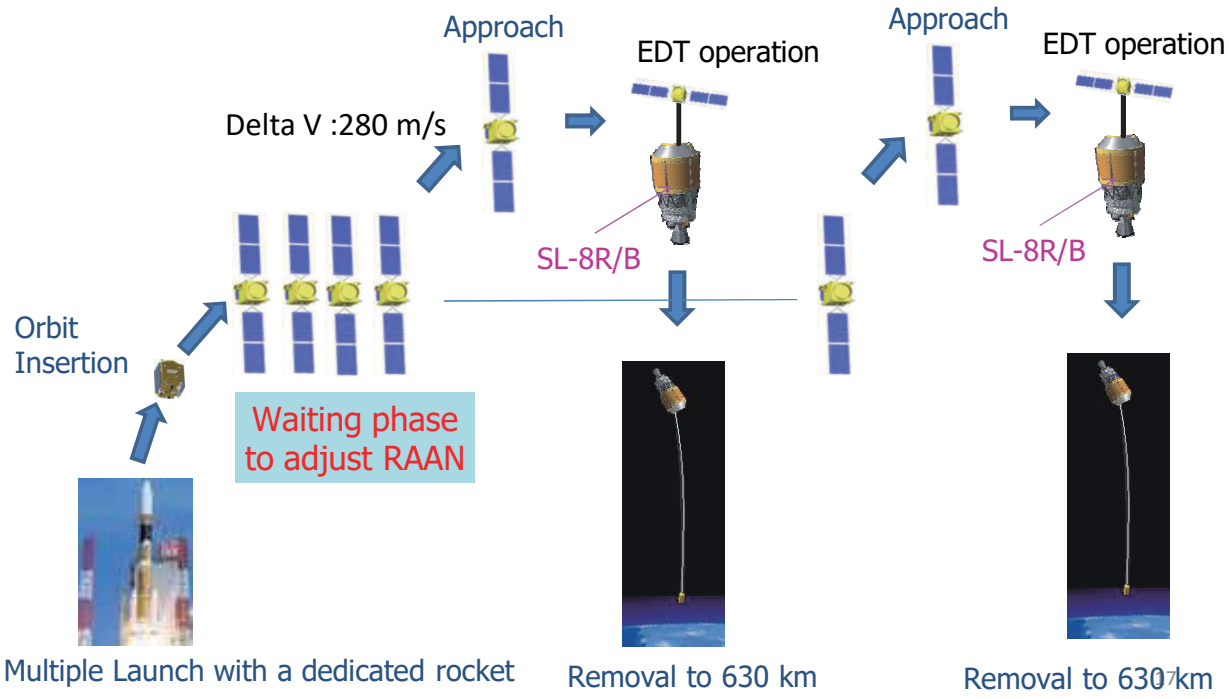
- Upper stage of KOSMOS-3M
- 1500 kg mass
- 142 R/Bs are in relatively small bin
  - Concentrating on 83 deg. Inclination
  - Altitude: ~1000 km



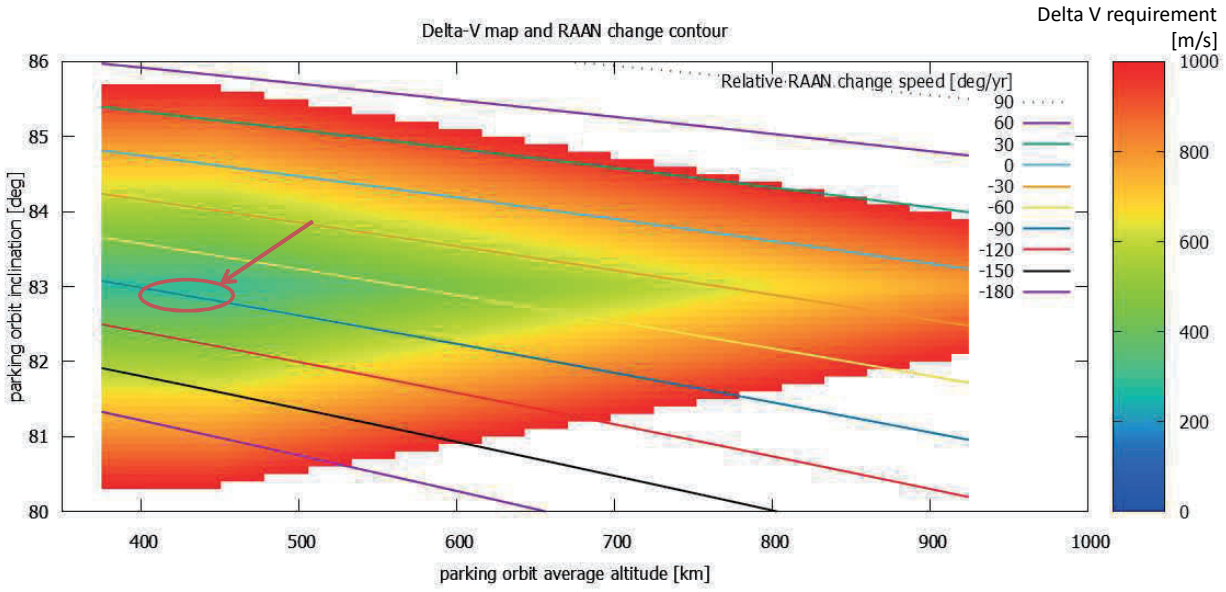


16

Scenario B:Example (SL-8 R/B case)



Scenario B:Example (SL-8 R/B case) Delta V and RAAN change calculation



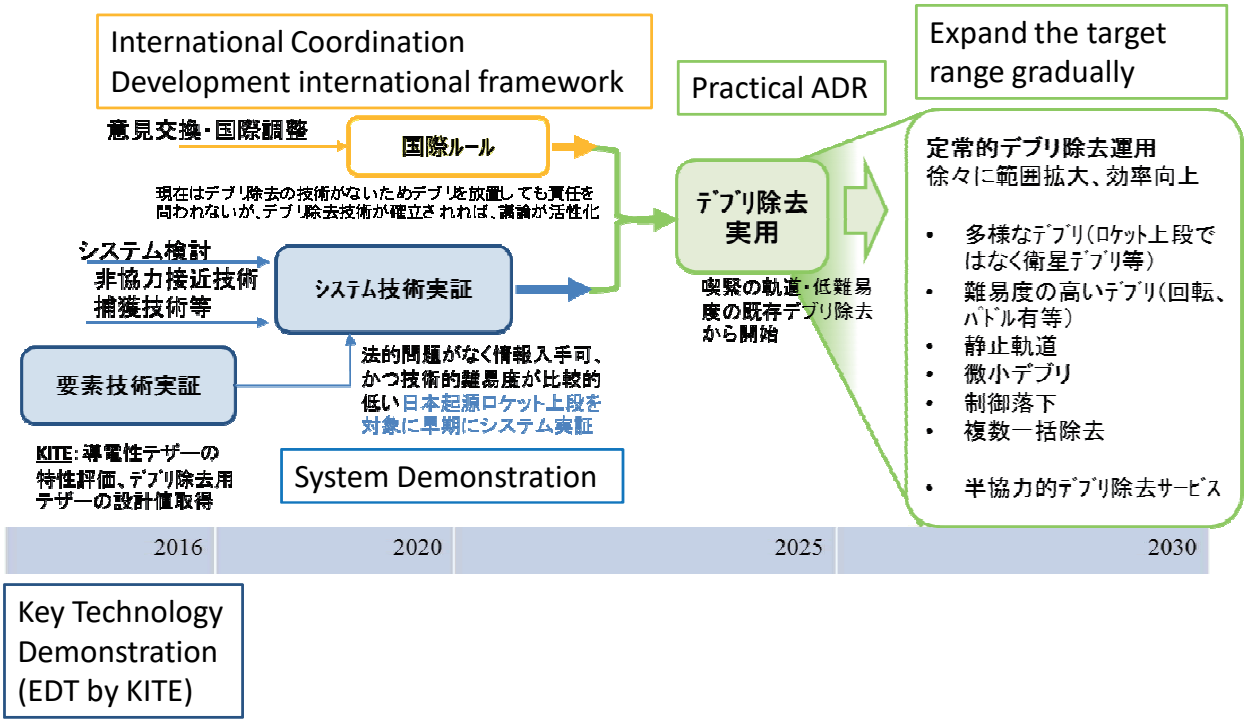
RAAN Change rate of 90 deg/yr can be achieved with 450km orbit.
Required delta V to Target is about 280 m/s

ADR Practical Scenario: Summary

- During Phase 2, demonstration and keep ADR activity in each country with multi national cooperation
  - For Japan, H-2 and H-2A R/B will be the first target
  - Remove R/B in top 500 targets
    - SL-16, SL-8, H-2A, etc.
- Parallel to ADR activity, more sophisticated measures will be developed, i.e. new capturing devices, propulsion, which can remove more complex target in reasonable cost. (i.e. ADEOS, ADEOS-II, ENVISAT, etc.)

19

ADR Practical Scenario: Summary



20

Agenda

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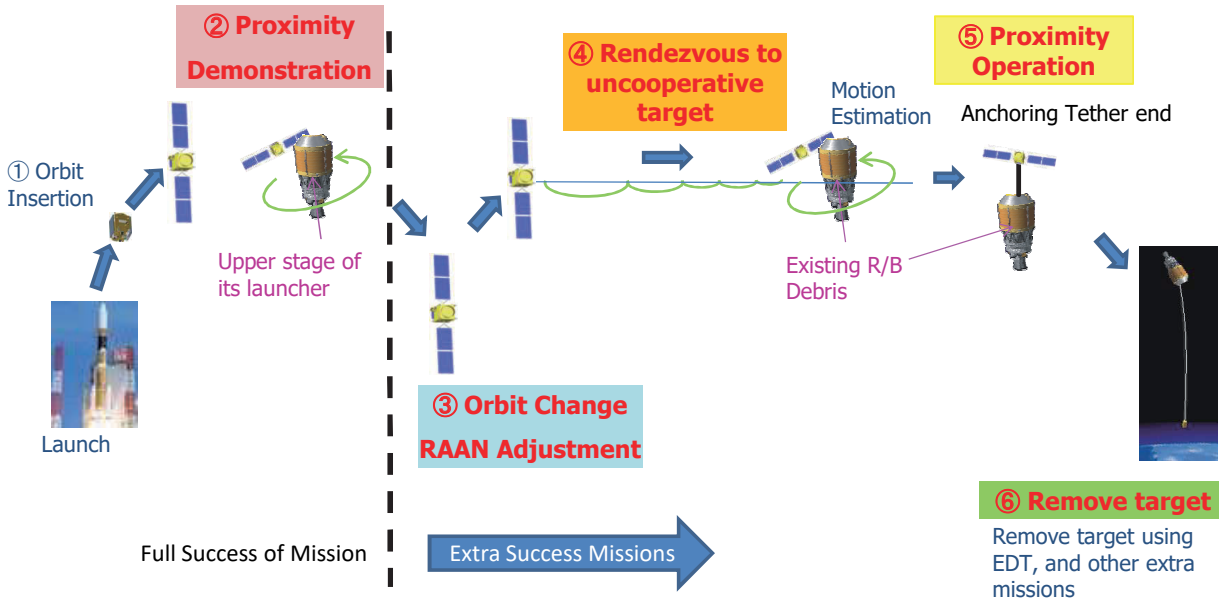
Demonstration Scenario

- What should be demonstrated/tested in space?
- Demonstrate End to End system feasibility with in the reasonable cost
  - Rendezvous with uncooperative target
  - Capture and anchoring the deorbit propulsion
  - Deorbit R/B within reasonable operating duration
  - Two scenario examples are considered
    1. Deorbit real debris
    2. Deorbit upper stage of ADR demonstration spacecraft launcher, and go to a real debris for further rendezvous and proximity demonstration
  - Small Satellite Solution to reduce the recurring cost
- Launch target schedule: FY2020

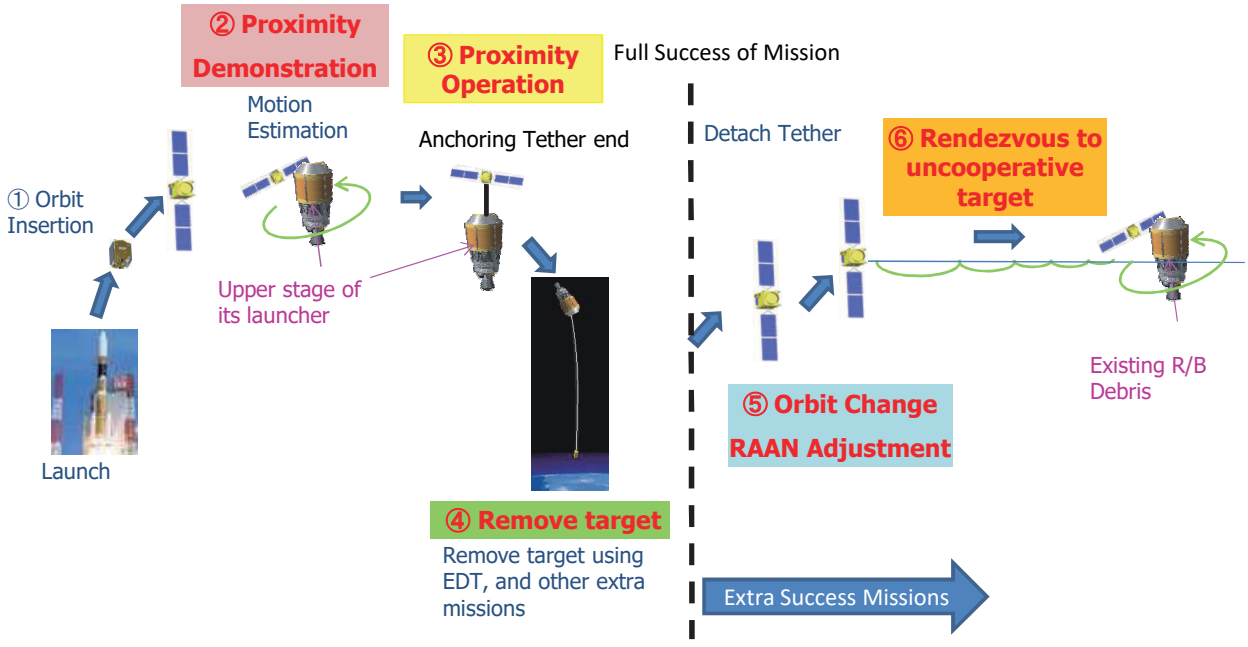
Demonstration Scenario: Example 1



Pros:
End-to-End Demonstration with real Debris

Cons:
Risks due to real debris: its attitude, orbit

Demonstration Scenario: Example 2



Pros:
Upper stage can be adjusted for proximity operation

Cons:
Removing demonstration with out real debris seemed to be less meaning and value of this mission

Demonstration Scenario: Timeline example2

1. Launch
   - Separation, Initial attitude acquisition
   - Upper stage stabilizes below 1 deg/s
2. Rendezvous and Proximity Demonstration
   1. Apart from upper stage (about 300 km) by drift.
   2. Rendezvous using TLE (far approach) and Optical sensor (near approach) to Go/NoGo point
   3. Rendezvous to Hold point using Optical sensor
   4. Take target image for motion estimation at ground.
   5. Proximity operation to PAF relative navigation point
      - PAF is used as a marker
   6. Maneuver to the capture point by PAF relative navigation
3. Capture
   - Extend/deploy capturing device
4. Deorbit
   1. Extend tether
   2. Open FEC lid
   3. Activate EDT and deorbit the target (upper stage)
   4. Detach tether
5. RAAN adjust
   1. Station keeping (altitude maintenance)
   2. Orbital elements determination (RAAN) from ground, and raise altitude to target

25

Demonstration Scenario

- Launcher

Launcher	Epsilon	H-3
Launch configuration	Dedicated Launch	Ride share with SSO satellite (probably)
Orbit insertion	Direct insertion to mission orbit	SSO (LST 10:30~13:30)
Upper Stage	B3PL (430 kg)	2nd Stage (3100 kg)*
Post separation maneuver	Rate damping for proximity demonstration	
Post separation attitude	1 deg/s for P and Y 2 deg/s for R	0.3 deg/s for 3-axis *
Default Payload Interface	PAF937	PAF 1194 (IKAROS adaptor assumed)
Launch Capability	590 kg for SSO 500km	Enough

* Estimation from H-2A performance

26

Demonstration Scenario: Differentiate

Mission contents	Demonstration (Epsilon)	Demonstration (H-3)	Practical Mission	Difference
Insertion Orbit	Target debris orbit (ca. 600 km altitude) Direct insertion by the dedicated rocket	Rideshare with SSO launch Or Rideshare with science satellite replacement	Rideshare with SSO, or multiple launch by the dedicated rocket	Almost similar launch of H-3 demonstration case and practical one
Target Debris	H-2A upper stage with PAF1194 on 600 km altitude SSO	H-2A upper stage with PAF1194 on 600 km altitude SSO Or H-2A upper stage with PAF1666 on 560 altitude with 31 degrees inclination	H-2A upper stage without PAF1194 on 800 km altitude SSO Foreign rocket with inclination 83 degrees, etc.	The mass of demonstration target is almost similar to practical one
Time Line	(1) Launch (2) Proximity Demonstration, Guidance and Navigation Demonstration (3) Travel to Target orbit (4) Proximity Operation, Capture (5) Remove Target	(1) Launch (2) Proximity Demonstration, Guidance and Navigation Demonstration (3) Orbit change (RAAN adjust) (4) Rendezvous, Proximity operation, Capture (5) Remove Target	(1) Launch (2) Orbit change (RAAN adjust) (3) Rendezvous, Proximity operation, Capture (4) Remove Target	Almost similar timeline of demonstration mission, differentiate from the practical mission is mainly the waiting duration for RAAN adjustment

27

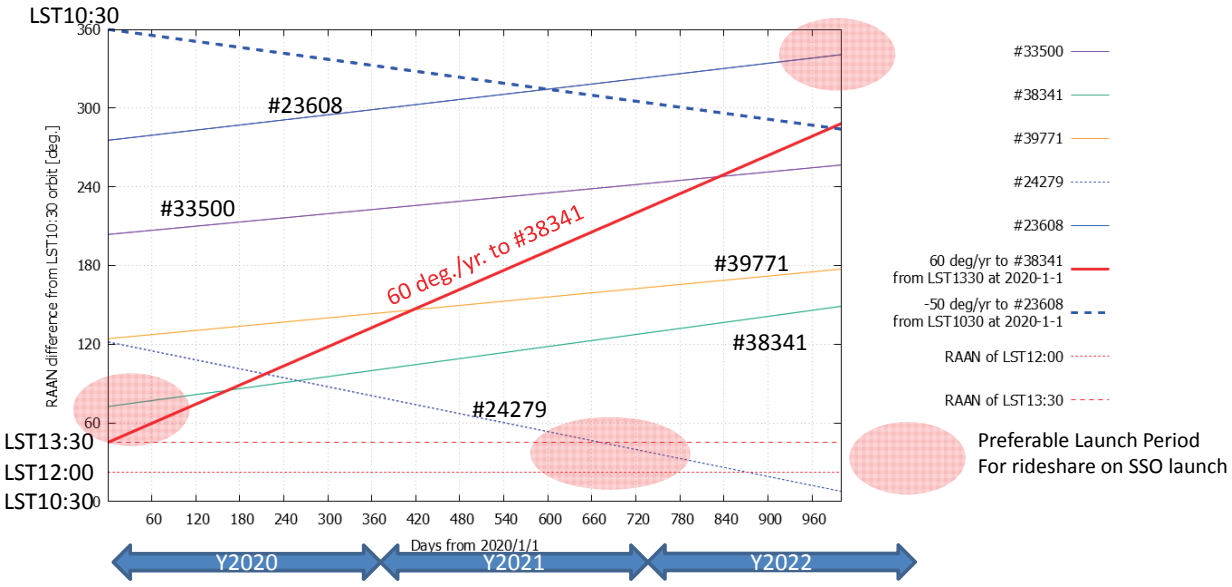
Demonstration Scenario

- The candidates:

NORAD Catalogue #	Name	Remarks
(removal demonstration candidate)		
39771	H-2A R/B	ALOS-2
38341	H-2A R/B	GCOM-W1
33500	H-2A R/B	GOSAT
41341	H-2A R/B	ASTRO-H
(observation candidate)		
24279	H-2A R/B	ADEOS-II
23608	ARIANE-40-3	HELIOS-1B

28

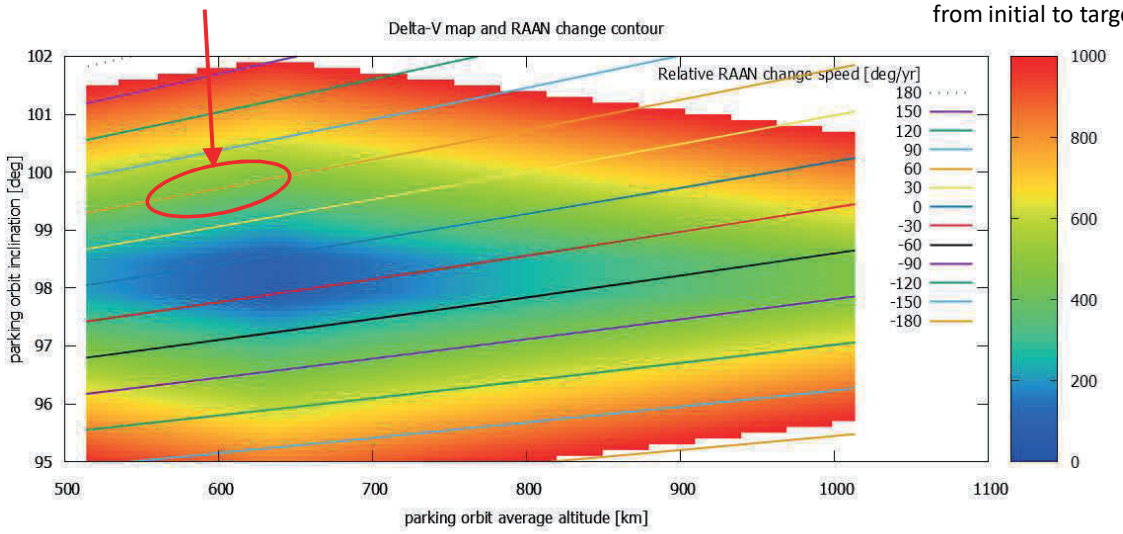
Demonstration Scenario: RAAN propagation



Demonstration Scenario: #38341 case

- Initial orbit : alt 628 km SSO (i=97.9)
- Target orbit: alt 616 km, i=98.478 (estimation, as of 1/Jan/2021)
- Required total delta-V : 415 m/s for 60 deg/yr to #38341

Required total delta-V from initial to target



Demonstration Scenario: Summary

- 2 example case of demonstration scenarios have been considered with candidate launchers.
- Demonstration satellite launch target is FY2020
- #38341 (H-2A upper stage of GCOM-W1 launch) is closest domestic R/B from LST13:30 orbit during Y2020