The Top 10 Questions for Active Debris Removal

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Outline

• Historical and current orbital debris environment

• The top 10 topics for active debris removal (ADR)
  – Focus the discussion on ≥10 cm objects
  – Limit the future projection to 200 years
  – Use the NASA orbital debris evolutionary model, LEGEND (an LEO-to-GEO Environment Debris model), for simulations
  – Address environment remediation only (will not discuss cost, technology, ownership, legal, liability, and policy issues)

• Recent and future active debris removal activities
  – ADR conference, workshops, studies, opportunities, etc.
Growth of the Historical Debris Populations

Monthly Number of Objects in Earth Orbit by Object Type

- Total Objects
- Fragmentation Debris
- Spacecraft
- Mission-related Debris
- Rocket Bodies

Key Events:
- FY-1C ASAT Test
- Iridium-Cosmos
An increase of 117% in the region below 1000 km
Mass in Orbit (1/2)

Mass Distribution in LEO

- LEO-to-GEO: ~5900 tons
- LEO: ~2500 tons
Mass Distribution in LEO

- Mass in Orbit (2/2)
- Mass Distribution in LEO

- All (blue)
- Rocket Bodies (46% of All) (red)
- Spacecraft (51% of All) (green)
- Others (gray)

Altitude (km):
- 200
- 400
- 600
- 800
- 1000
- 1200
- 1400
- 1600
- 1800
- 2000

Mass (metric ton) per 50 km Altitude Bin:
- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350

Mass in Orbit (2/2)
The Top 10 Topics for Active Debris Removal
The Top-10 List

1. Which region (LEO/MEO/GEO) has the fastest projected growth rate and the highest collision activities?
2. Can the commonly-adopted mitigation measures stabilize the future environment?
3. What are the objectives of ADR?
4. How can effective ADR target selection criteria to stabilize the future LEO environment be defined?
5. What are the keys to remediate the future LEO environment?
6. What is the timeframe for ADR implementation?
7. What is the effect of practical/operational constraints?
8. What are the collision probabilities and masses of the current objects?
9. What are the benefits of collision avoidance maneuvers?
10. What is the next step?
1. Which region (LEO/MEO/GEO) has the fastest projected growth rate and the highest collision activities?
Projected Growth of the Future Debris Populations

Non-Mitigation Projection (averages and 1-σ from 100 MC runs)

- LEO (200-2000 km alt)
- MEO (2000-35,586 km alt)
- GEO (35,586-35,986 km alt)

Ave. collisions in the next 200 years (non-mitigation scenario)

<table>
<thead>
<tr>
<th>Category</th>
<th>Cat.</th>
<th>Non-cat.</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>LEO</td>
<td>83</td>
<td>95</td>
<td>178</td>
</tr>
<tr>
<td>MEO</td>
<td>0.5</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>GEO</td>
<td>1.5</td>
<td>1.5</td>
<td>3</td>
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</tbody>
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Assessments of the Non-Mitigation Projection

• **LEO:** the non-mitigation scenario predicts the debris population (≥10 cm objects) will have a rapid non-linear increase in the next 200 years
  – This is a well-known trend that was the motivation for developing the currently-adopted mitigation measures more than 10 years ago

• **MEO and GEO:** the non-mitigation scenario predicts a moderate population growth
  – Only a few accidental collisions between ≥10 cm objects are predicted in the next 200 years
  – The currently-adopted mitigation measures will further limit the population growth in key regions
  – Active debris removal is not a priority
2. Will the commonly-adopted mitigation measures stabilize the future LEO environment?
Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant.

Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions.
A Realistic Assessment

• In reality, the situation will be worse than the “no new launches” scenario as
  – Satellites launches will continue
  – Major breakups may continue to occur (e.g., Fengyun-1C, Briz-M, Iridium 33/Cosmos 2251)

• Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening

• To preserve the near-Earth space for future generations, ADR must be considered
LEO Environment After FY-1C and Iridium/Cosmos Breakups

- Solid lines: 1957-to-2006, no new launches beyond 2006
- Dashed lines: 1957-to-2009, no new launches beyond 2009

Increased baseline of ~2500 objects
Another 8-to-9 collisions are expected in the next 40 years (~1 every 5 years)
3. What are the objectives of ADR? (How to define mission success?)
How to Define Mission Success?

• The mission objectives guide the removal target selection criteria and the execution of ADR

• Specific objectives
  – Control population growth (≥10 cm or others)
  – Limit collision activities
  – Mitigate short-/long-term risks (damage, not necessarily catastrophic destruction) to selected payloads
  – Mitigate risks to human space activities
  – And so on

• Common objectives
  – Follow practical/mission constraints (in altitude, inclination, class, size, etc.)
  – Maximize benefit-to-cost ratio
One Example: Risks From Small Debris

• The U.S. segments of the ISS are protected against orbital debris about 1.4 cm and smaller
  – “Currently”, the number of objects between 1.5 cm and 10 cm, with orbits crossing that of the ISS, is approximately 1200
    • ~800 of them are between 1.5 cm and 3 cm
  – To reduce 50% of the ISS-crossing orbital debris in this size range (1.5 cm to 3 cm) will require, for example, a collector with an area-time product of ~1000 km² year
4. How can effective ADR target selection criteria to stabilize the future LEO environment be defined?
A Simple Physical Argument

• Future LEO environment is likely to be dominated by fragments generated via accidental collisions

• The effort to reduce future accidental collision fragments should focus on
  – Objects with the highest collision probabilities
  – Objects with the potential of generating the greatest amount of fragments after collisions

• An effective ADR target selection criterion can be defined as
  – Objects with the highest \([M \times Pc]\);   \(M\): mass, \(Pc\): collision probability
5. What are the keys to remediate the future LEO environment?
A 2008-2009 LEGEND study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are

- A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, etc.)
- An active debris removal of about five objects per year
  - Select objects with the highest $[M \times P_c]$
  - Is based on two assumptions: (1) future launches can be represented by the traffic cycle from the last 8 years, and (2) implementation of ADR start in 2020
  - Does not include Iridium 33/Cosmos 2251 fragments
- Future LEO environment can become better than what it is today if more than five objects per year are removed
LEO Population Control

LEO Environment Projection (averages of 100 LEGEND MC runs)

- PMD scenario predicts the LEO populations would increase by ~75% in 200 years
- The population growth could be reduced by half with a removal rate of 2 obj/year
- LEO environment could be stabilized with PMD and a removal rate of 5 obj/year

(Liou, Johnson, and Hill 2010)
Mass in Orbit and Mass Removed

- Mass in LEO (PMD): ~6.8 tons per year
- Mass in LEO (PMD + ADR02): ~4.3 tons per year
6. What is the timeframe for ADR implementation?
Sooner or Later?

LEO Environment Projection (averages of 50 LEGEND MC runs)

- Red: Reg Launches + 90% PMD
- Blue: Reg Launches + 90% PMD + ADR2060/05
- Green: Reg Launches + 90% PMD + ADR2020/05

Average difference from waiting for 40 more years
7. What is the effect of practical/operational constraints?
Distributions of R/Bs and S/Cs in LEO

Current LEO R/Bs and S/Cs (masses >50 kg)

- **Apogee** (red crosses)
- **Perigee** (blue circles)

**Axes:**
- **Altitude (km)**
- **Inclination (deg)**
One Example
(Limiting ADR Targets to 900-1050 km alt and 82.5°-83.5°)

Does not address growth in other altitude regimes
8. What are the collision probabilities and masses of the current objects?
Objects with the Highest $[M \times P_c]$ Values

Top 200 Current R/Bs and S/Cs

- Apogee
- Perigee

SL-8 R/B (1400 kg)

Cosmos (2000-6000 kg)

METEOR (2200 kg)

SL-8 R/B (1400 kg)

Cosmos (2500 kg)

Cosmos (1300-4000 kg)

SL-16 R/B (8300 kg)

Cosmos (3300 kg)

Varies (1100-8300 kg)
9. What are the benefits of collision avoidance maneuvers?
Effects of Collision Avoidance Maneuvers

• Collision avoidance (COLA) maneuvers
  – Can prevent spacecraft from colliding with objects in the U.S. Space Surveillance Network (SSN) catalog
    • ~80% of the ~300 currently active payloads in LEO have the maneuvering capability
  – Do not protect spacecraft from non-catalog objects
    • Objects smaller than 10 cm are still lethal to payloads
    • The LEO population growth is a concern to every satellite operator/owner
  – Do not significantly reduce the long-term LEO debris population growth
Mass Distribution of “Young” Spacecraft

Mass Distribution in LEO (January 2010)

- **All (R/Bs + S/Cs + Debris)**
- **Spacecraft launched after 2001** (total ~220 tons)

~9% of the total LEO mass
Benefits of COLA Maneuvers

LEO Environment Projection (averages of 50 LEGEND MC runs)

- Reg Launches + 90% PMD
- Reg Launches + 90% PMD + COLA

Effective Number of Objects (>10 cm)

All payloads younger than 9 years old were excluded from collision consideration
10. What is the next step?
The Challenges Ahead – a Personal Perspective

• Reach a consensus on the instability problem of the LEO debris environment

• Determine if there is a need to use ADR for environment remediation
  – Define “what is acceptable”
  – Establish a timeframe to move forward

• Commit the necessary resources to support the development of low-cost and viable removal technologies

• Address the policy, coordination, ownership, legal, liability, and other issues at the national and international levels
Recent and Future Activities Related to Active Debris Removal
The International Conference on Orbital Debris Removal (Dec. 2009)

- The 2.5-day conference included 10 sessions
  - Understanding the Problem; Solution Framework; Legal & Economic; Operational Concepts; Using Environmental Forces; Capturing Objects; Orbital Transfer; Technical Requirements; In Situ vs. Remote Solutions; Laser Systems.
  - Had 275 participants from 10 countries; 52 presentations plus 4 keynote speeches

- The conference reflected a growing concern for the future debris environment
- It represented the first joint effort for different communities to explore the issues and challenges of active debris removal
Maintaining a Good Momentum to Move Forward

- ISTC Space Debris Mitigation Workshop (April 2010)
- European Workshop on Active Debris Removal
- IAA study on removal technologies, IADC study on the LEO environment, debris removal papers at upcoming COSPAR, IAC, etc.
- NASA RFI for small satellite demonstration missions
  - orbital debris removal, autonomous/collaborative/close proximity operations, etc.
- Potential collaboration on ADR demonstration missions
The Future is in Our Hands

Pre 1957 → 2010 → 2210+
Backup Charts
Journal Publications
(LEGEND and LEGEND Applications)


