Space Debris Mitigation: Mechanical Electrodynamic Tether Payload Design For Rapid Deorbiting of Nanosatellite

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Agenda

- Space Debris Introduction & Theory
- Removal Methods
- CubeSat Introduction & Comparisons
- The EDT
- Design Philosophy
- Testing & Results
- Future Plans & Conclusion
- Questions
Space Debris Intro & Theory
Introduction

International Industry Growth

Increase in Accidents!

Increase in Spacecraft
What is Space Debris?

- Objects included defunct satellites, discarded spacecraft parts, and spent launch vehicles
  - Are called "orbital space debris" or "space junk"

- This space debris pose a critical challenge in Low Earth Orbit (LEO)
  - Accumulation of these objects increases the chances of a collision

- Space debris can vary in size, but all equally as deadly due to speed
  - From flakes of paint to rocket boosters
  - 7 KM per second
Space Debris: Over 58 Years of Orbital Waste

Photo: Reddit
Space Debris: Numbers and Scale

Monthly Number of Objects in Earth Orbit by Object Type

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

Photo: NASA JSC
Kessler Syndrome

- Scenario in space where the density of debris in Low Earth Orbit becomes so high that collisions between objects create a chain reaction
  - More space junk in LEO has a greater likelihood of orbital accident

- High density of debris in LEO can make certain orbits unusable due to heightened collision risk

- Kessler Syndrome poses a threat to operational satellites, spacecraft, and the International Space Station (ISS)
Kessler Syndrome: Simulated Result

Photo: ESA
Removal Methods
Removal Methods

Deorbiting Methods:
Passive Systems:
▪ Systems rely on natural forces to gradually lower a satellite’s orbit until reentry
Active Systems:
▪ Technologies actively enhance the deorbiting process

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Advantage</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag Augmentation</td>
<td>Passive and gradual deorbiting</td>
<td>Low-cost and simple implementation</td>
<td>Limited effectiveness in higher orbits</td>
</tr>
<tr>
<td>Inflated Method</td>
<td>Rapid acceleration for deorbiting</td>
<td>Quick deorbiting process</td>
<td>Deployment challenges</td>
</tr>
<tr>
<td>ElectroDynamic Tether</td>
<td>Propulsion without consuming propellant</td>
<td>No propellant required, long-term solution</td>
<td>Technical complexity, limited altitude</td>
</tr>
<tr>
<td>Solar Radiation Force</td>
<td>Propulsion using solar radiation pressure</td>
<td>Sustainable and fuel-free</td>
<td>Limited force, effectiveness in LEO</td>
</tr>
<tr>
<td>Method</td>
<td>Drag Augmentation System</td>
<td>Inflated Method</td>
<td>Electro-Dynamic Tether</td>
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<tr>
<td><strong>Example</strong></td>
<td>RemoveDEBRIS</td>
<td>InflateSail</td>
<td>DESCENT</td>
</tr>
<tr>
<td><strong>Image</strong></td>
<td><img src="image1" alt="Photo: SST" /></td>
<td><img src="image2" alt="Photo: SST" /></td>
<td><img src="image3" alt="Photo: YorkU" /></td>
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CubeSat Intro & Comparisons
CubeSats

Small Satellites include **CubeSats**, NanoSats, and MircoSat

- Standardized sizes and allow for modular development

- Density of SmallSats in LEO is increasing
  - Industry & Academia use

- Simple design, cost effective, & accessible
CubeSat

Photo: CSA
Tethered CubeSat Examples

▷ TEPCE Navy Mission

Photo: NASA

▷ DESCENT R&D Mission

Photo: YorkU
Electrodynamic Tether (EDT)
ETD

Electrodynamic Tether:
• Polymer core embedded with aluminum
  ▪ Extraordinary strength, lightweight nature, and unique electrical properties

Photo: YorkU
Lorenz Force

- ETD & CNT generates a propulsive force
- Opposed motion & reduces velocity
  - Increase in atmospheric drag & faster orbital decay

\[ F = q(v \times B) \]

F: Force vector acting on CubeSat
q: Charge of the CubeSat
v: Velocity vector of CubeSat
B: Magnetic field vector

Photo: YorkU
Design Philosophy
Mechanical Payload Design

- Controlled deployment of EDT for improved efficiency
- Address possible jamming and ratchet free by redesigning locking system
- Optimize the EDT layout and increasing tape length
- Reducing footprint while adding modularity
Current Revision

- Locking Pins (x2)
- motherSat
- daughterSat
- Wave Spring
- Electrodynamic Tether (EDT)
- Carbon Nanotube (CNT) Cathode
- Tether Storage Bay
## Revision Table

<table>
<thead>
<tr>
<th>Revision</th>
<th>Additions &amp; Modifications</th>
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</thead>
</table>
| 1        | • Adapted to 1U format  
• Introduced efficient locking system  
• Magazine-style tether storage  
• CNT Cathode on DaughterSar |
| 2        | • Downsized to 1/3 size of tether storage & redesigned DaughterSat  
• Relocated CNT Cathode  
• Revamped locking pins  
• Transitioned to circular disk profile |
| 3        | • Widened locking pin slots  
• Added removable center support, center divider, & rear access panel  
• Further revised locking pins, notch for secure pin insertion  
• Transitioned to dual-plate configuration & added bottom plate for support |
Fig. 2  Labeled changes for revision 1 tether components.

Fig. 3  Labeled changes for revision 2 tether components.
Fig. 3  Labeled changes for revision 2 tether components.

Fig. 4  Labeled changes for revision 3 tether components.
<table>
<thead>
<tr>
<th>Revision 1</th>
<th>Revision 2</th>
<th>Revision 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Design</td>
<td>Rail Design</td>
<td>Sandwich Design</td>
</tr>
<tr>
<td>Closed Hole Design</td>
<td>Open Hole Design</td>
<td>Closed Hole</td>
</tr>
</tbody>
</table>
CubeSat Integration
3D Printed Difference
Testing & Results
Testing

Initial Phase:
- Use steel wire to test ejection mechanism
- Focus on locking pins and wave spring

Burn Wire System:
- Test different wire materials
- Aim for flawless system to release locking pins accurately
Results
Future Plans & Conclusion
Conclusion

- ETD Payload is compact & effective system
- AM allows for iterative testing

Future Plans

- Test different wire materials
- Develop integrated burn wire system
Questions?