Two Space Debris Issues:
- Long-Term Cost of Satellite Operations
- Refining Reentry Disposal Hazards

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Outline

Space debris and costs
- How debris might affect costs of operating satellites

Refining reentry disposal hazards
- New device designed to refine understanding of reentry hazards
Space Debris and Costs
The Problem with Space Debris

- **Tracked objects**
  - Objects larger that ~10 cm
  - >20000 objects, ~1000 operating satellites
  - Operating satellites with maneuver capability can move
  - Predict ~2 collisions per 10 years among tracked objects
  - Collision ends satellite’s mission, creates more debris

- **Untracked objects**
  - ~600000 objects larger than 1 cm (impacts can damage or end mission)
  - Millions larger that 1 mm (impacts degrade solar panels)
  - Collisions much more common

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**4-mm-diameter crater on windshield of Space Shuttle Orbiter made by 0.2 mm fleck of white paint; relative velocity at impact: 3–6 km/sec (NASA photo)**
How will Debris Environment Affect Costs of Maintaining Satellites?

Analysis Approach
- Look at worst-case altitude range (~850 km altitude)
- Define three generic satellite types
- Define critical areas for each satellite type and size of impacting object
- Project populations of orbiting objects for 50 years (1 mm, 1 cm, >10 cm size ranges)
- Estimate changes in satellite operational lifetime due to debris environment
- Estimate increased cost to maintain constellation at full strength for 20 years; constellations fully constituted in 2010, 2020, 2030
Location of Constellations

- Satellites placed in region where flux of objects (and probability of collision) is highest
- Sun-synchronous orbits at 850 km
Results from Flux Model

Plots show the annual particle flux for a sample satellite in LEO Sun-synch orbit for 3 particles sizes:

1. The smaller particles will decay more rapidly than larger ones.
   - Decay is a function of the 11-year solar cycle’s effect on the atmosphere.
   - For purposes of comparison, flux predictions for ESA’s Master05 model are shown.
2. Master05 does not contain the recent FY1C or Iridium/Cosmos events.
Three Satellite Types & Sizes

- **Generic Government Satellite**
  - X direction
  - Y direction
  - Z direction

- **Government satellite** (5 in constellation)
  - Multiple missions
  - High reliability
  - High cost
  - 6-year design life
  - Exposed areas 5.5/15.5 m² (Min/Max)
  - 50-60 solar panel strings

- **Commercial #1** (20 in constellation)
  - Medium cost
  - 9-year design life
  - Exposed area 8/25 m² (Min/Max)
  - 30-40 solar panel strings

- **Commercial #2** (70 in constellation)
  - Single mission
  - Low cost “factory built”
  - 12-year design life
  - Exposed area 6.5/22.5 m² (Min/Max)
  - 20 solar panel strings
Replenishment Costs due to Debris

### Cost Assumptions

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Satellite Unit Cost ($M)*</th>
<th>Launch Cost ($M)*</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Government</td>
<td>750</td>
<td>250</td>
<td>Heavy lift ELV</td>
</tr>
<tr>
<td>Commercial #1</td>
<td>250</td>
<td>80</td>
<td>Medium lift ELV</td>
</tr>
<tr>
<td>Commercial #2</td>
<td>50</td>
<td>80</td>
<td>Medium lift ELV, 5 satellites co-manifested per launch</td>
</tr>
</tbody>
</table>

### Results

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Year Constellation Constituted</th>
<th>Replenishment Cost ($B)*</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No debris</td>
</tr>
<tr>
<td>Government</td>
<td>2010</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>2030</td>
<td>20.1</td>
</tr>
<tr>
<td>Commercial #1</td>
<td>2010</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>2020</td>
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<tr>
<td></td>
<td>2030</td>
<td>17.0</td>
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<tr>
<td>Commercial #2</td>
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<td>7.9</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>2030</td>
<td>7.9</td>
</tr>
</tbody>
</table>

*Costs in 2009 Dollars

1-9% increase  3-18% increase
Summary

- Degradation of solar panels by small debris increases overall constellation maintenance costs
  - 1-2% for government satellites
  - 4-9% for commercial satellites

- Debris environment increases costs of maintaining constellations over no-debris costs by as much as
  - 3% today and 3% in 2030 for government constellation (i.e., no major change)
  - 14% today and as much as 18% in 2030 for large commercial constellation (increasing solar panel robustness reduces cost increase by ~50%)

- Results indicate slow growth cost due to debris environment at worst-case altitude over next 50 years
  - Less than 1% growth for government systems
  - As much as 4% growth for commercial systems

- Collision avoidance service reduces cost increase by ~10% (does not account for loss-of-service costs, etc.)

- Design-based debris mitigation (e.g., increasing solar panel robustness) may be acceptable strategy for significant period
Refining Reentry Disposal Hazards
Reentry Breakup Basics

- Space hardware reenters at very shallow angle (<1 degree)
- ~50 objects weighing more than 1 ton reenter randomly per year
- Major breakup at ~78 km (42 nmi)
- 10 to 40% of dry mass on orbit survives and impacts the Earth’s surface; poses hazard to people and property
- Debris spread over long, thin ground footprint

Recovered Debris

Texas, 1997 (NASA photo)

Oklahoma, 1997 (World Staff Photo by Brandi Stafford)

South Africa, 2000 (Photo: Die Burger/Johann van Tonder)

Saudi Arabia, 2001 (NASA Photo)

South Africa 2000 (Photo: Argus/Enver Essop)
Current Status of Reentry Hazard Modeling

- Emerging requirements state that space hardware must be deorbited into a safe region if casualty expectation for random reentry exceeds a threshold value (1 in 10,000 in U.S.).
- Computer models are used to predict surviving debris and resulting hazards.
- Validated reentry survivability models are needed for reliable “design for demise.”
- Design for demise for future hardware will help satisfy policy requirements.
- Results from reentry observations indicate reentry heating/breakup models at critical altitudes can be improved.
Motivation for Reentry Measurement Data

- Quality benchmark data, from relevant flight regimes, needed to validate these models.
- Ground facilities don’t have capability to match reentry conditions.
- Data collected during actual reentry and breakup needed to upgrade prediction models.
- Data from multiple reentries would bound uncertainties.
New Recording Device

Reentry Breakup Recorder (REBR) is
- Light-weight (~4 kg), self-contained, autonomous, survivable, locatable
  - Solid state sensors, low-power data recorder to collect data
  - Internal GPS sensor to provide location
  - Light-weight, rugged heat shield material to protect recorded information
  - Satellite-based cell phone (modem) to send recorded information and location near real-time
- Attached to host vehicle, sleeps until atmospheric reentry
- Wakes up and records data on host vehicle leading up to and during breakup
- Transmits recorded data via Iridium satellite system during freefall
- Retrieval not required
REBR Instrument: “Cell Phone with a Heat Shield”

GPS & Iridium Antennas

Iridium Modem & GPS

Batteries & Electronics
- 24 AA batteries
- Electronics include
  - Command and control
  - Accelerometers
  - Rate gyro
  - Data recorder
  - Temperature & pressure sensors
  - Data from thermocouples in heat shield
2011 – First Flights

- First reentry tests scheduled for 1st Quarter 2011 aboard European Space Agency’s Automated Transfer Vehicle ATV-2 and Japanese HTV-2 missions to the International Space Station
  - REBR will record data during reentry breakup of ATV-2 and HTV-2
  - REBR will protect data through reentry
  - Recorded data will be transmitted during post-reentry flight and before ground impact
- Information recorded during breakup
  - First ever collected during breakup of unprotected vehicle
  - Revolutionize study of reentry hazards
    - Enable validation of hazard prediction models
    - Enable spacecraft, launch stages to be designed to minimize risks from surviving debris
    - Maximize spacecraft mission life, assure hazard limits not exceeded
  - Precise information on impact location
- REBR will also be platform for testing new heat shield materials
- REBR paves way for spacecraft “Black Box” system
Summary

- Device developed to collect, protect, and transmit data collected during breakup of space hardware
- Data critical for validating hazard models and designing hardware to minimize hazards after reentry, increase compliance with safety requirements
- First reentry test in 2011

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Additional Information

Effect of space debris on long-term costs of space operations


Refining reentry disposal hazards