SATELLITE VULNERABILITY TO SPACE DEBRIS RISK

Denis Bensoussan
Space debris risks assessment

• Satellites potential casualty of Earth orbits rapidly altering environment
• Danger zone myth or reality: to which extent are satellites vulnerable?
• Satellite vulnerability to space debris assessed through 2 factors:
  – Impact probabilities for satellites
  – Assessment of damage caused by impact from space debris
• Revus Project: Reducing the vulnerability of space systems

The ReVuS consortium selected in the framework of European Commission FP7 programme is led by Astrium SAS with 8 additional partners:
EMI Fraunhofer - Technische Universitaet of Braunschweig - University of Southampton - University of Leicester - Astrium GmbH - PHS Space Ltd. - Tencate Advanced Composites - Hiscox - Astri Polska
Reported impacts

- 8 major impacts on LEO satellites since 1991, 3 involving active satellites
- All events unavoidable
- No reported events in GEO, but recent increase in conjunction alerts

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>Inactive Cosmos 1934 satellite hit by cataloged debris from Cosmos 296 satellite</td>
</tr>
<tr>
<td>1996</td>
<td>Active French Cerise satellite hit by cataloged debris from Ariane rocket stage</td>
</tr>
<tr>
<td>1997</td>
<td>Inactive NOAA 7 satellite hit by uncataloged debris large enough to change its orbit and create additional debris</td>
</tr>
<tr>
<td>2002</td>
<td>Inactive Cosmos 539 satellite hit by uncataloged debris large enough to change its orbit and create additional debris</td>
</tr>
<tr>
<td>2005</td>
<td>U.S. rocket body hit by cataloged debris from Chinese rocket stage</td>
</tr>
<tr>
<td>2007</td>
<td>Active Meteosat 8 satellite hit by uncataloged debris large enough to change its orbit</td>
</tr>
<tr>
<td>2007</td>
<td>Inactive NASA UARS satellite believed hit by uncataloged debris large enough to create additional debris</td>
</tr>
<tr>
<td>2009</td>
<td>Active Iridium satellite hit by inactive Cosmos 2251</td>
</tr>
</tbody>
</table>
Impacts

Mir Docking Module

Kvant-2 Solar Panel

WSRF 2012, Dubai
Impact probabilities: GEO

• ‘Big Sky Theory’: randomly flying objects will likely never collide as the three dimensional space is so large relative to the objects

• Well...
  – Average current risk of collision at GEO is 1 every 135 years
  – Involving active satellite: 1 every 155 years

*Study presented by Ailor, W.H. and Peterson, G.E. at 55th International Astronautical Congress – Vancouver, Oct. 2004, based on >400 satellites (within 300 km of GEO altitude) plus all objects passing through*

• Assumed generic probability of collision still low
Probabilities: LEO

- Probability that any given satellite at 800-900km will be hit by debris larger than 1 cm approaching 3% over 5 to 10 year lifetime (est. NASA)
- **Revus study: modelling and simulation tests analysis on 2 spacecrafts orbiting at 600-700km:**
  - $< 1\text{mm} = 27 \text{impacts/m}^2/\text{year}$
  - $< 10\text{mm} = \text{up to 0.1 impacts/m}^2/\text{year}$
  - $< 50\text{mm} = \text{up to 0.0007 impacts/m}^2/\text{year}$
- Probabilities of impact/damage remain very low for dangerous debris
- Failure risk due to debris impact remains a substantially lower probability than risks of launcher or satellite mechanical failure
Damage / Severity assessment

- Revus study: ‘Vulnerability of Spacecraft Equipment to Hypervelocity Impacts of Space Debris’ - Fraunhofer EMI (prime), OHB-System, QinetiQ

- Comprehensive test investigation of the vulnerability of equipment to HVI
- Determine equipment failure modes
- Total of ~100 impact experiments
- Largest study on satellite equipment vulnerability ever conducted

Investigated equipment:
- fuel / heat pipes
- pressure vessels
- electr. boxes
- harnesses
- batteries

Placement representative of satellite structures

Equipment under operation

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Fuel pipes

Hypervelocity impacts on fuel pipes

Shadowgraphs: upper hypervelocity (6-7 km/s)

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Pressure vessels

filled with air and pressurized to 9 MPa (90 bar) with N₂

SLGG-4755
METOP
\( d_p = 4.5 \) mm
\( S = 100 \) mm
\( v_0 = 6.5 \) km/s

SLGG-4757
METOP
\( d_p = 5.0 \) mm
\( S = 100 \) mm
\( v_0 = 6.5 \) km/s

SLGG-4754
METOP
\( d_p = 6.0 \) mm
\( S = 200 \) mm
\( v_0 = 6.5 \) km/s

WSRF 2012, Dubai
Harnesses

Exp. 4738
"MLI+MetOp"
$S_1 = 100 \text{ mm}$
$d_p = 2.0 \text{ mm}$
$v_0 = 7.7 \text{ km/s}$
data: no failure
power: no failure
RF: no failure

Exp. 4736
"MLI+MetOp"
$S_1 = 100 \text{ mm}$
$d_p = 4.0 \text{ mm}$
$v_0 = 6.8 \text{ km/s}$
data: permanent failure
power: permanent failure
RF: permanent failure

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Electronic boxes

WSRF 2012, Dubai
Batteries

SLGG-4761
\[ S = 100 \text{ mm} \]
\[ d_p = 3.5 \text{ mm} \]
\[ v_0 = 6.7 \text{ km/s} \]

no perforation
no failure

SLGG-4763
\[ S = 100 \text{ mm} \]
\[ d_p = 6.0 \text{ mm} \]
\[ v_0 = 6.4 \text{ km/s} \]

perforation (both cells)
failure (both cells)
Tests results

Vulnerability vs. debris size: general

<table>
<thead>
<tr>
<th>Debris size</th>
<th>Impact m²/year</th>
<th>Penetration risk</th>
<th>Outside (speed side)</th>
<th>Inside (speed side)</th>
<th>antennae</th>
<th>Optic (earth side)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1mm</td>
<td>27</td>
<td>0</td>
<td>SA &amp; MLI</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&lt; 10 mm</td>
<td>3.6 10⁻²</td>
<td>2.0 10⁻²</td>
<td>2.10⁻²</td>
<td>1.0 10⁻²</td>
<td>5 10⁻²</td>
<td>2.10⁻² (impact)</td>
</tr>
<tr>
<td>&lt; 50 mm</td>
<td>1.5 10⁻⁴</td>
<td>5 10⁻⁵</td>
<td>10⁻³</td>
<td>10⁻³</td>
<td>10⁻³</td>
<td>10⁻³</td>
</tr>
</tbody>
</table>

- Orbit, debris density and satellite cross-section conditioning occurrence frequency probability
- Impact location, size and speed of debris key damage severity factors
- Qualitative measure of realistic debris impact risk → single impact could be a killer
- Satellite design and operations robustness may need to be revisited to improve prevention / mitigation

Source: NASA
Tests VS Reality

LDEF mission

• During its 8 years in space, LDEF was impacted millions of times. Some of the impacts were made by very tiny particles and by other impacts visible to the naked eye.
• LDEF revealed that microparticle levels were higher than previously believed.

Eureca mission

• Atlantis released Eureca on 31/07/1992 at a 508 km orbit. It was retrieved after 326 days of space exposure.
• 71 impacts on the outer layer of the thermal blankets on the spacecraft body (largest 2mm).
• +1000 impacts on each solar arrays (largest 6.4mm).
• Impacts range from 100 microns to several mm.
• Impact damage to Eureca caused no system failures.
Insurance and space debris (1)

- Risk of collision not a severe worry for insurers until recently
  - No exclusion in insurance policies for damages caused by space debris, as the risk of collision considered low compared with other threats such as technical malfunction or launch vehicle failure
- PD insurance covers all kind of potential satellites failures, including debris impacts
  - Subrogation actions possible against third parties
- TPL insurance available for damage to third parties arising from operations of launchers and satellites in-orbit
  - Never tested for space collision (only tested for damage to property on the ground)
  - Definition/interpretation of occurrence and duration of cover uncertain
  - Few satellites covered, insurance generally not mandatory
- Insured behaviour? Best efforts or obligation to achieve?
Insurance and space debris (2)

- Values at risk at 01/2012
  - ~200 satellites in Earth orbit with average insured value 125m$
  - GEO orbit: $23bn$ (175 satellites)
  - LEO orbit: $1.8bn$ (25 satellites)

- Stakes are rising! → Debris density / satellite values

- If incidents frequency increases, insurance premiums likely to rise, or damage due to debris could be excluded entirely
  → Significant additional cost / risk to operating a satellite

- Prevention/Mitigation critical
RDS for space debris

• The Iridium collision dramatically revealed a worrying situation

• Current scenarios do not monitor/measure this risk while damages and consequences might be catastrophic

• Reflection is needed (IUAI, LMA?) to revise/expand current scenarios

• General risk of satellites loss of control related to debris impact or even space weather to be considered

• New scenario could also be linked to a generic failure scenario: similar satellites presenting same faulty sensitivity/vulnerability to space environment

• This ‘newly discovered’ risk should be factored in ‘revised’ space PD and TPL risks assessment, covers and rates
Thank you.
Denis Bensoussan

Denis Bensoussan is a Senior Underwriter for space risks at Hiscox Lloyd’s Syndicate, since 2006.

Denis has more than 10 years experience in the aerospace industry. He has also obtained extensive experience in legal and risk management through various positions at ESA, the UN and the European Commission.

Denis holds a degree in Law and two post-graduate degrees (LLM) in International Law from Paris XI University and in Air & Space Law from McGill University (Montreal, Canada).

Denis is the author of a Master Thesis published in 2003 by McGill Institute of Air and Space Law on Satellite Navigation legal/liability aspects, is a member of the European Centre for Space Law and of the International Academy of Astronautics and regularly writes articles and gives speeches on Space legal, risk management and insurance affairs.

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