Space debris

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Space debris (orbital debris)

Space Debris
Orbiting stuff which no more serves any useful purpose.
A global environmental problem ...

“Just 60 years ago there was nothing but pristine, inky space --- and now it’s messier than a freshman’s dorm room.”

Chris Kemp, CityBeat, Jun 2001
... with widespread public interest

from Donald Duck (Finnish edition)
9 August 1989

This amount of space debris. The scenery has been completely spoiled!

I'm more worried about that clump ahead of us!

Hmm! Looks like Swiss cheese to me.
Catalogued objects, June 11, 2007

~10 000 pieces, > 10 cm
Altitude distribution of catalogued objects

as on Aug 21st, 1997  
Source: UN, 1999

ESR, July 2006
Space debris stuff

Mass of debris
\(5 \cdot 10^6 \text{ kg}\)

\(~200'000\) pieces larger than 1 cm

Source: Klinkrad, 2006
Number of catalogued fragmentation objects

Year

Number of fragments

NASA ODQN, July 2007
Solid rocket motor => dust and slag

Jan 16, 2003
Mission related objects

from Donald Duck (Finnish edition)
9 August 1989

This amount of space debris. The scenery has been completely spoiled!

I'm more worried about that clump ahead of us!

Hmm! Looks like Swiss cheese to me.
Spatial density is not high

So .... What’s the problem ?
Collisions typically at Mach 30

70 km/h

4 g, 10 km/s $\Rightarrow$ 0.2 MJ
Collisions do occur

Mean time between impacts on a sphere with 10 m² cross section

<table>
<thead>
<tr>
<th>Height of circular orbit</th>
<th>Objects 0.1-1.0 cm</th>
<th>Objects 1-10 cm</th>
<th>Objects &gt;10 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 km</td>
<td>10-100 years</td>
<td>3,500-7,000 years</td>
<td>150,000 years</td>
</tr>
<tr>
<td>1,000 km</td>
<td>3-30 years</td>
<td>700-1,400 years</td>
<td>20,000 years</td>
</tr>
<tr>
<td>1,500 km</td>
<td>7-70 years</td>
<td>1,000-2,000 years</td>
<td>30,000 years</td>
</tr>
</tbody>
</table>

Cause: paint flake

cause: Grain of fiber glass, 1.2 mm, 2 mg, Mach 12.
Debris and the space shuttle

RCC areas vulnerable to the OD particle that perforated STS-115 radiator RH4.

* OD particle properties:
  - type = glass (or ceramic) fiber composite
  - diameter = 1.0 – 1.2mm
  - assumed impact angle = 45°
  - assumed impact velocity = 4km/sec

<table>
<thead>
<tr>
<th>Failure Criteria</th>
<th>Critical Orbital Debris Ø (7km/s &amp; 0°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00” Ø hole</td>
<td>4.89mm</td>
</tr>
<tr>
<td>0.50” Ø hole</td>
<td>2.75mm</td>
</tr>
<tr>
<td>0.25” Ø hole</td>
<td>1.68mm</td>
</tr>
<tr>
<td>0.10” – 0.99” Ø hole</td>
<td>1.10-4.84mm</td>
</tr>
<tr>
<td>0.25” Ø exposed substrate (Test 6)</td>
<td>0.81mm</td>
</tr>
<tr>
<td>0.19” Ø exposed substrate (Test 11)</td>
<td>0.69mm</td>
</tr>
<tr>
<td>0.14” Ø exposed substrate (Test 5)</td>
<td>0.58mm</td>
</tr>
<tr>
<td>0.09” Ø exposed substrate (Test 4)</td>
<td>0.47mm</td>
</tr>
</tbody>
</table>

NASA ODQN
July 2007
Measuring space debris

- The SMALL: < 1 cm
- The LARGE: > 10 cm
EISCAT space debris receiver
Sensitivity is “diffraction limited”

\[
\text{RCS} = \begin{cases} 
\left(\frac{d}{d_c}\right)^4 \sigma_{\text{GEOM}} & \text{when } d < d_c = \frac{\lambda}{\pi \sqrt{3}} \\
\sigma_{\text{GEOM}} & \text{when } d > d_c 
\end{cases}
\]

<table>
<thead>
<tr>
<th>Radar</th>
<th>(d_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHF</td>
<td>5.9 cm</td>
</tr>
<tr>
<td>VHF</td>
<td>26.6 cm</td>
</tr>
<tr>
<td>ESR</td>
<td>11.0 cm</td>
</tr>
</tbody>
</table>
Use amplitude domain signal processing

Assume point target with \( a_r = \text{const.} \)

\[
R = R_0 + v_0 + \frac{1}{2} a(R_0) t^2
\]

Get signal parameters by statistical inversion

\[
(\hat{A}, \hat{R}, \hat{v}) = \arg \max_{A, R, v} D_p(A, R, v | z)
\]

Posterior prob. density

Signal parameters

Measured signal on interval \([t_0, t_0 + \Delta]\)
Fit to beam passage => event parameters

Multi-target analysis not attempted

=>

missed targets
IPY SD data summaries publicly available

http://www.sgo.fi/~jussi/spade/ipy/index.html
Getting rid of?

MOST PROBLEMS GO AWAY IF YOU WAIT LONG ENOUGH, ASOK.
Getting rid of?
How long is long enough?

A MODEL CALCULATION

Satellite breakup at 1000 km producing 300 catalogue-size fragments

Initial distribution

400 years later

800 years later

Kassler, 1991
How long is long enough?

Predicted decay of the FY1C debris cloud

Decayed Percent of Total

Source: Celestrak/CSSI (http://celestrak.com/events/FY1C-Lifetime.pdf)
Predicted time development

Source: H Klinkrad, Space Debris, Models and Risk Analysis, p181.