45th Session of the Scientific and Technical Sub-Committee of the UN COPUOS

UN Space Debris Mitigation Measures – German National Implementation Mechanism

Uwe WIRT, DLR e.V., German Space Agency
19 February 2008, Vienna
Scope

In Resolution 62/217 “International cooperation in the peaceful uses of outer space”, the General Assembly in para 26 endorses the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space and in para 27 agrees that the voluntary guidelines for the mitigation of space debris reflect the existing practices as developed by a number of national and international organizations, and invites Member States to implement those guidelines through relevant national mechanisms.

This presentation outlines relevant process/procedures being under development at the German Space Agency DLR for the implementation of these guidelines.
Contents

- From UN Space Debris Mitigation Guidelines to Implementation
- Product Assurance Requirements Tailoring Process
- Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation
From Guidelines to Implementation (1/4)

**Fundamental principles**

UN COPUOS STSC
Space Debris Mitigation Guidelines

**Technical Guidelines**

IADC*)
Space Debris Mitigation Guidelines

**Applicable Rules**

European Code of Conduct (ECoC)
on Space Debris Mitigation

Nat. Guidelines derived from ECoC

International Standards, e.g. ISO**

Support documents, tools

How shall things be done?
By which means can things be done?

*) Inter-Agency Space Debris Coordination Committee
** International Organisation for Standardization
From Guidelines to Implementation (2/4)

European Code of Conduct Requirements, Protected Regions

List of European Code of Conduct Requirements
### From Guidelines to Implementation (3/4)

<table>
<thead>
<tr>
<th>UN-Guideline 1: Limit debris released during normal operations</th>
<th>IADC-Guideline 5.1 Limit Debris Released during Normal Operations</th>
<th>European Code of Conduct Guideline/s on Design Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space systems should be designed not to release debris during normal operations. If this is not feasible, the effect of any release of debris on the outer space environment should be minimized.</td>
<td>In all operational orbit regimes, space systems should be designed not to release debris during normal operations. Where this is not feasible any release of debris should be minimised in number, area and orbital lifetime. Any program, project or experiment that will release objects in orbit should not be planned unless an adequate assessment can verify that the effect on the orbital environment, and the hazard to other operating space systems, is acceptably low in the long-term. The potential hazard of tethered systems should be analysed by considering both an intact and severed system.</td>
<td>SD-DE-01</td>
</tr>
<tr>
<td>SD-DE-01</td>
<td>a) For the launch of a single payload, there should be only one element (for example, stage) of the launch vehicle injected into orbit, excluding the payload.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) For the launch of multiple payloads, there should be at most two elements (for example, stage, adaptation structure for multiple payloads) of the launch vehicle injected into orbit, excluding payloads.</td>
<td>SD-DE-02</td>
</tr>
<tr>
<td>SD-DE-02</td>
<td>a) For payloads, mission related components (for example, attachments of electrical wiring, devices retaining antennas, apogee boost motor heat shields, solid propellant thruster nozzle blanks, observation instruments protections, explosive bolts, springs, belts) should be designed so that released parts are retained.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Devices, which by design release objects other than payloads into orbit, should be avoided (for example, &quot;yo-yo&quot; device).</td>
<td>When a) or b) cannot be fulfilled, potential space debris should be identified (number, size, orbit parameters, orbit evolution, orbital lifetime, etc.) and included in the space debris mitigation plan.</td>
</tr>
<tr>
<td>SD-DE-03</td>
<td>Any suborbital space object (for example, launch vehicle stage, adaptation structure for a launch of multiple payloads) should not generate long-lived space debris.</td>
<td></td>
</tr>
<tr>
<td>SD-DE-06</td>
<td>Solid propellants likely to generate space debris in the form of particles greater than 10 microns should be avoided.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The use of pyrotechnics (for example, pyrotechnic cutters) in orbit should not generate any particle of size greater than 10 microns.</td>
<td>SD-DE-07</td>
</tr>
<tr>
<td></td>
<td>The materials, their application, and the design (structures, tanks, propellant, equipment, surface materials, etc.) should not generate space debris during the orbital phase of any space system.</td>
<td>Where the generation of space debris due to the materials and basic technologies cannot be avoided, the number, size, and lifetime of debris generated should be minimized.</td>
</tr>
<tr>
<td></td>
<td>The materials and basic technologies selected for space systems should be qualified accordingly (for example, qualification plans should include tests - radiation, shock, etc. - demonstrating minimal space debris production).</td>
<td></td>
</tr>
</tbody>
</table>
From Guidelines to Implementation (4/4)

**Fundamental principles**

**Technical Guidelines**

**Applicable Rules**

**Support documents, tools**

1.7.3 Supporting Documents

- The following documents are used to support those involved in the management, design, operation, and mission control:
  - CoC Guidelines
  - SDETES: Space Debris End-to-End Service

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**SDETES: Space Debris End-to-End Service**

**SDETES Process**

1. Step 1: Work Instruction CoC 3
2. Step 2: Work Instruction CoC 4
3. Step 1: Work Instruction CoC 5.1
4. Step 2: Work Instruction CoC 5.2
5. Step 1: Work Instruction CoC 5.3

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**UN COPUOS STGC**

**Space Debris Mitigation Guidelines**

**IADC**

**European Code of Conduct on Space Debris Mitigation**

**Coding Levels for Destructive Re-Entry Analysis**

- Code Level: Very Simple
- Complexity: Day
- Code: Free download
- Availability: Self-implementation

**CoC Guidelines**

- CoC 3
- CoC 4
- CoC 5
  - CoC 5.1
  - CoC 5.2
  - CoC 5.3

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**Deutsche Zentrum für Luft- und Raumfahrt e.V.**

**Technical Resources**

- Technical & Background documents
Contents

- From UN Space Debris Mitigation Guidelines to Implementation

- Product Assurance Requirements Tailoring Process

- Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation
Product Assurance Requirements Tailoring Process (1/5)
Product Assurance Requirements Tailoring Process (2/5)
## Product Assurance Requirements Tailoring Process (3/5)

### Content of the DLR Standard Product Assurance Requirements Catalogue

<table>
<thead>
<tr>
<th>Subject</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Assurance Management</strong></td>
<td>ECSS-Q-00, ECSS-Q-20, ECSS-Q-20-09</td>
</tr>
<tr>
<td><strong>Quality Assurance &amp; Verification</strong></td>
<td>ECSS-Q-20, ECSS-Q-20-04, ECSS-M-40, ECSS-E-10, ECSS-E-10-02, ECSS-E-20</td>
</tr>
<tr>
<td><strong>Dependability</strong></td>
<td>ECSS-Q-30, ECSS-Q-30-02, ECSS-Q-30-01, ECSS-Q-40-12, ECSS-Q-60-11, ECSS-E-10-05</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>ECSS-Q-40, ECSS-Q-40-02, ECSS-Q-70-29, ECSS-M-20, ECSS-Q-70-36, ECSS-E-30-01</td>
</tr>
<tr>
<td><strong>EEE-Parts Procurement</strong></td>
<td>ECSS-Q-60, ECSS-Q-60-01, ECSS-Q-60-05</td>
</tr>
<tr>
<td><strong>Software Product Assurance</strong></td>
<td>ECSS-Q-00, ECSS-Q-80, ECSS-E-40</td>
</tr>
<tr>
<td><strong>Mission Operation</strong></td>
<td>ECSS-Q-20, ECSS-E-70</td>
</tr>
</tbody>
</table>
Product Assurance Requirements Tailoring Process (4/5)

Stage-1) Request for Proposal
- Project Requirements
- Tailoring PA-Requirements
- Project PA-Requirements
- Request for Proposal

DLR PA-Requ. Catalogue

Stage-2) Proposal
- Response Compliance Matrix
- Proposal Assessment
- Winner
Product Assurance Requirements Tailoring Process (5/5)

Stage-3) Contract
- Consolidation of PA-Aktivities
- Consolidation PA-Requirements
  - Resp, Comp.Matrix
  - Project PA-Requ.

Stage-4) Contractor PA-Planning
- Contractor PA-Plan
  - Consol, Comp.Matrix
  - Project PA-Requ.

Stage-5) PA-Controlling
- Reviews
- Reports
- Inspection
- Audits
- PA-Plan
- Consol, Comp.Matrix
- Project PA-Requirements
Contents

- From UN Space Debris Mitigation Guidelines to Implementation
- Product Assurance Requirements Tailoring Process
- Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation
Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (1/7)

EnMAP (Environmental Mapping and Analysis Program)

<table>
<thead>
<tr>
<th>Bus</th>
<th>Modified OHB Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>New Design</td>
</tr>
<tr>
<td>S/C Weight</td>
<td>740 kg</td>
</tr>
<tr>
<td>S/C Dimension</td>
<td>1.3m x 1.7m x 3.1m</td>
</tr>
<tr>
<td>Orbit altitude</td>
<td>643 km</td>
</tr>
<tr>
<td>Orbital period</td>
<td>ca. 98 min</td>
</tr>
<tr>
<td>Orbit inclination</td>
<td>97.96°, SSO</td>
</tr>
<tr>
<td>Mission lifetime</td>
<td>5 years</td>
</tr>
</tbody>
</table>
Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (2/7)

Guideline 1: Limit debris released during normal operations

Guideline 2: Minimize the potential for break-ups during operational phases

Guideline 3: Limit the probability of accidental collision in orbit

Guideline 4: Avoid intentional destruction and other harmful activities

Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

Time span (in year) between collisions with a space debris/meteoroids

<table>
<thead>
<tr>
<th>Particle class</th>
<th>1 mm – 1 cm</th>
<th>1 cm – 10 cm</th>
<th>10 cm – 1 m</th>
<th>1 m – 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>14.85</td>
<td>737</td>
<td>17,230</td>
<td>55,503</td>
</tr>
<tr>
<td>Natural meteoroids</td>
<td>8.05</td>
<td>2,632</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Probability (%) of collisions with a space debris/meteoroids over 5 years

<table>
<thead>
<tr>
<th>Particle class</th>
<th>1 mm – 1 cm</th>
<th>1 cm – 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Debris</td>
<td>29%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Natural meteoroids</td>
<td>46%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Requirement</td>
<td>1%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

5,268 impacts per year for debris in the range of [1 µm, 1 mm], contribute mainly to surface degradation.
Guideline 1: Limit debris released during normal operations

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Penetration probability (%) with respect to incoming particles flux

<table>
<thead>
<tr>
<th>Penetration Probability</th>
<th>Particle size</th>
<th>[1mm, 1 cm]</th>
<th>[1cm, 10 cm]</th>
<th>[1mm, 1 cm]</th>
<th>[1cm, 10 cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space debris</td>
<td></td>
<td>41.2%</td>
<td>0.09%</td>
<td>1.29%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Natural Meteoroids</td>
<td></td>
<td>15.7%</td>
<td>0.00%</td>
<td>0.17%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Requirement</td>
<td></td>
<td>1%</td>
<td>0.10%</td>
<td>1%</td>
<td>0.10%</td>
</tr>
</tbody>
</table>

Note: Equipment housing between 2 to 4 mm (aluminium)
Guideline 1: Limit debris released during normal operations
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Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (4/7)

Under Investigation: Re-entry Safety

Study frame

- Altitude at re-entry: 120 km altitude
- Re-entry date: 1st January 2031 – Maximum 25 years de-orbiting
- Re-entry type: Natural orbit decay – Uncontrolled
- Scenario: Break-up altitude 78 km – “Shadowing” effect neglected
- Software: DRAMA*) for Re-entry analysis – Survivability and Risk analysis

Survivability

- No component reaches the surface
- Minimum altitude reaches by a S/C component: 60 km
- Last component to demise in the atmosphere: Prism

Casualty risk on ground

- No component reaches the surface

*) Debris Risk Assessment and Mitigation Analysis, European Space Agency, ESA
Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (5/7)

Under Investigation: Re-entry Safety, Contamination Aspects

Guideline 2: Minimize the potential for break-ups during operational phases

<table>
<thead>
<tr>
<th>Substance</th>
<th>Hydrazine (N₂H₄)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>Highly toxic</td>
</tr>
<tr>
<td>Measure</td>
<td>ACS Hydrazine propellant burnout [1.5 kg residual] - O₃ + OH → N₂H₄ → N₂ + NH₃</td>
</tr>
<tr>
<td></td>
<td>- Disposal Maneuver Lower perigee altitude - Orbital lifetime &lt; 25 years</td>
</tr>
<tr>
<td></td>
<td>- Passivation Release of onboard stored energy</td>
</tr>
<tr>
<td></td>
<td>- Re-entry Prevention of potential contamination</td>
</tr>
</tbody>
</table>

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

<table>
<thead>
<tr>
<th>Substance</th>
<th>Lithium ion battery (Li-ion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>Explosion</td>
</tr>
<tr>
<td>Measure</td>
<td>End of life passivation - Demise at minimum 60 km altitude</td>
</tr>
<tr>
<td></td>
<td>- Passivation Release of onboard stored energy</td>
</tr>
<tr>
<td></td>
<td>Disconnection of power lines</td>
</tr>
</tbody>
</table>
Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (6/7)

TET-1 (Technology Test Carrier)

<table>
<thead>
<tr>
<th>System</th>
<th>Payload segment</th>
<th>460 x 460 x 400 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload segment</td>
<td>payload mass capacity</td>
<td>40 kg</td>
</tr>
<tr>
<td></td>
<td>power consumption</td>
<td>0 – 20 W</td>
</tr>
<tr>
<td></td>
<td>peak power consumption</td>
<td>160 W / 20 min (5 times per day)</td>
</tr>
<tr>
<td></td>
<td>nominal oper. voltage</td>
<td>20 , DC V</td>
</tr>
<tr>
<td></td>
<td>max. current</td>
<td>8 A</td>
</tr>
</tbody>
</table>

| satellite mass   | 110 kg           |
| satellite envelope | 550 x 650 x 880 mm |
| communications /S –band | uplink: 4 kbits/s downlink: 2200 kbits/s |
| Orbit            | LEO             |
| average height   | 450 – 850 km    |
| inclination      | 53° - sun-synchronous |
| stabilisation    | 3-axis stabilisation |
Space Debris Mitigation Measures – Examples upon Subjects of Analysis and Implementation (7/7)

Guideline 1: Limit debris released during normal operations
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Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission.

End-of-life Measures / Disposal (European CoC-Requirement SD-OP-03): the current baseline for TET operational orbit is 820km. In order to limit the permanent or periodic presence of TET in the protected regions to a maximum of 25 years, TET should be de-orbited to a 550 km orbit. Measures under investigation comprise following options:

- Rising of drag coefficient by enlarging cross section
- Application of a tether, both conductive (electro-magnetic drag) and non-conductive (momentum exchange) under consideration
- Application of a propulsion system
- Application of a mechanical interface for cooperative docking within the frame of a recovery mission.

End-of-life Measures / Passivation (European CoC-Requirement SD-DE-08): processes/technical solutions to eliminate all stored energy to reduce the chance of break-up (e.g. venting or burning excess propellant, discharging batteries, relieving pressure vessels) are under investigation.

Prevention Measures / Mission Related Objects (European CoC-Requirement SD-DE-02): on both satellite bus and payload level verification is ongoing to ensure that no mission related components (e.g. attachments of electrical wiring, devices retaining antennas, apogee boost motor heat shields, solid propellant thruster nozzle blanks, observation instruments protections, explosive bolts, springs, belts) will be released.

Prevention Measures / Fragmentation (European CoC-Requirement SD-DE-05): the accidental destruction probability due to an internal origin of any stored energy element (AOCS, propulsion, pressurised parts, energy storage elements - batteries, fuel cells, etc.) which should be lower than or equal to 10^-4 for the operational phase is under investigation within the frame of the System-FMECA.

Prevention Measures / Materials and technologies (European CoC-Requirement SD-DE-07): analysis of materials, their application, and the design (structures, tanks, propellant, equipment, surface materials, etc.) not to generate space debris during the orbital phase is ongoing.
Conclusions

- The General Assembly endorsed the Space Debris Mitigation Guidelines of the COPUOS and invited Member States to implement those guidelines through relevant national mechanisms.
- This presentation outlined the process for the implementation of these guidelines being under development at the German Space Agency DLR.

- The conversion of Guidelines to implementation mechanism/s is not a trivial task.
- Substantial resources on different levels upon supporting documents and tools for assistance in the implementation of technical measures for space debris mitigation exist.

- Implementation of Guidelines at DLR is carried out by a dedicated sub-process within the frame of the Product Assurance Requirements Tailoring Process.
Acknowledgements

- Mr. Christian CHLEBEK
  Head of Project „EnMAP“

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  Head of Quality and Product Assurance

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- Dr. Philip WILLEMSEN
  Deputy Head On-Orbit Verification Programme (OOV)