National Aeronautics and Space Administration

Orbital Debris Mitigation and CubeSats

Chris L. Ostrom[1], John N. Opiela[2]

[1] HX5-Jacobs JETS Contract
[2] Jacobs JETS
NASA Orbital Debris Program Office

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Agenda

- **Orbital Debris Mitigation Standard Practices, 2001**
  - 2019 Update and Inclusion of CubeSats
- **Explosion Probability**
- **Orbit Lifetime**
- **Reentry Casualty Risk**
- **Future Developments**

ODMSP (2001)

- **The US Government Orbital Debris Mitigation Standard Practices (ODMSP) were established in 2001 to "address the increase in orbital debris in the near-Earth environment"**

- **Four objectives were put forth:**
  - Minimize the generation of long-lived debris
  - Minimize the likelihood of accidental explosions
  - Minimize the likelihood of collision with 10-cm objects
  - Minimize the impact on future space operations (by reducing the residual orbit lifetime)

ODMSP (2019)

- **The ODMSP had been successful in decreasing the growth of the orbital debris population in the 2000s and 2010s, but by mid-2010s, it was clear they were no longer sufficient**
  - Increased launches of CubeSats (and smallsats in general)
  - Large constellations in LEO

- **Space Policy Directive 3 (National Space Traffic Management Policy, 2019) created an interagency working group, led by NASA, to update the ODMSP**
  - Quantitative figures for each objective were added
  - New Objective 5: “Special Classes of Space Operations”
    - **First inclusion of CubeSats as a special class in governmental-level documents**

ODMSP (2019)

- **NASA has provided funding and launch opportunities for CubeSat missions since at least 2011**
  - Far from limiting their use and deployment, NASA promotes research and development of these unique orbital platforms

- **However, CubeSat reliability remains low (historically) and thinking they are "too small to cause any harm" does not apply any longer**

Explosion Probability (1/2)

- **Projects must take steps to limit the probability of accidental explosion of their spacecraft, both during and after mission operations**
  - "The integrated probability of debris-generating explosions for all credible failure modes … is less than 0.001 during deployment and mission operations" (Obj. 2-1)
  - "All on-board sources of stored energy … should be depleted or safed when they are no longer required" (Obj. 2-2)
- **Batteries and pressure vessels are typically the sources of stored energy on a CubeSat**
- **To date, no known on-orbit breakups of a CubeSat have occurred**
  - A specific cause of mission failure can, however, be difficult to ascertain

Explosion Probability (2/2)

- **CubeSat Design Specification, rev. 13, suggests that CubeSat missions limit their stored electrical energy to 100Wh (mirroring an FAA limit for carry-ons)**
  - Post-mission, designers should limit the state-of-charge (SOC) of their battery to no more than 30%
  - Testing indicates that thermal runaway is much less likely for low SOC; for some cells, runaway can occur at SOC as low as 15%

- **Pressure vessels and systems should be designed to allow for as complete a depressurization as possible at the end of mission**
  - If this is not possible, "soft passivation" is recommended:

    Energy generation and storage should be controlled "to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft"

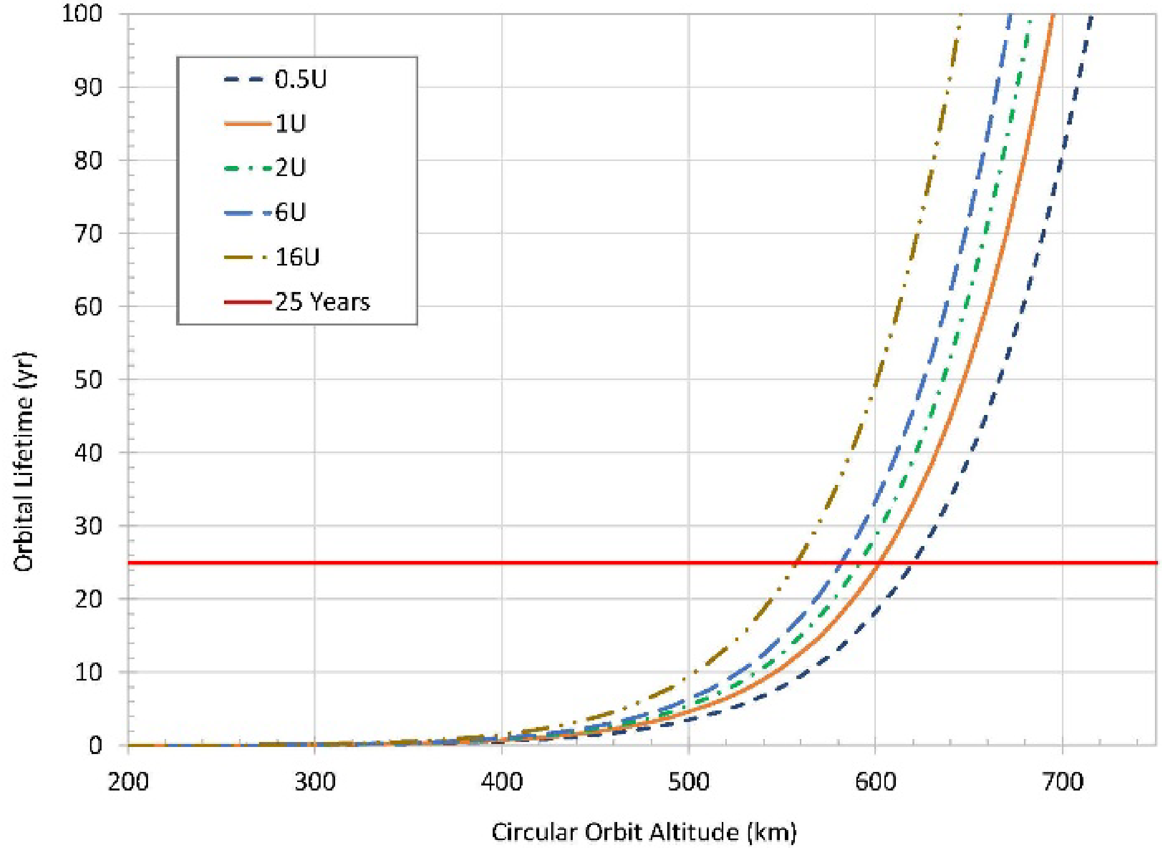
Orbit Lifetime (1/3)

- **End of mission does not mean end of mitigation efforts by an operator**
  - A successful mission is one that safely disposes its spacecraft and upper stage(s)

- **ODMSP Objective 4-1 includes options for postmission disposal (PMD)**
  - For the first time, "immediate removal" is the preferred option (4-1a)
    - **Immediate reentry or Earth-escape trajectory at end of mission**
  - If this is not feasible for a mission, residual lifetime should be limited to "as short as practicable, but no more than 25 years after completion of mission" (4-1b)

Orbit Lifetime (2/3)

- **CubeSats are not typically compliant when deployed above 600 km**



- **In addition to the 25-year limit, CubeSat developers and operators should consider the functional requirements for collision avoidance when deploying above ~550km**

Orbit Lifetime (3/3)

- **Orbit Lifetime can be computed using the Debris Assessment Software (DAS), freely available from NASA ODPO via the Software Catalog: https://software.nasa.gov/software/MSC-26690-1**

- **CubeSat missions planning to deploy sub-satellites should be aware of a new Standard Practice:**
  - "For spacecraft smaller than 10 cm x 10 cm x 10 cm when fully deployed … the total spacecraft object-time product should be less than 100 object-years per mission" (Obj. 5-2)
  - For example, a mission planning to deploy 100 femtosats must ensure each of the smaller objects has an orbit lifetime of 1 year or less

Reentry Casualty Risk (1/3)

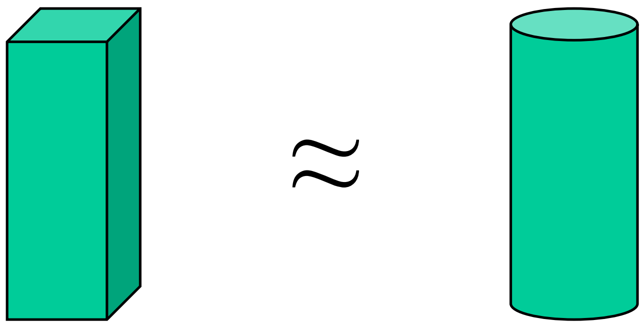
- **Another element of the ODMSP is human casualty risk**
  - Consequence of removing debris from the on-orbit environment, and should be minimized to the extent practicable

- **Ground risk should be limited to no more than 1:10,000 expectation of casualty per mission**
  - This can also be assessed using DAS (the official tool for evaluating compliance with NASA debris mitigation requirements)

- **Assessing ground casualty risk can be challenging, even for experienced developers**

Reentry Casualty Risk (2/3)

- **Some Best Practices for Reentry Analysis in DAS:**
  - Ensure all components with mass > 15g are included in the analysis
  - Components with 1 dimension much smaller than the other two should be modeled as flat plates
    - **E.g., 0.5m x 0.5m x 0.05m should be a flat plate, not a box**
    - **E.g., 0.5m x 0.5m x 0.1m could be better as a box**
  - Components with two similar dimensions and one that is ~1.5x larger should be modeled as a cylinder
    - **Cylinder diameter can be modeled as hydraulic diameter (4*area/perimeter)**



Reentry Casualty Risk (3/3)

- **Missions that do not meet the casualty risk limit of 1:10,000 typically do two things to mitigate the excess risk:**
  - "Design for demise", or redesign certain surviving components using materials that melt at lower temperatures to cause them to demise during reentry
    - **e.g., change a ballast mass's material from tungsten to copper**
  - "Design for containment" or "design for minimum debris casualty area", or designing assemblies to purposely survive, but with lower quantity, lowering the total risk
    - **E.g., changing a battery box from aluminum to steel, causing it to survive, but containing battery cells (each of which would otherwise pose separate ground casualty risk) during entire reentry process**

Summary

- **The 2019 Update to the US Government ODMSP reflects this new era of spaceflight, as well as an acknowledgment of the new classes of spacecraft operations (such as CubeSats and large constellations)**

- **This update has spurred updates to standards, instructions, and regulation throughout the US Government, including through the FCC, FAA, NASA, and DoD**

Future Developments

- **CubeSat designers and operators should be vigilant in pre-launch testing, verification, and validation of their systems and subsystems to ensure both a successful mission and good stewardship of the orbital environment**

- **Freely available guides such as the CubeSat Design Standard, and software tools such as NASA's DAS, allow designers to evaluate their compliance with the standard practices and guide future missions in guaranteeing environmentally responsible spaceflight**