Space Traffic Safety
A New Self-Governance Approach for the Smallsat Community

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Introduction

- Increasing risk, both real and perceived, of operational spacecraft to interference and damage caused by collision with other space objects (debris and other operational spacecraft)
- Crewed systems (e.g. ISS) face risk of loss of human life
- “Smallsats” in particular are called out as contributing to this increased risk
- A new focus has been placed on reducing this risk through possible new rules, regulations, and technical solutions
- Here we aim to tackle the two key questions:
  - What is the risk of smallsats to spaceflight safety?
  - What should be done to mitigate this risk?
- In conclusion, we recommend that our smallsat community organize a Self-Regulatory Organization to address spaceflight safety risk created by smallsats
Approach

• Analyze and quantify the spaceflight safety risk of smallsats

• Assess and evaluate technical control mitigation schemes

• Assess and evaluate process and management mitigation schemes

• Provide final recommendations
ADEPT (Aerospace Debris Environment Projection Tool) was used to predict the future orbit debris environment out to 200 years (end date driven by policy analysis)
- Business-as-Usual (BAU) model based on replicating last 10 years of historical catalog
  - Provides baseline for comparison with additional small satellite activity
- Additional small satellite future constellation model (FCM) includes:
  - 4080 satellites at 1100 km, polar; 6 year lifetime (680 satellites/year replaced); 50 kg mass
  - 720 satellites at 1200 km, polar; 6 year lifetime (120 satellites/year replaced); 150 kg mass
- Additional CubeSats were modeled in the following manner
  - All future launches to Earth orbit were assumed to be depositing CubeSats
    - CubeSats were deposited by the upper stage from each launch; total of ~1722 per year
  - Resulting CubeSats were grouped into three categories:
    - LEO, compliant: CubeSats that are in LEO and satisfy the 25-year decay rule
    - LEO, non-compliant: CubeSats in LEO but high enough that they do not follow the 25-year rule
    - GEO, non-compliant: CubeSats deposited by upper stage
  - All CubeSats were then allowed to decay naturally
Modeling Results

- BAU Spatial density will increase after 100 years by ~order of magnitude over current levels
- Small satellite activity could double that again
- Number of collisions will increase for BAU
- Collisions from small satellite activity could increase that substantially
- Manned objects have to avoid re-entering debris (currently ~400 re-entries per year causing ~2 debris avoidance maneuvers per year)

Spatial Density at 100 years (>1 cm)

Number of Expected Collisions

Historical Re-entering Objects
Analysis Observations

• Future debris will increase if future launch activity continues
  • Increase will be ~order of magnitude after 100 years if no new small sats (BAU model)
  • Addition of small satellites will increase the debris environment over BAU
    • LEO, non-compliant CubeSats were one main driver of the increase
    • FCM failures were the other main driver (i.e., post-mission disposal reliability)
    • Both of these are non-compliant; one by design, the other by accident
• However, what goes up must come down
  • Current re-entries number ~400 per year
  • For the assumed FCM model, expect ~800 satellite re-entries per year
  • For the assumed CubeSats, expect ~1700 re-entries per year
  • Poses a risk to lower altitude manned objects like ISS (~factor of 6 increase in number of debris avoidance maneuvers)
Risk Mitigation: Technical Controls

Knowledge
Knowing where an object is allows...

Avoidance
Maneuver around collisions

Prevention
Prevent self from creating debris

Elimination
Third-part debris removal
Technical Controls: *Knowledge*

- Increase positional knowledge to improve avoidance, prevention, and elimination
- Most smallsats rely on JSPOC TLEs
  - Low priority $\rightarrow$ reduced tracking frequency
  - SGP4 propagator inherently low fidelity
- Areas for improvement
  - Better onboard solutions (GPS)
  - Improved tracking
  - Enhanced propagation algorithms
  - Broader data dissemination
Technical Controls: *Avoidance*

- Conduct Collision Avoidance (COLA) Maneuvers to reduce debris generation events
-Extensively used for large spacecraft
- Limited applicability to smallsats due to little or no propulsive capability
- Effectiveness of COLAs dependent on tracking uncertainty – balance risk vs. false alarms
Technical Controls: Prevention

• Reduce debris problem through prevention of debris generation

• ODMSP “25-year” rule is primary source of prevention
  • 25-year altitude threshold low for dense CubeSats
  • Secondary launches limit compliant orbits
  • Loose enforcement
  • Deorbit techniques complex and require “live” satellite

Physics of Terminator Tape™
Credit: Tethers Unlimited, Inc.
Technical Controls: *Elimination*

- Utilize Active Debris Removal (ADR) systems to reduce number of resident objects
  
  Challenge: Impossible to predict far in advance objects that will collide.

- Statistical Analysis can provide a Probability-Severity (P-S) Metric combining cross-sectional area with debris generation potential

- P-S biases removal needs toward large objects

Small sats may have a role to play in removable of un-trackable objects. However value is questionable

![Graph showing PS Index for different satellites](image)
# Management/Process Controls

## “Policy Stack” Model

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level principles adopted by governing body</td>
<td>National Space Policy</td>
</tr>
<tr>
<td>“The law” or effect thereof created by legislation or rule making authorities</td>
<td>10 U.S. Code § 2274 (SSA) 47 CFR Part 25 (Satellite Communications)</td>
</tr>
<tr>
<td>Consensus requirements created by private bodies</td>
<td>CCSDS CDM Data Standard [AIAA] Standard: Occupant-Imparted Loads for Commercial Suborbital RLVs</td>
</tr>
<tr>
<td>Codified recommendations/advice provided by an organization</td>
<td>IADC Space Debris Mitigation Guidelines JFCC Space, JSPOC Recommendations for Optimal Cubesat Operations</td>
</tr>
<tr>
<td>Techniques/methods that through experience show to produce desired results</td>
<td>Recommended Practice: Mass Properties Control for Satellites, Missiles, and Launch Vehicles (AIAA R-020A-1999)</td>
</tr>
</tbody>
</table>
## Organizational Body Choices for STM of Smallsats

<table>
<thead>
<tr>
<th>Body</th>
<th>Example(s)</th>
</tr>
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<tbody>
<tr>
<td>Law Making Body</td>
<td>US Congress, UN</td>
</tr>
<tr>
<td>Federal Agency</td>
<td>FAA, FCC</td>
</tr>
<tr>
<td>Federal Advisory Committee (FACA)</td>
<td>COMSTAC</td>
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<tr>
<td>Congressionally Chartered Non-Profit Organization (&quot;Title 36 Corporation&quot;)</td>
<td>National Council on Radiation Protection Measurements</td>
</tr>
<tr>
<td>Standards Body</td>
<td>AIAA, ANSI</td>
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<tr>
<td>Self-Regulatory Organization (SRO)</td>
<td>Institute for Nuclear Power Operations (INPO) CONFERS</td>
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Recommendation: $S^3C$

- Begin to organize, publicize, and define a SRO committed to Smallsat spaceflight safety: The “Smallsat Space-Traffic Safety Consortium” or $S^3C$
- $S^3C$ Membership: Non-government researchers, industry, finance etc.
  - Consider governmental roles but avoiding potential conflicts
- Governance: President, Board, Committees
- Financing: Sponsorship, dues, government initiation funds
- Initial Focus (examples):
  - Governance structure/Finance/Governmental Roles
  - Best practices $\rightarrow$ Guidelines $\rightarrow$ Standards for orbital lifetimes
  - Best practices $\rightarrow$ Guidelines $\rightarrow$ Standards for re-entry through human spaceflight orbital zones