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

Risk Informed Analysis Model

- 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

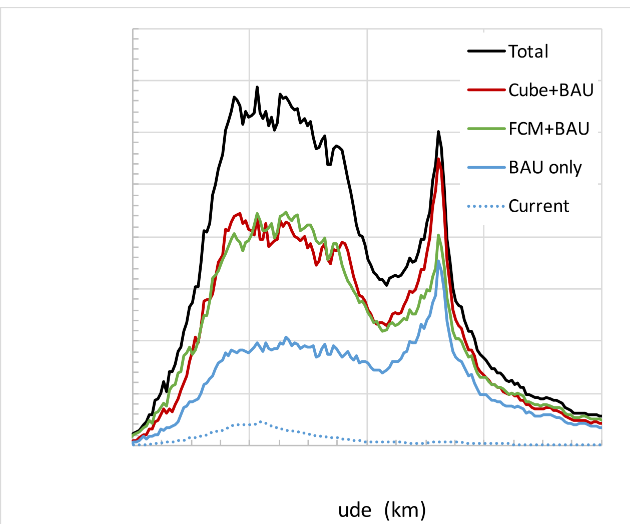
Modeling Results

- BAU Spatial density will increase after 100 years by ~order of magnitude over current levels
- Small satellite activity could double that again

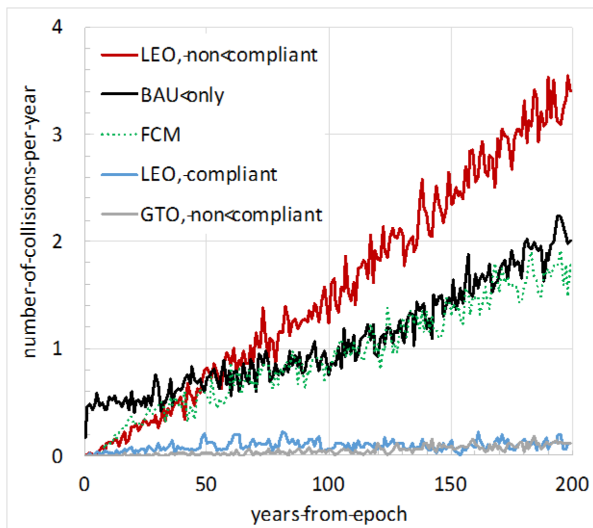
- Number of collisions will increase for BAU
- Collisions from small satellite activity could increase that substantially

- Manned objects have to avoid re-entering debris (currently ~400 re-entries per year causing ~2 debris avoidance maneuvers per year)

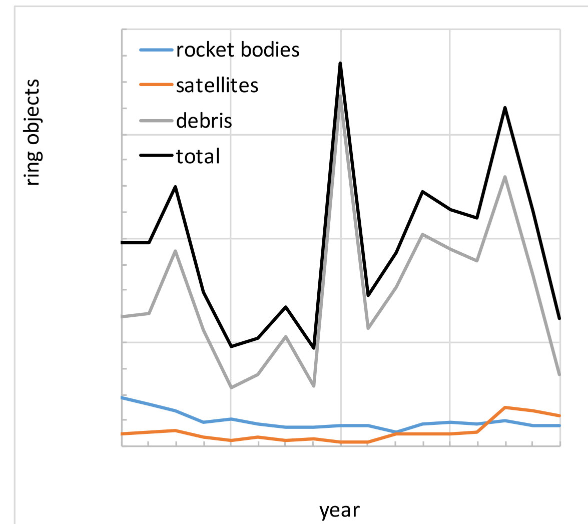
Spatial Density at 100 years (>1 cm)



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

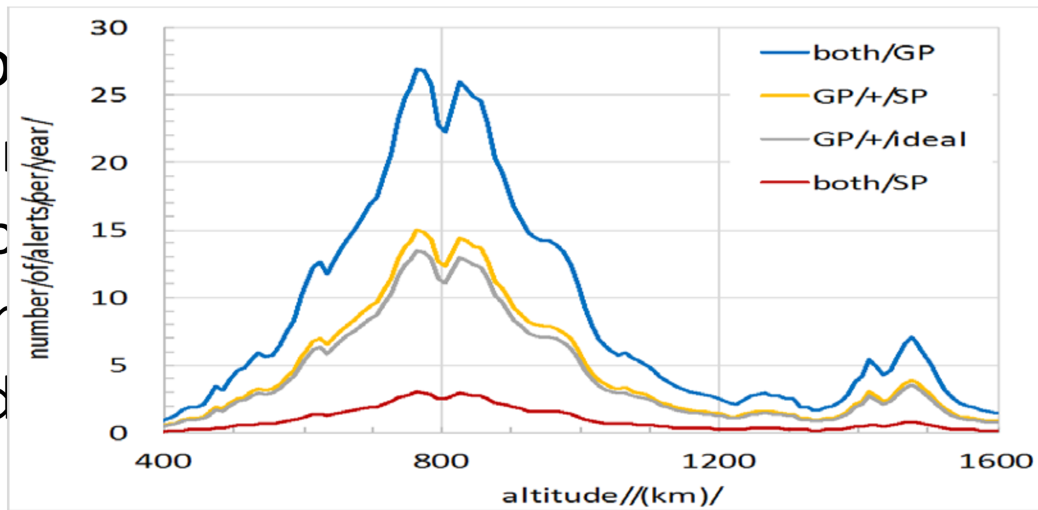
Prevent self from creating debris

Elimination

Third-part debris removal

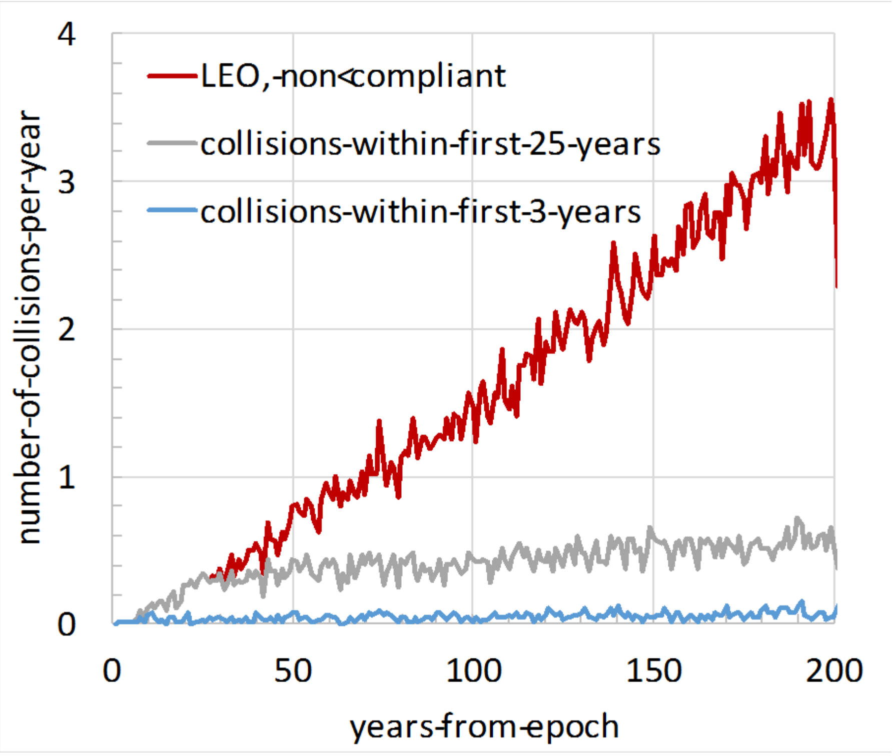
Technical Controls: *Knowledge*

- Increase positional knowledge to improve avoidance, prevention, and elimination
- Most smallsats rely on JSPOC TLEs
  - Low priority → reduced tracking frequency
  - SGP4 propagator inherently low fidelity
- Areas fo
  - Bette
  - Impro
  - Enhar
  - Broad



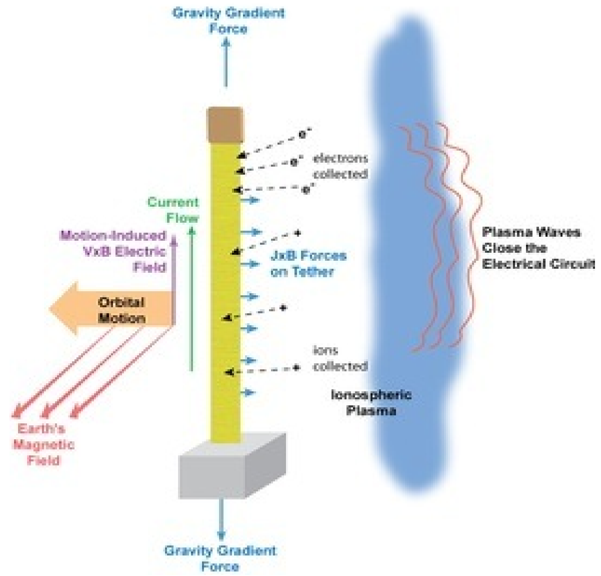
Technical Controls: *Avoidance*

- 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.

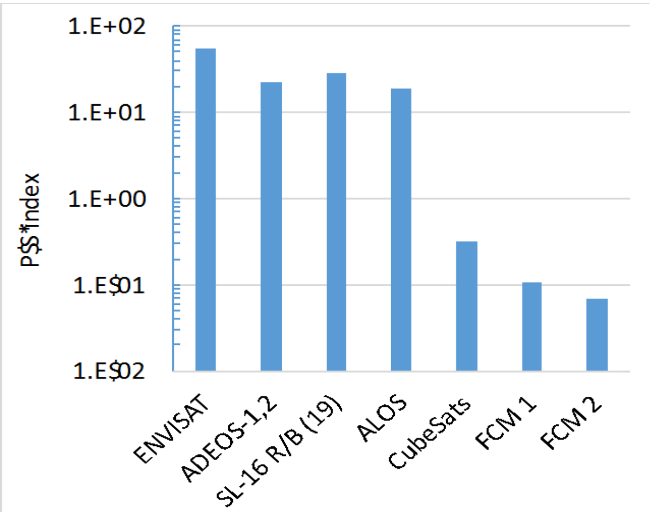
Technical Controls: *Elimination*

- 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

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



Management/Process Controls

Policies

Rules & Regulations

Standards

Guidelines

Best Practices

“Policy Stack” Model

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

Organizational Body Choices for STM of Smallsats

Body	Example(s)
Law Making Body	US Congress, UN
Federal Agency	FAA, FCC
Federal Advisory Committee (FACA)	COMSTAC
Congressionally Chartered Non-Profit Organization ("Title 36 Corporation")	National Council on Radiation Protection Measurements
Standards Body	AIAA, ANSI
Self-Regulatory Organization (SRO)	Institute for Nuclear Power Operations (INPO) CONFERS

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→Guidelines→Standards for orbital lifetimes
  - Best practices→Guidelines→Standards for re-entry through human spaceflight orbital zones