Dynamic Orbital Risk and Safety Assessments in a Changing Space Debris Environment

"Space capacity allocation for the sustainability of space activities" workshop 2023

Keiran McNally (GMV)
Callum Wilson (University of Strathclyde)
Massimiliano Vasile (University of Strathclyde)
Jinglang Feng (University of Strathclyde)
Alfredo M. Anton (GMV)
Francesca Letizia (ESA)

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Project Goals

Project Outline

- Development of tool that can assess the induced and encountered risk of a space mission
  - Induced risk: The risk to the space environment due to the new mission → **Long-term risk**
  - Encountered risk: The risk to the mission due to the current/future space environment → **Short-term risk**
- Target users are any **active risk takers** in a mission: Operators and licensors + insurers

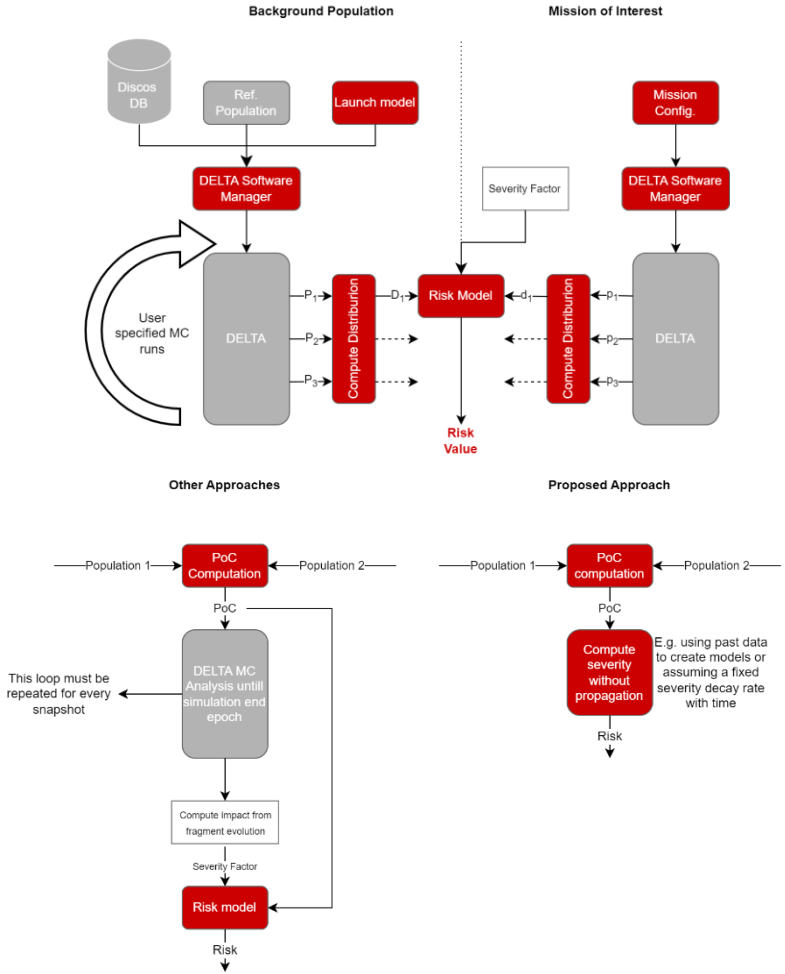
Project Plan

- Development of a configurable future launch traffic model
- Development of a risk model
- Definition of use cases and mitigation actions to be tested
  - Finalised tool to be used to analyse the effectiveness of each mitigation action
- Integration of all elements into a standalone software, with 2 modes of operation:
  - Simple: Minimal user configuration, built it baselines values used where possible
  - Expert: Complete configuration of all elements

Software Design

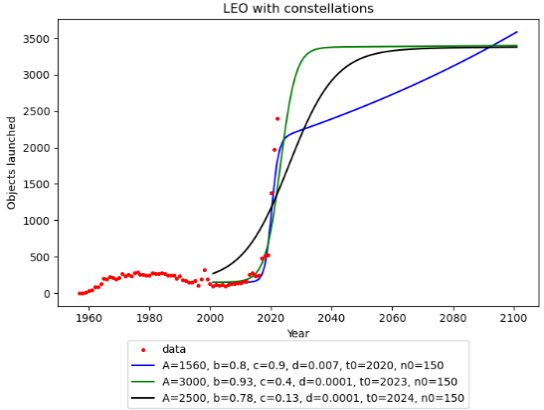
- Software considers discrete populations:
  1. Background population: Initial population + launch traffic model → propagated by ESA's DELTA software
  2. Mission of interest: User configured mission
- Multiple missions can be configured to simulate different mission phases or changing spacecraft design
- Optional fragmentations can be inserted by the user as a separate population

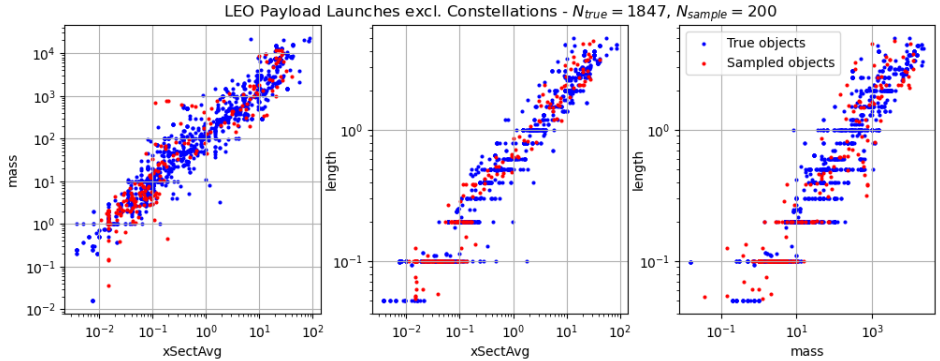
- Decoupling of background population and mission allows for **rapid analysis of multiple mission configurations**
- **Risk** is evaluated between all populations at configured snapshots, severity is estimated **without further propagation**



Launch Traffic Model

- Model total launches with an exponential-logistic curve
  - User selects when the trend plateaus, the magnitude, and further rate of increase
- Constellations defined separately or included in model
- Gives distributions in terms of:
  - Orbital parameters
  - Physical characteristics (mass, area, diameter)
- Separate models for different orbit regimes





Risk Model

Example orbits:
sma = [7000,7600]km, ecc=1e-5, inc = [50,90]
cov_sma = [1,5]km, cov_ecc=1e-6, cov_inc=0.01

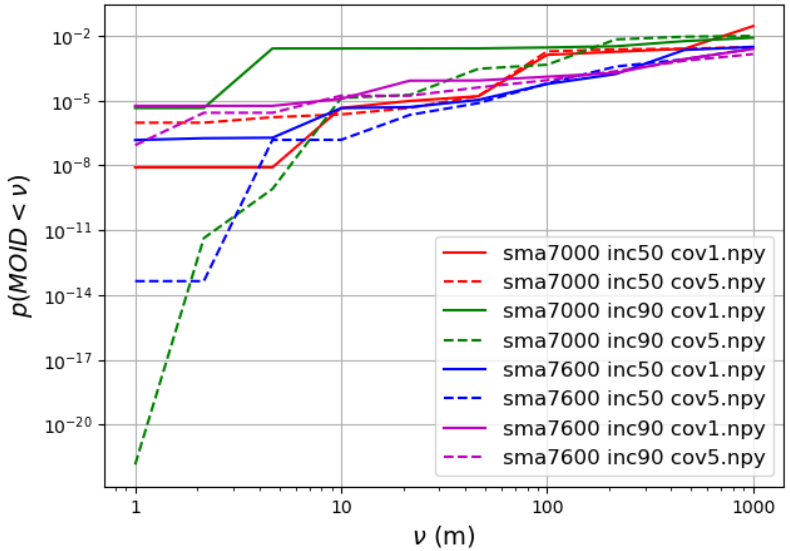
PoC Calculation

- Collision probability calculated from the integral of distributions of RSOs and mission of interest where the MOID is less than a threshold value:

$$p(MOID < \nu) = N_{sat} \cdot N_{rso} \iint_{(MOID<\nu)} \left(p(\vec{x}_{sat}) \cdot p(\vec{x}_{rso})\right) d\vec{x}_{sat} d\vec{x}_{rso}$$

- Numerical approximation:

$$p(MOID < \nu) \approx N_{sat} \cdot N_{rso} \frac{1}{k} \sum_{i=1}^{k} \left(p(\vec{x}_{sat,i}) \cdot p(\vec{x}_{rso,i}) \cdot (MOID_i < \nu) \cdot V_{sat} \cdot V_{rso}\right)$$



Risk Model

Encountered Severity Factor

- Collisions can range from minor damage to spacecraft to loss of mission
- Model divides collisions into low, medium, and high severity depending on the energy
- Severity thresholds can be adjusted based on the spacecraft
- High severity from catastrophic collisions (40J/g)
  - User Specifies low/medium threshold

Ratio of impactor kinetic energy to satellite mass (NASA SBM)

$$E = \frac{1}{2}\frac{m_{chaser}}{m_{target}} {v_{rel}}^2$$

$$p(High) = PoC \cdot p\left(m_{chaser} > m_{high}\right)$$

$$p(Low) = PoC \cdot p(m_{chaser} < m_{medium})$$

Assuming spacecraft mass of 1200kg, relative impact velocity of 15km/s, low severity threshold of 1J/g:

- Medium/high severity – 427g
- Low/medium severity – 10.7g

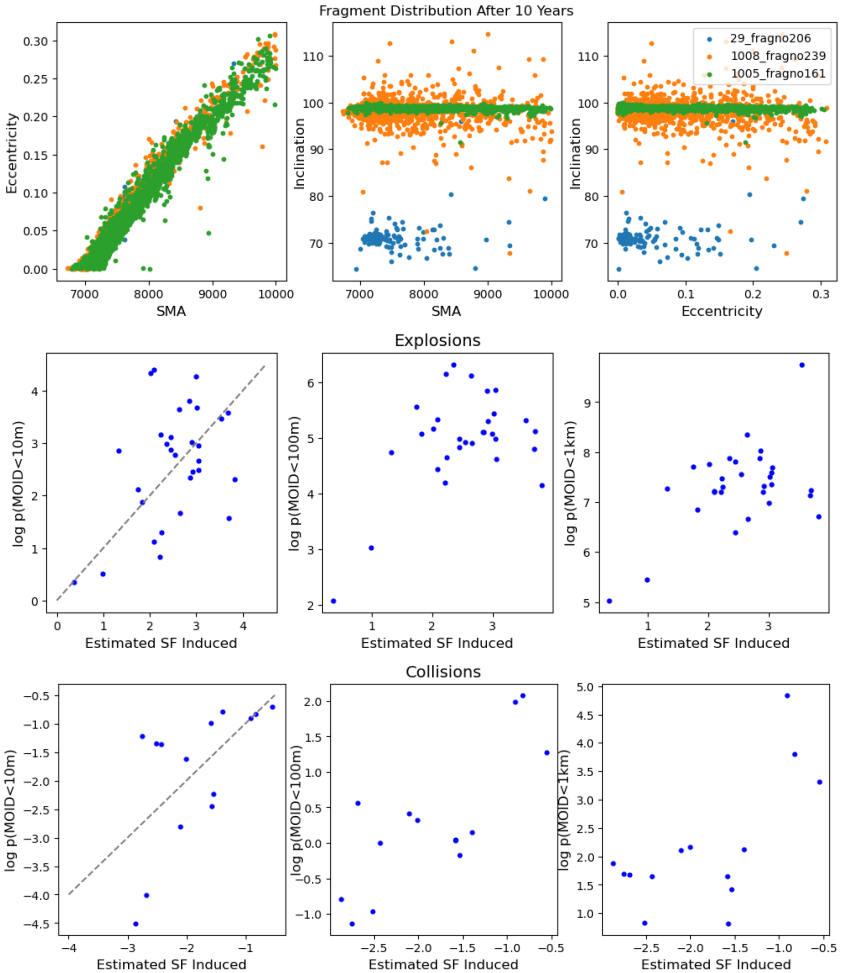
Risk Model

Induced Severity Factor

- Fragments from explosions and collisions propagated with DELTA and used to create distributions
- PoC between this distribution and maximum density of active payloads indicates induced severity
- Simple expression for explosions:

$$sf = a \cdot M^{0.75} + b \cdot M^2 + c \cdot \rho(h) + d \cdot \rho(h)^2 + e \cdot h + d \cdot h^2$$

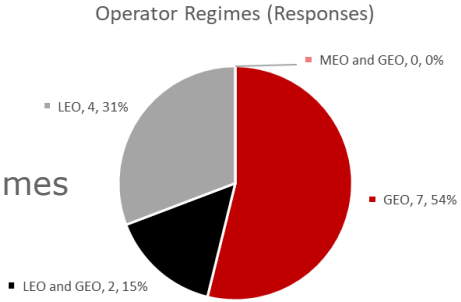
- Similar for collisions, with additional energy terms
- Fit to PoC between payloads and fragments>1cm with MOID threshold of 10m

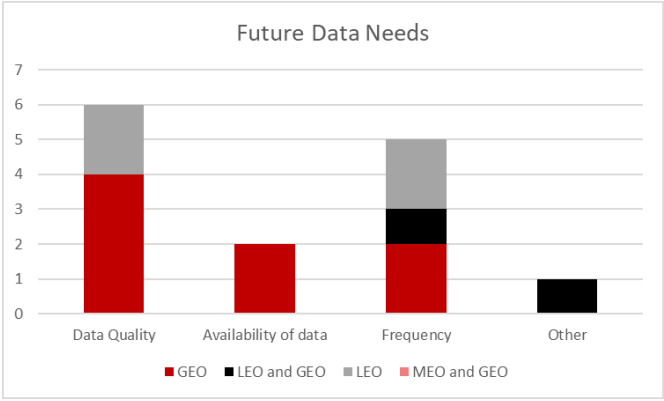


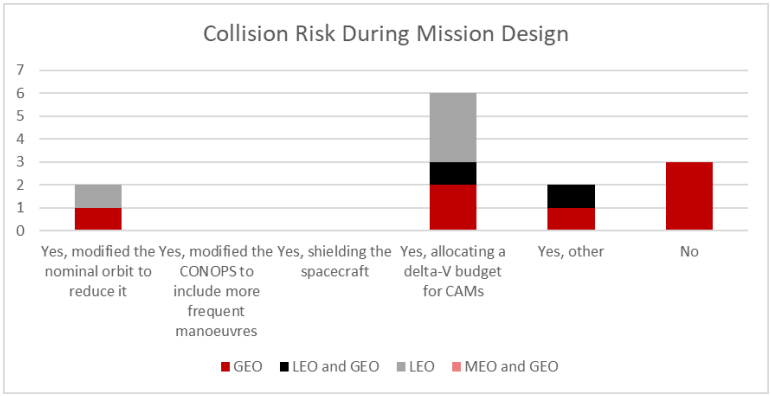
Stakeholder Survey

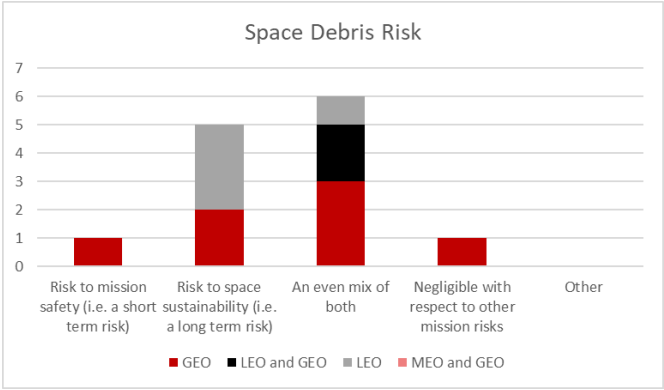
Highlights

- Responses from 13 operators in all regimes
  - Data quality ≈ frequency of data
  - Space sustainability > mission safety
  - Minimal changes to mission due to collision risk









Use Cases & Mitigation Actions

Use Cases

- Large LEO internet constellation
  - 1,296 sats at 1400km vs. 10,800 at 500-550km
- SSO Earth observation satellite
  - Risk in different SSO orbits.
- ADR mission
  - How does choice of target affect risk?
- MEO navigation constellation
- GEO telecoms satellite

Mitigation Actions

- Alternative PMD strategies
  - 25 year deorbit vs 5 year
  - Graveyard orbit choice
  - ADR for failed satellites
  - Drag augmentation
- Change of mission design
  - Avoiding crowded regions
  - Choosing low altitude for natural de-orbit
- Satellite passivation success rate
- Effect of SST data quality

Project Status

Current Status and Upcoming work

- Software requirements and design complete → Software prototype developed
- Stakeholder survey + analysis completed
- Definition of launch model complete → Implementation starting soon
- Risk model defined → Further analysis to be done
- Integration of launch and risk models with the main software
- Simulation and assessment of mitigation actions for each use case

Thank you

Keiran McNally
kmcnally@gmv.com