A Handbook for Post-Mission Disposal of Micro Satellites and Smaller

Dr. David B. Spencer
The Pennsylvania State University

IAA Study Group SG4.23

- Actually, the report name is being tweaked
  - “A Handbook for Post-Mission Disposal of sub-100kg Satellites”
- International Academy of Astronautics Study Group
  - Commission 4 – Space Systems Operations and Utilization
  - Study Team Chairs: Darren McKnight, Toshiya Hanada, Alex de Silva Curie, Peter Martinez, Rei Kawashima (Secretary)
  - > 35 Study Team Members
  - Reviewers always welcome!

Report History

- Kick-off – September 2017
- Planning Meeting – March 2018
- First draft – October 2018
- Currently under revision – new version expected any time
- Next draft (final?) by January 2019

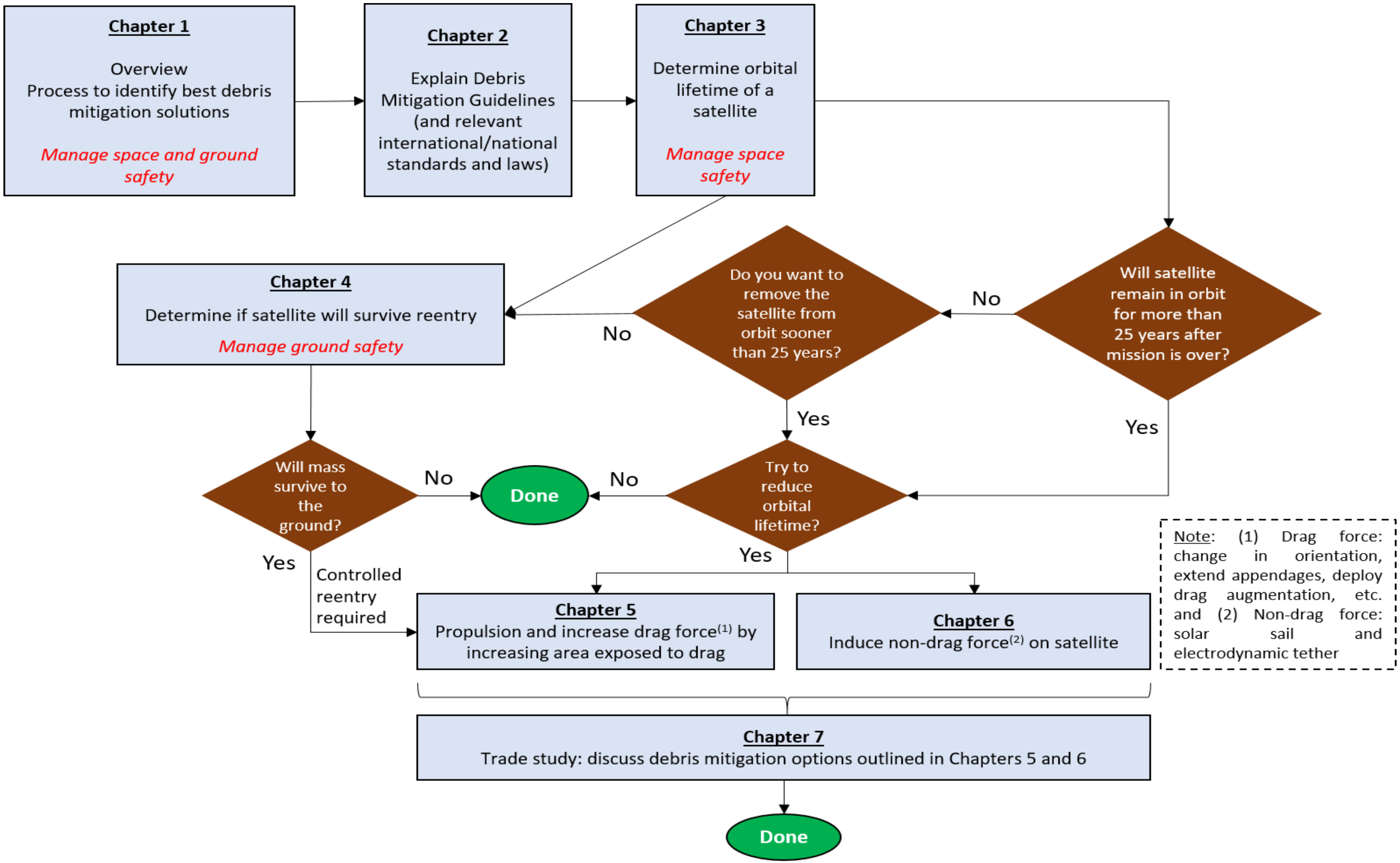
Overall Goal

- Provide framework for a practical implementation to assure compliance with Space Debris Mitigation guidelines for micro and smaller satellites
  - Provide easy to use design tradeoff information to small satellite community
  - Assumes reader has no background in orbital debris analysis

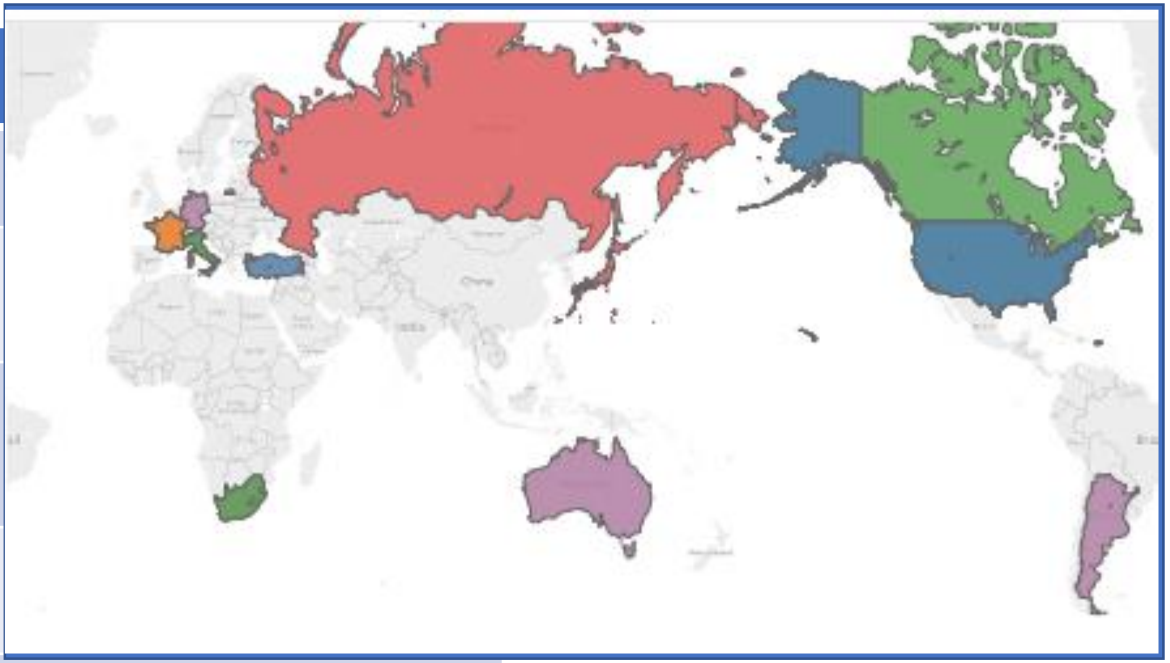
Study of Scope and Objectives

- Create framework (from trade study organization and results of trade study) for debris mitigation compliance for university space users leveraging post-mission disposal (PMD) devices.
  - Define all relevant terms
  - Do not recommend specific products
  - Useful for emerging space powers and possibly regulators

Plan – Logical and Compelling



An International Effort



Chapter	Authors
1. Overview	Darren McKnight (USA)
2. Mitigation Guidelines	Christophe Bonnal (France)
3. Determine Orbital Lifetime	Darren McKnight (USA) and Alim Rustem Aslan (Turkey)
4. Reentry Survival	David B. Spencer (USA)
5. Propulsion and Drag Force	Norman Fitz-Coy (USA), Aaron Rogers (USA), Alfred Ng (Canada), Fabio Santoni (Italy), and Lourens Visagie (South Africa)
6. Non-drag Force	Sergey Trofimov (Russia) and Satomi Kawamoto (JAXA, Japan)
7. Trade Study	Juan Carlos Dolado Perez (CNES, France) and Marlon Sorge (USA)
Reviewers	Peter Martinez (South Africa), Barnaby Osborne (Australia) Livio Gratton (Argentina), Klaus Schilling (Germany), Roberto Opromolla (Italy), Christophe Bonnal (France)

Debris Mitigation Guidelines

- In general, all the space debris mitigation rules (such as ISO 24113) apply to any spacecraft, whatever its size.
- Debris mitigation guidelines for this handbook basically present four major requirements:

  1. Passivate energetic sources (e.g., batteries and capacitors) and vent excess propellant.

  2. Eliminate creation of all debris greater than 1mm; especially avoid explosions and collisions.

  3. Ensure that all objects left on-orbit are reentered or moved to an acceptable graveyard orbit within 25 years after their operational life with a probability of 90%.

  4. Reentry casualty risk to humans must be less than 10^{-4}.

- This handbook primarily focuses on the last two requirements.

How Small is Small?

SMALLSATS 500kg and smaller

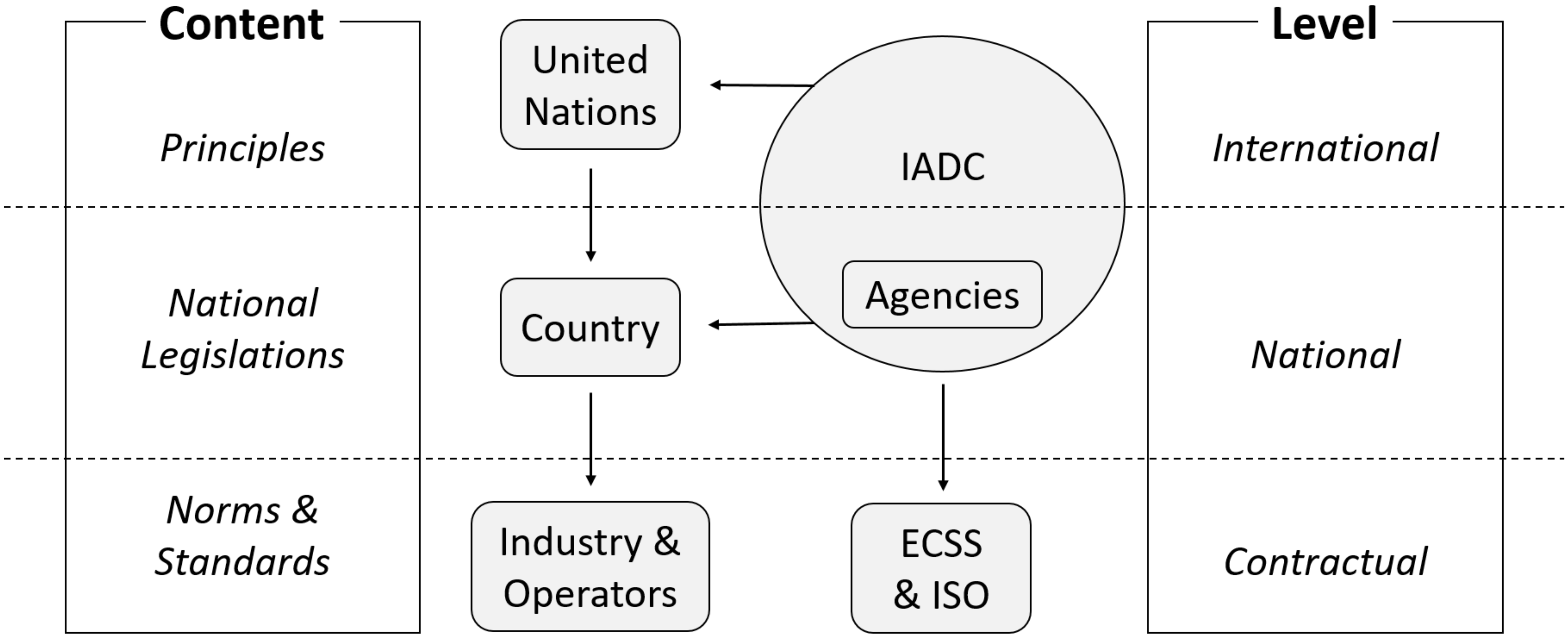
MICROSATS 100kg and smaller

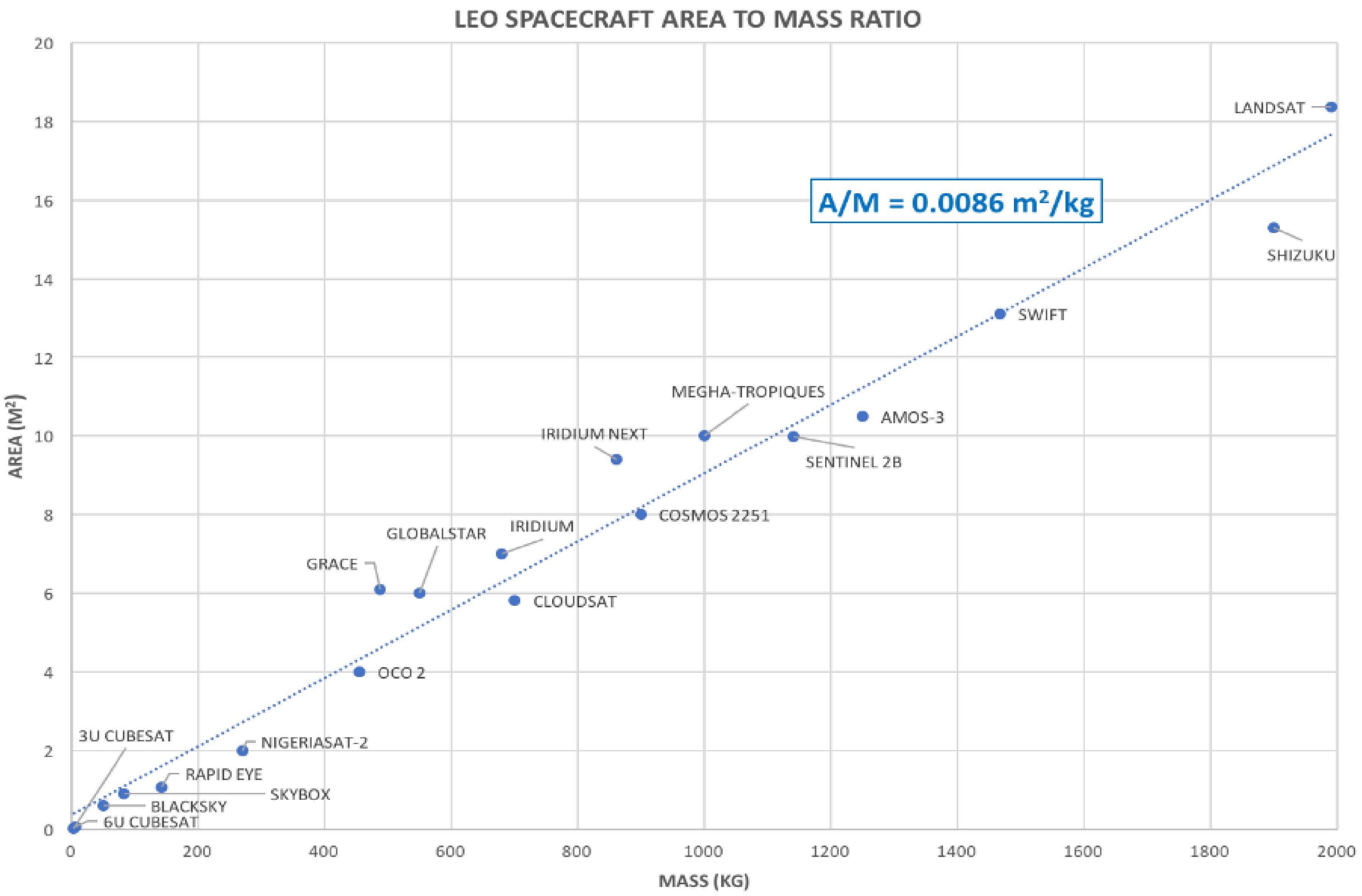
NANOSATS 10kg and smaller

1U cubesat: 1kg → 3U cubesat: 5kg → 6U cubesat: 10kg

PICOSATS 1kg and smaller

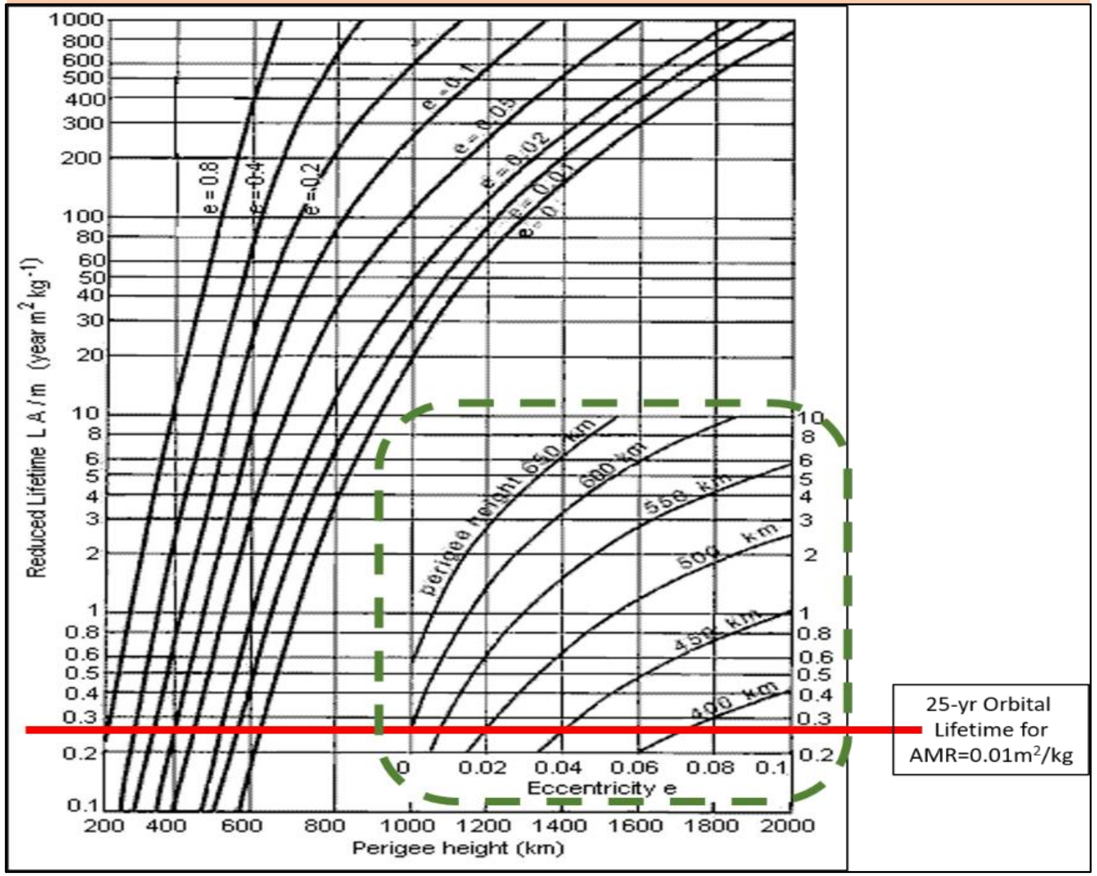
Norms and Standards Through National Laws to International Principles




LEO SPACECRAFT AREA TO MASS RATIO
AREA (M²)
MASS (KG)
A/M = 0.0086 m²/kg
LANDSAT
SHIZUKU
SWIFT
MEGHA-TROPIQUES
AMOS-3
IRIDIUM NEXT
SENTINEL 2B
COSMOS 2251
IRIDIUM
GLOBALSTAR
GRACE
CLOUDSAT
OCO 2
3U CUBESAT
NIGERIASAT-2
RAPID EYE
SKYBOX
BLACKSKY
6U CUBESAT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Calculating Orbital Lifetimes: An Art and Science

Empirical – Simple, Intuitive



Analytical – Complete, Accurate

- STELA
  - ✓**S**emi-analytic **T**ool for **E**nd of **L**ife **A**nalysis
  - ✓Designed by *CNES* to support the *French Space Operations Act*
  - ✓STELA is available for download
    - https://logiciels.cnes.fr/en/content/stela
- Provides more flexibility in dealing with varying spacecraft orientations, solar activity levels, and altitudes/orbits

✓ **Meet 25yr threshold in LEO: circular below ~625km or perigee below ~400km**

✓ **Effect of increased area increasing drag is evident…**

Reentry Survival

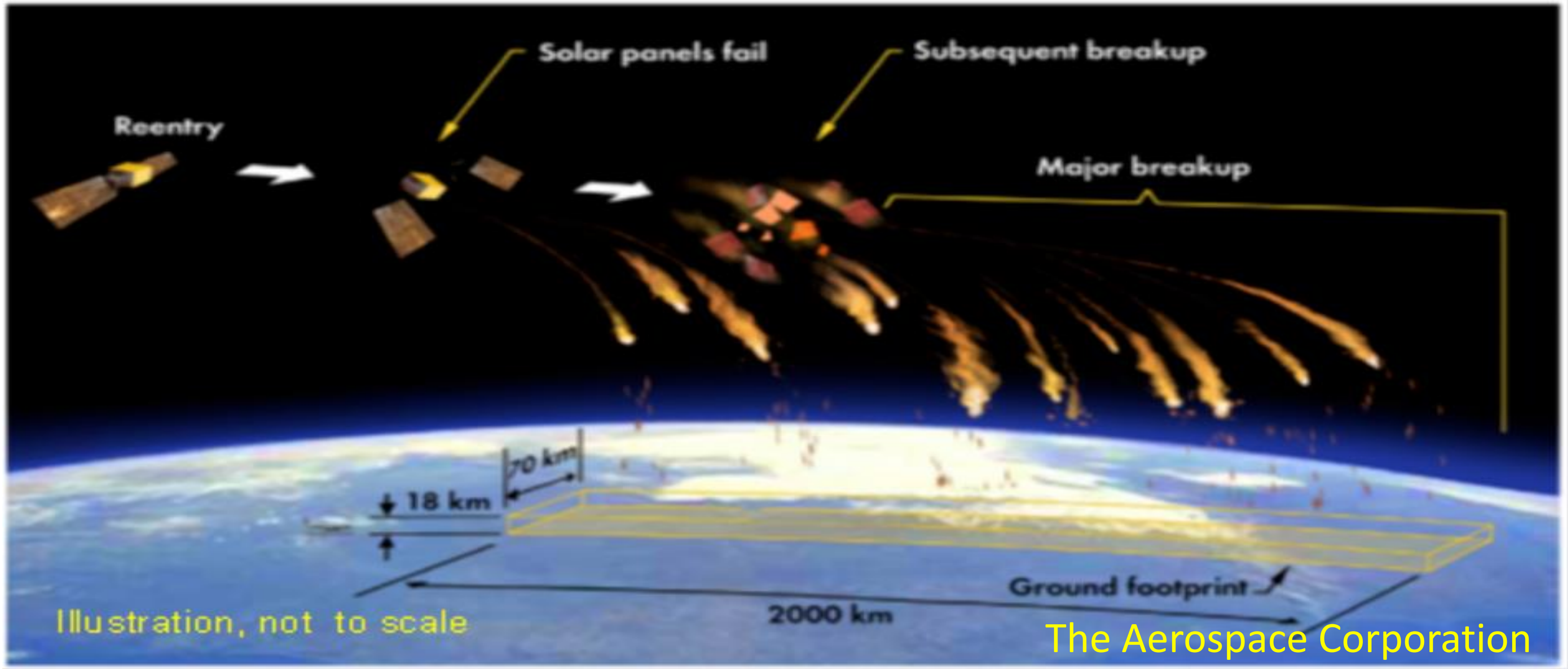
- Four primary characteristics that drive reentry survival:
  - ✓Material: typically aluminum and circuit boards
  - ✓Mass: under 100kg (for microsats and smaller)
  - ✓Construction: no hardened or high density devices
  - ✓Reentry Trajectory: due to contraction from atmospheric drag

Material

Mass

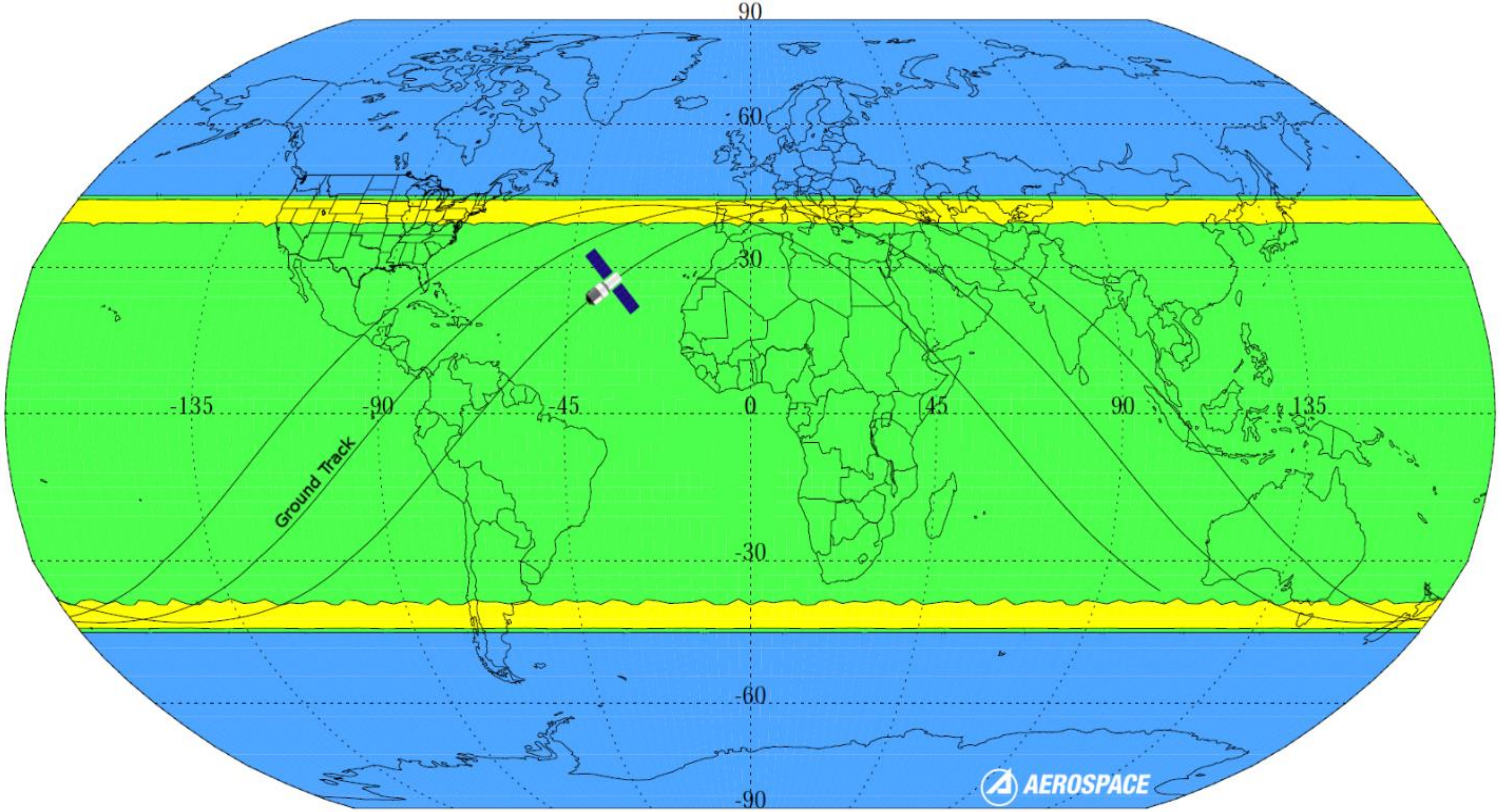
Construction

Reentry Trajectory



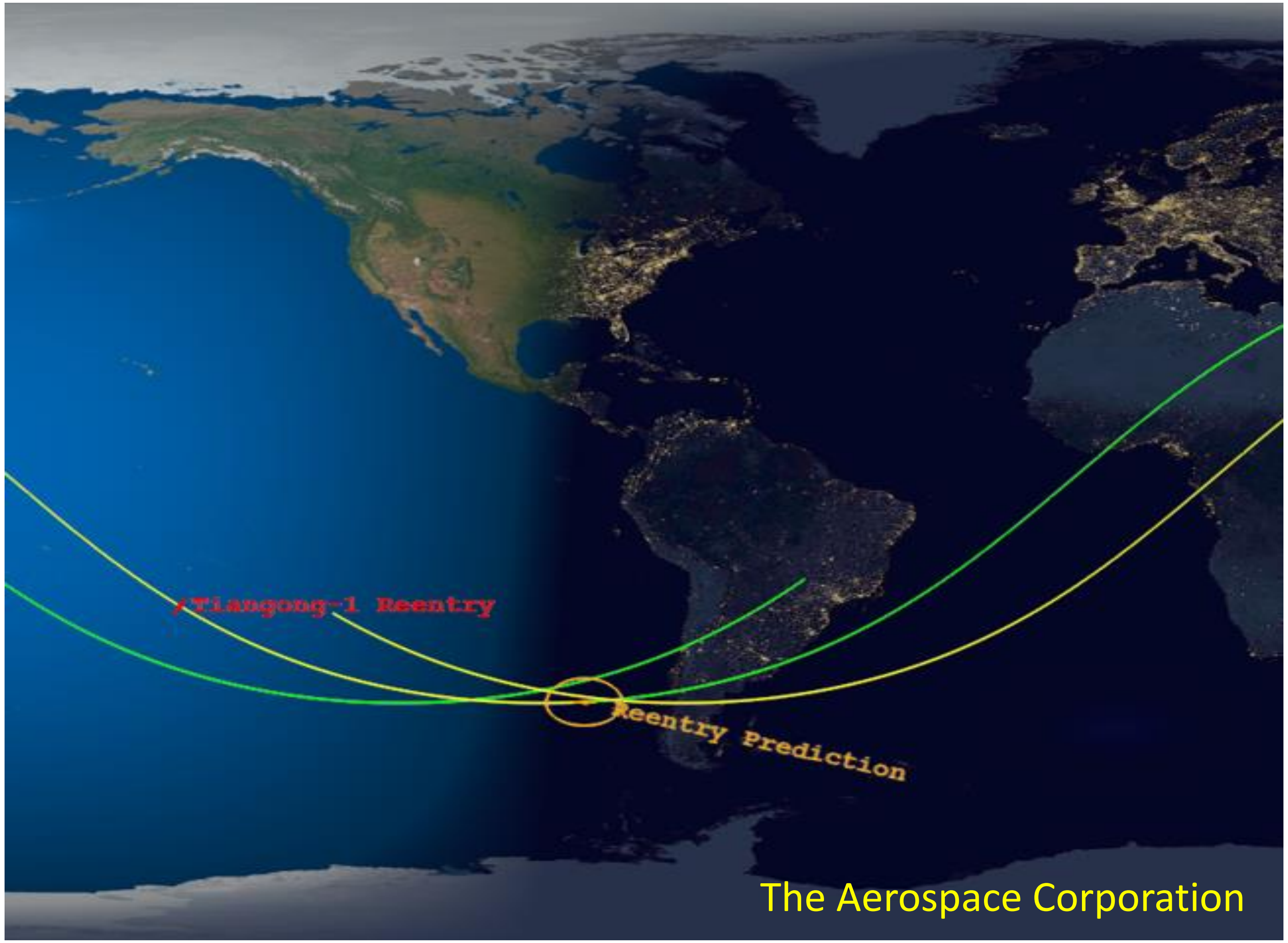
Microsats and smaller satellites will pose little air or ground impact risks
- *Beware of densely-built components such as control moment gyros and batteries*

Tiangong-1 Ground Track and Reentry Risk Areas



Tiangong-1 – Predicting the last orbits

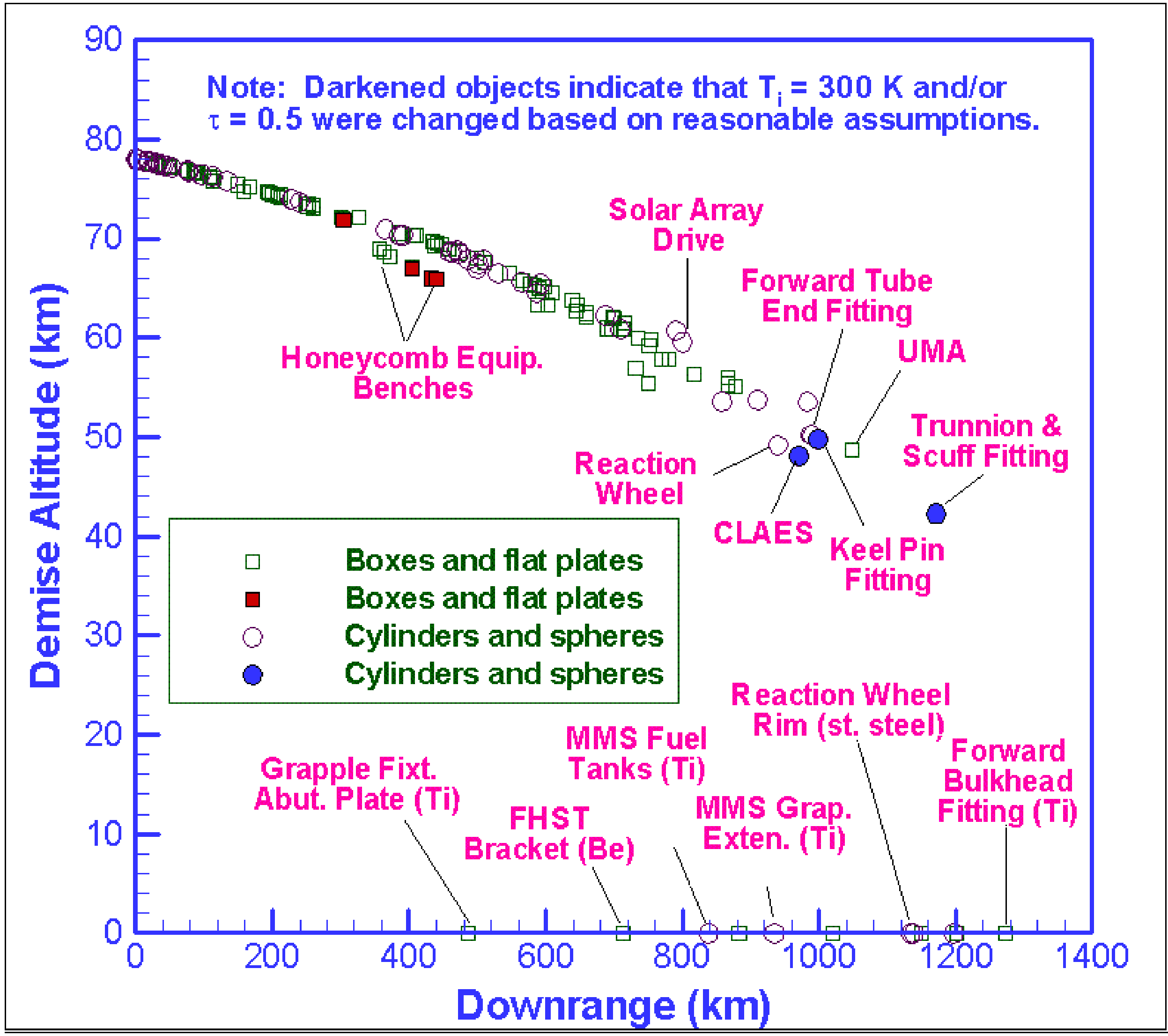
- Predictions:
  - Late February, 2018, prediction early April
  - $\pm$ 1 week
- Rule of thumb – 10%-20% of the “time to go” prediction
- Reentered off the coast of South America on 1 April 2018



NASA’s Upper Atmosphere Research Satellite (UARS)
- 6,000 kg
- Reentered in 2006

Example of NASA's ORSAT Software Output

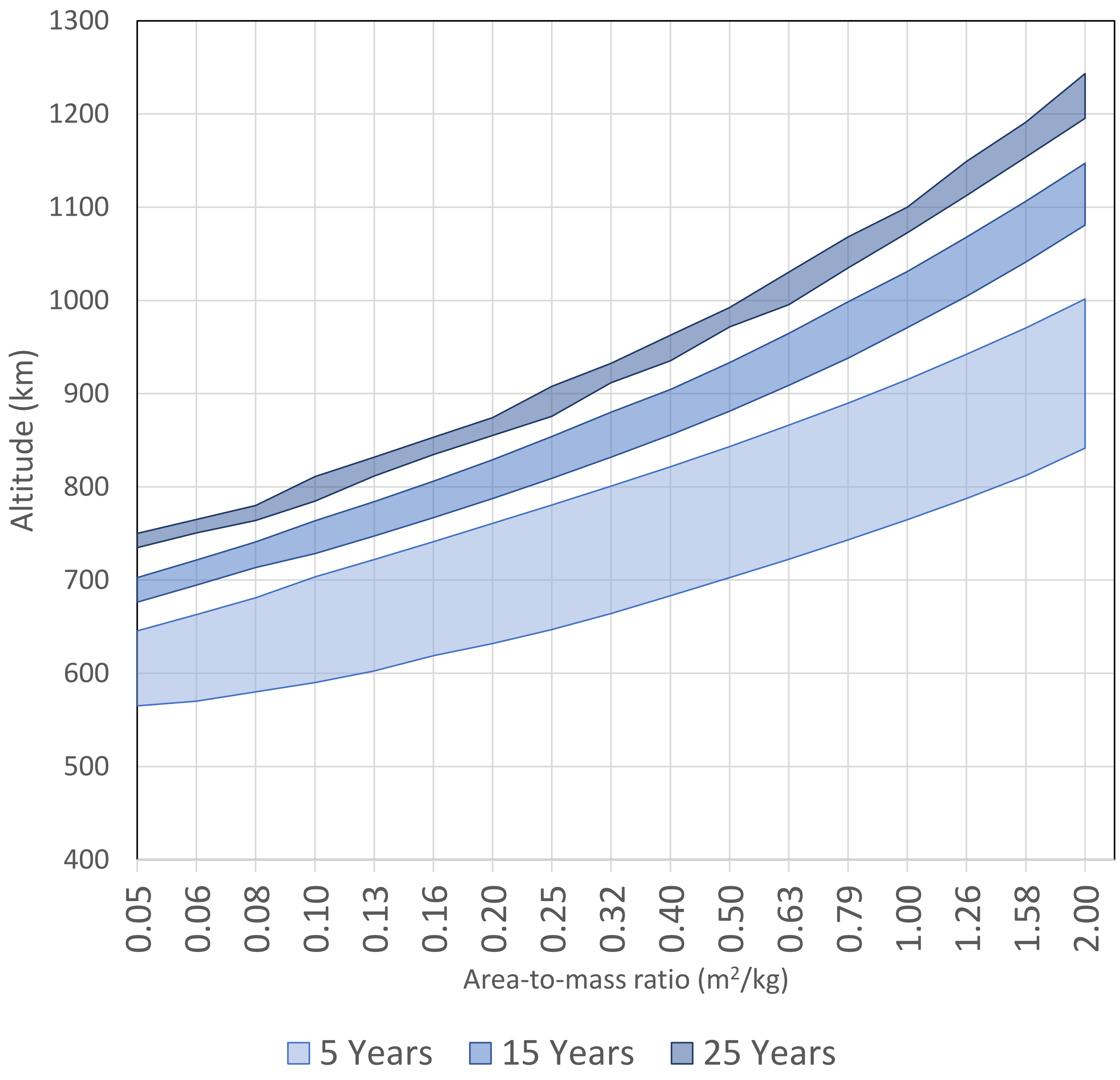
- Analysis used to predict UARS spacecraft reentry breakup
- Most lightweight and odd-shaped pieces vaporized in the atmosphere between 40 and 80 km altitude
- Heavy parts would survive reentry
- No reports of pieces from this reentry



Propulsion and Drag Augmentation Methods

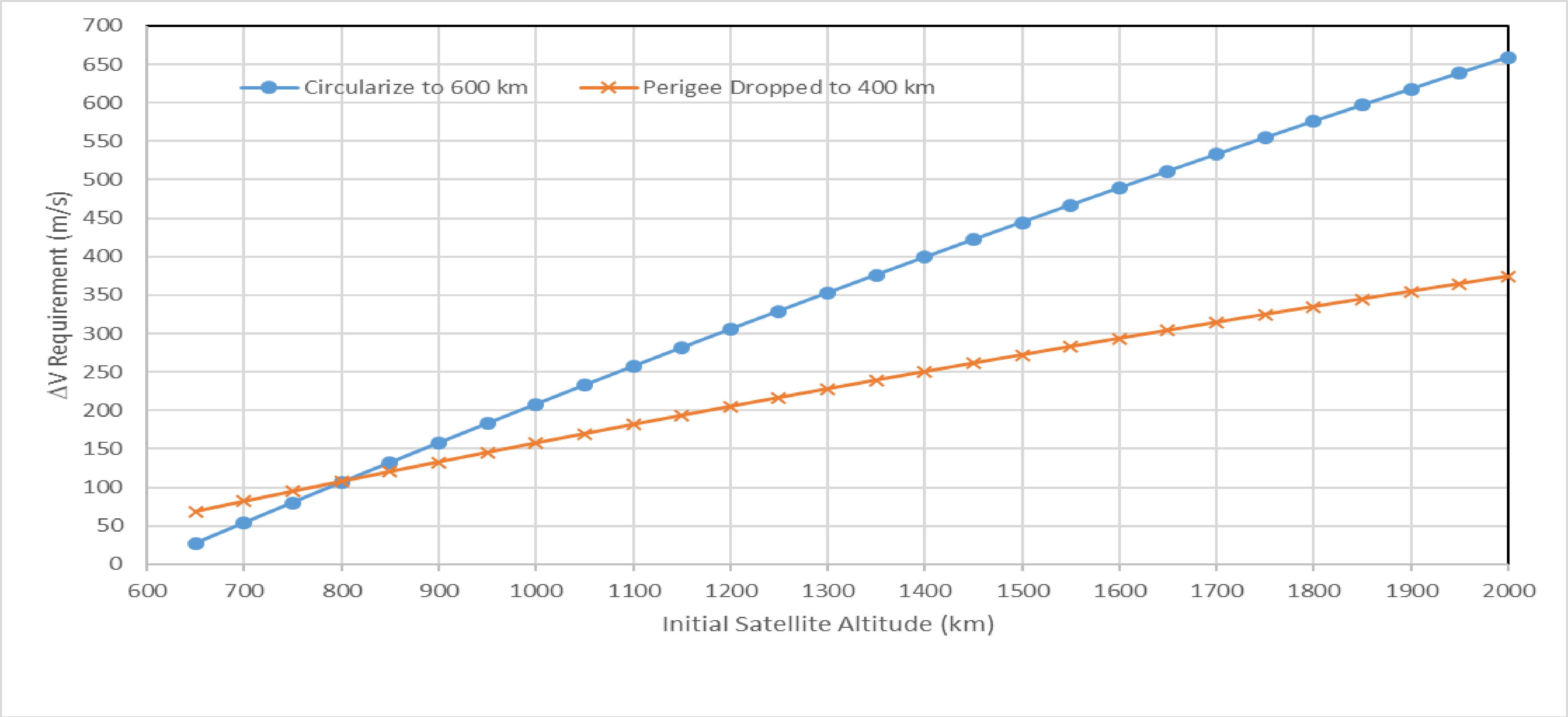
- Propulsion systems,
- Drag augmentation devices,
- Electrodynamic tethers, and
- Solar sails.

Altitude range to deorbit as a function of area-to-mass ratio



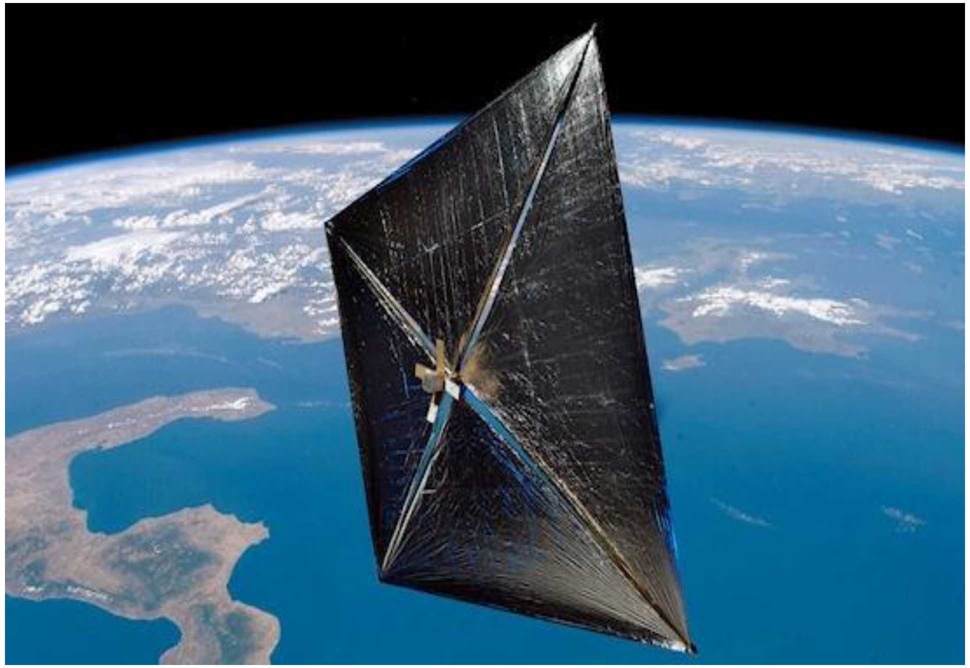
Reduce Lifetime by Propulsion

✓Strategy varies across LEO: require 10s to 100s m/s of delta velocity

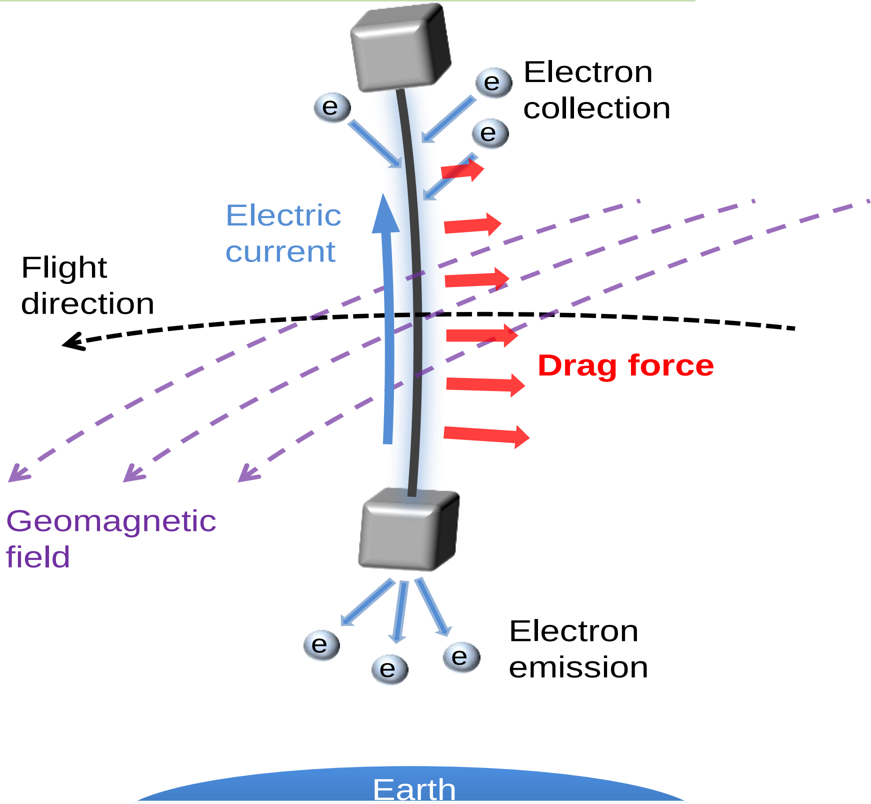


Reduce Lifetime by Non-Drag Forces

- Solar Radiation Pressure



- Electrodynamic Tether (EDT)

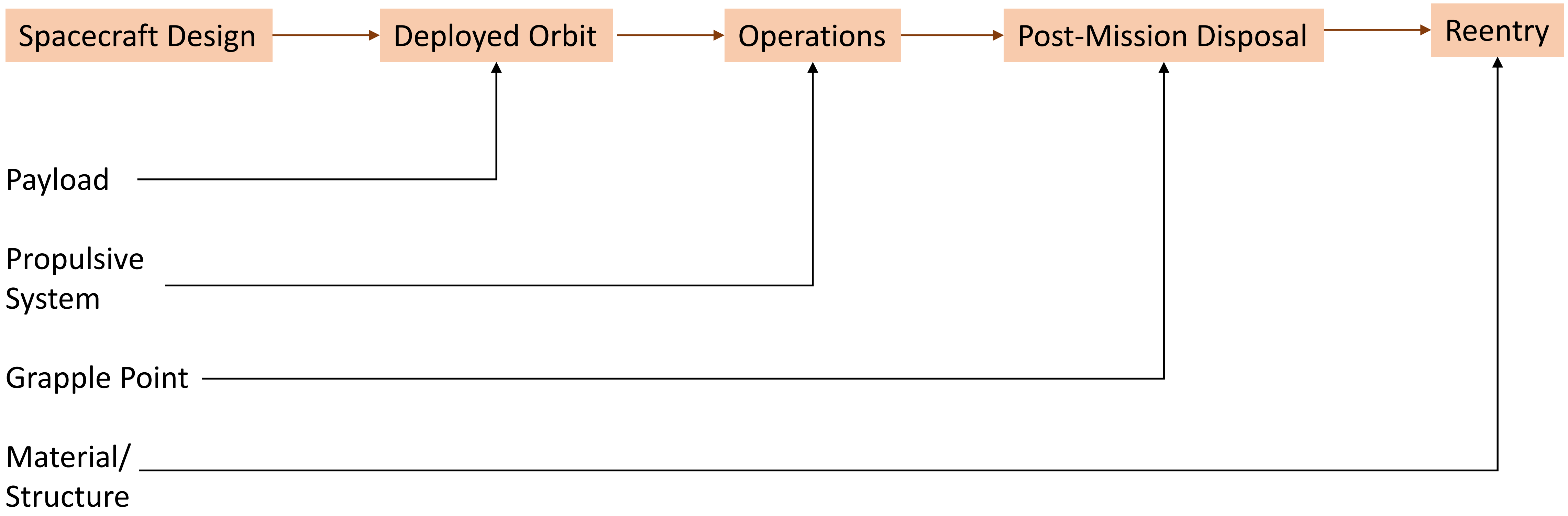


✓ **Solar – simple, slow**; deal with stability, durability, & collision cross-section issues

✓ **EDT - flexible, fast**; deal with stability, durability, & collision cross-section issues

Trade Study – What is Best for you?

- What can you control and what will provide greatest effects?



Summary

- This manual complements other standards…
  - ✓ ISO 24113, Space Systems – Debris Mitigation
  - ✓ ISO/TS 20991, Space Systems – Requirements for Small Spacecraft
- Encourage and enable microsat (and smaller) operators to be responsible space users
- Choice for assuring adherence of a specific microsat or smaller to debris mitigation guidelines depends on…
  - Operational altitude, functional capabilities, and resources available
- **Completion planned NLT than 1 January 2019**

We'd like your feedback

- Upon release of the next draft, we are ready for a new review
- Due out on November 15
- E-mail me (dbs9@psu.edu) or Dr. Darren McKnight (dmcknight@integrity-apps.com) for a copy of the next draft
- Reviews due back ~January 1
- Goal is to submit for IAA review in March 2019

Thank you…