Space Debris Mitigation: Cranfield University's Family of Drag Augmentation Systems

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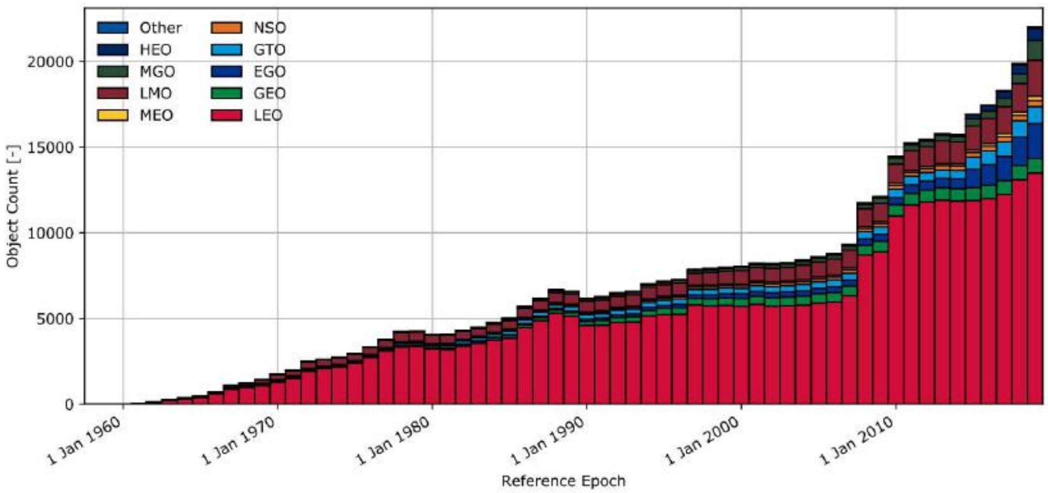
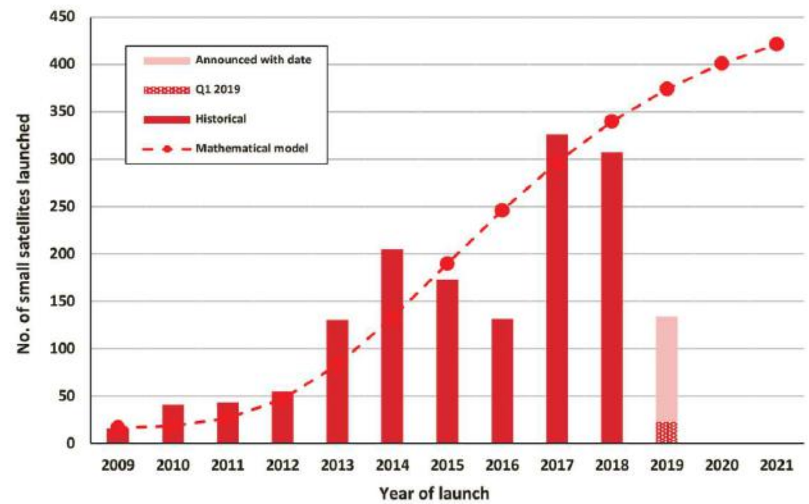
Space Debris Challenge

- Space debris in LEO ~14,000 objects
- Majority of satellites are small satellites <500 kg (69% in 2018)

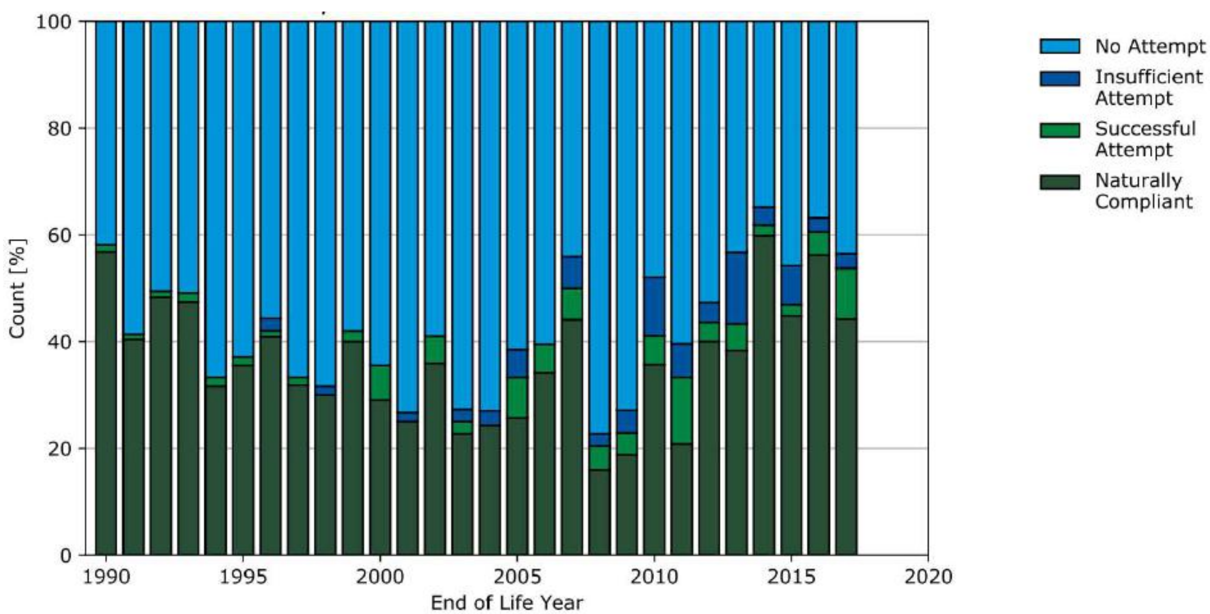


Evolution of Number of Objects in All Orbits (ESA's Annual Space Environment Report)



Small Satellite (<500 kg) Launches: Historical and Projection (Satellite Applications Catapult Small Satellite Market Intelligence Report)

Mitigation Guideline Compliance

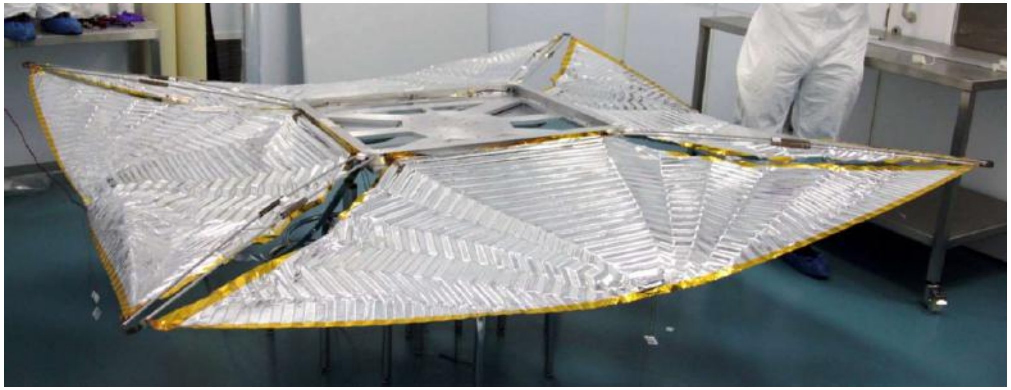


Payload Clearance by Payloads in Low Earth Orbit (ESA's Annual Space Environment Report)

- IADC and UN COPUOS – standardising debris mitigation measures and creating guidelines for long-term sustainable space
- ISO 24113 – satellites shall limit post-mission presence in LEO to a maximum of 25 years from end of mission
- In 2017, more than 50% of satellites were not naturally compliant with mitigation guidelines

Cranfield University's Drag Augmentation System Family

- Target Market – microsatellites (10 – 100kg) and minisatellites (100 – 500kg)
- Two qualified drag augmentation systems (DAS): Icarus and De-Orbit Mechanism (DOM)



Icarus-1 in the Cleanroom at Cranfield University

Icarus-1

Launched on TechDemoSat-1, July 2014

- Low-mass
- Reliability
- Safety
- No additional debris production

Sail deployed April 2019

Icarus-3

Launched on Carbonite-1, July 2015

- Reliability of deployment improved
- Sail folding pattern simplified

Sail deployed November 2018

Cranfield University's Drag Augmentation System Family

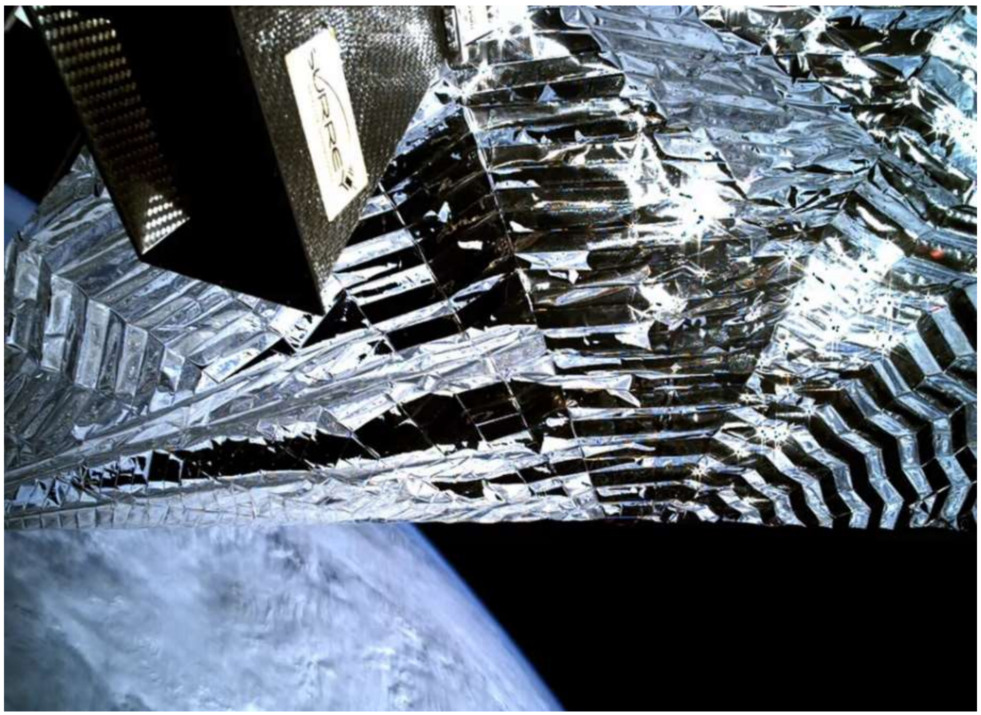
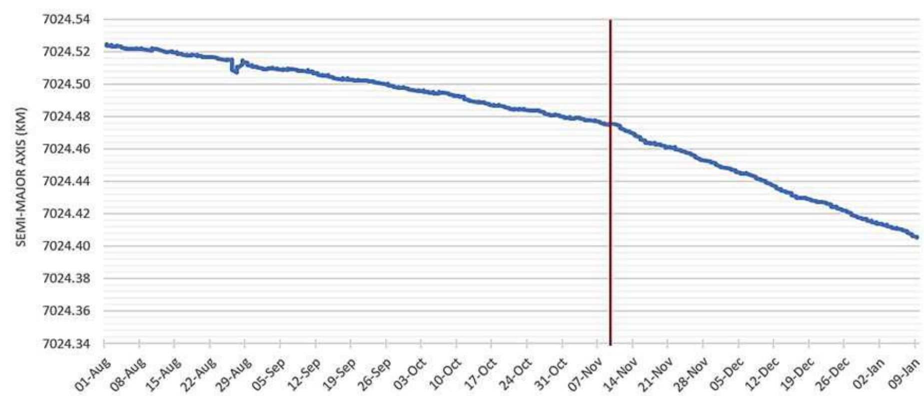


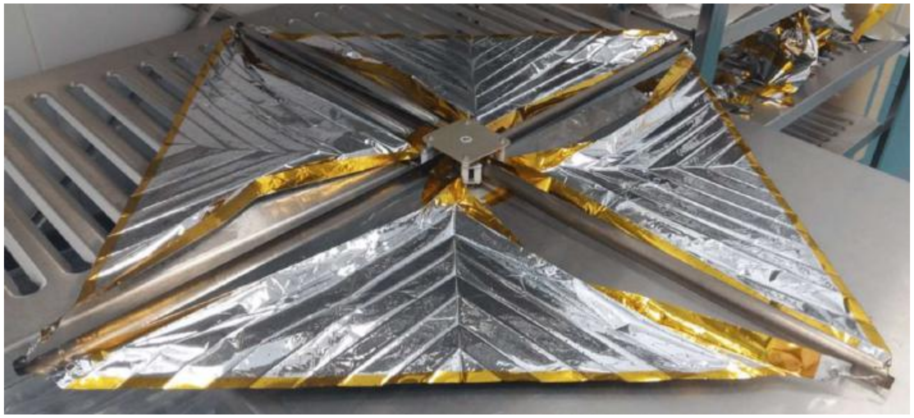
Image Captured by TechDemoSat-1 Post Sail Deployment (SSTL)

Icarus-3 rate of change of semi-major axis doubled, in line with doubling of sail area from 0.6m^2 to 1.25m^2



Change in Carbonite-1 Semi-Major Axis Decay

Cranfield University's Drag Augmentation System Family



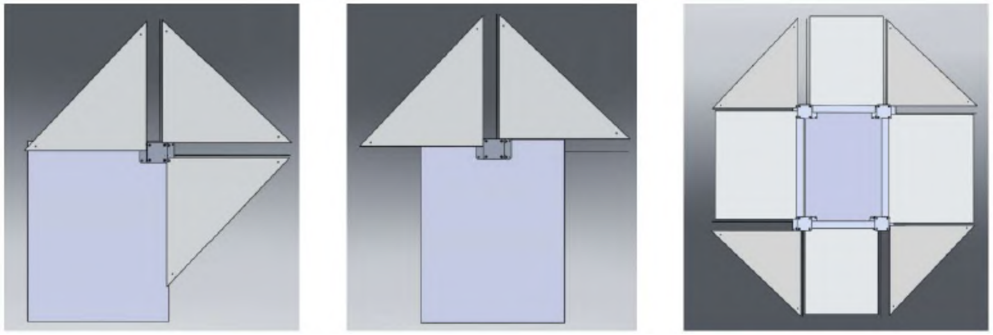
DOM Flight Model at Cranfield University

DOM

Launched on ESEO, December 2018
- Self-contained unit
- Significantly smaller
- Assembly time improved

Hybrid Design

- Modular design
- Designed taking into account strengths and weaknesses of Icarus and DOM
- Improve adaptability
- Improved scalability

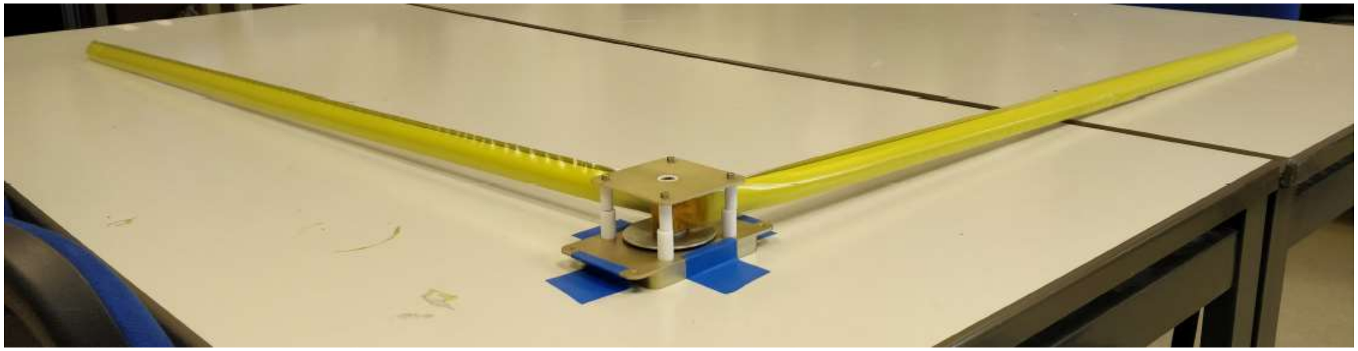


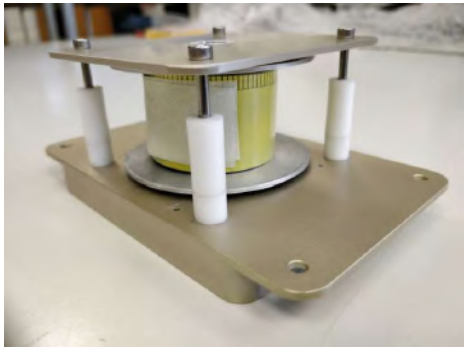
Proposed Hybrid Concept Based on the Icarus and DOM Designs

DOM Scalability

Scalability of Hybrid Design depends on scalability of DOM
Spring steel booms used to simulate copper beryllium booms

- Maximum length of static single shell boom in *1 g: ~1 m*
- Maximum length of two shells held together in sheath in *1 g: 1.5 m* supported and *1.1 m* unsupported
- Four sheathed 1.14 m booms can fit within the current DOM housing
- Changing configuration and distribution of booms did not have adverse effects on deployment





Two Perpendicular Lenticular Sheathed Booms, Supported Deployment (left) and Spring Steel Booms Held Together by Polythene Sheath in DOM Housing (right)

Lightweight Booms

Scalability also depends on mass of booms

Configuration	***Requirements***	***Impact***
Stowed	High strain to failure ratio Low axial Young's modulus	Compact storage Reduced creep Predictable deployment dynamics
Deployed	High axial Young's modulus	Maximised boom stiffness Reduced global column buckling

Optimal boom

- Collapsible tubular mast (CTM) cross-section
- Thin-ply materials
- Toughened epoxy
- Asymmetric [-45/0/45] or [0-90PW/45PW] layup

Composite booms will be ***~56%*** the mass of copper beryllium booms

Deployment Dynamics Assessment

Cranfield University and Belstead Research Ltd. UKSA Pathfinder project objectives, assess:

1. Impact of sail deployment on short-term vehicle dynamics
2. Influence of deployed sail on mission dynamics and ability to extend mission
3. Effect of drag sail on entry and demise of spacecraft

Icarus-1 and Icarus-3 used as case studies

1. Attitude predictions suggested satellite will enter a slow tumbling motion after passivation of AOCS and deployment of sail – validated by observed data
2. Operations could potentially continue after sail deployment, reducing risk of deployment failures
3. Currently, the sail is not expected to have a significant impact on the vehicle's demise

Conclusions

DAS appear to be a practical and effective means for small satellites to operate sustainably

Cranfield University assessed the scalability of the drag sails and the short- and medium- term deployment dynamics of the Icarus sails

- Altering cross-section of DOM booms: length of booms doubled without altering deployment method or DOM housing, however, significant mass increase
  - Composite booms suggested as viable solution and will be investigated further
- Deployment dynamics study concluded:
  - Operations could potentially continue after sail deployment, reducing risk of deployment failures
  - Currently sails not expected to have significant impact on vehicle's demise, but this will be reassessed after studying impact of atomic oxygen on Kapton sails in greater detail