COST-EFFECTIVE SPACECRAFT DRAG SAIL FOR SATELLITE REENTRY

C. BARSTOW, A. NASEEM, R. PEREZ-ALEMANY, D.C. LOUCKS
United States Military Academy, Department of Physics and Nuclear Engineering

DEPARTMENT OF PHYSICS AND NUCLEAR ENGINEERING
UNITED STATES MILITARY ACADEMY

PROBLEM STATEMENT

The aim of this research is to demonstrate the feasibility of using low-cost materials and designs in spacecraft drag sail technology to decrease the orbital lifetime of satellites in Low Earth Orbit (LEO) as seen in Fig. 1. These designs could be applied to a broad range of satellites in LEO and could decrease the threat posed by space debris.

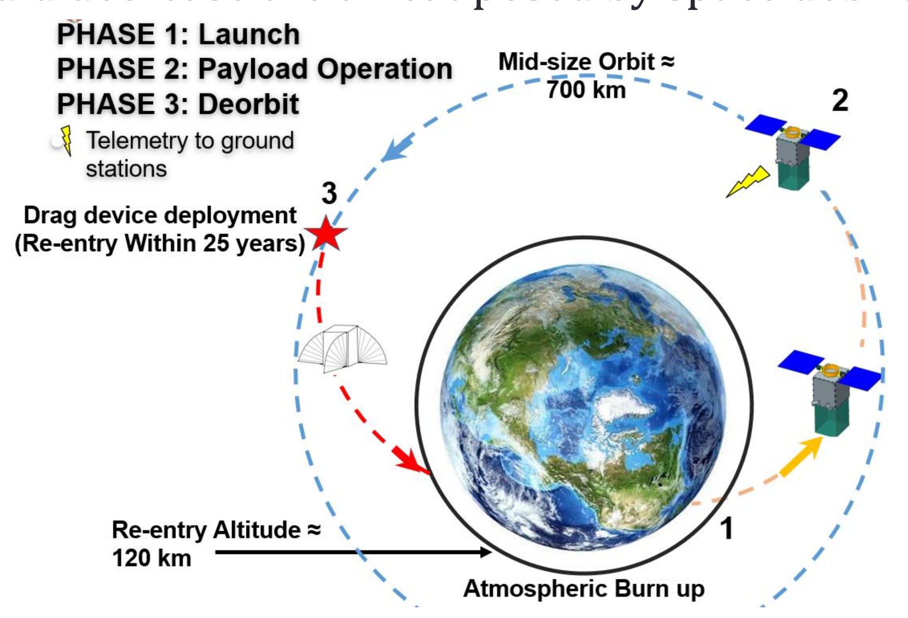

Figure 1: Deployment of a Spacecraft Drag Sail 3-Phase Concept of the Operation.

BACKGROUND

As space exploration continues to progress, so do the difficulties posed by space debris. Space debris severely threatens satellites currently operating that provide essential services like communication and Global Positioning System (GPS). NASA and other authorities have instituted policies to limit space debris by mandating a maximum dwell-time of 25 years for decommissioned satellites in LEO.

PREVIOUS WORK

Traditional Drag Sail Design (Fig. 2):

- Made of thin film and deployed via extension mechanism.

Solar Sail Design (Fig. 3):

- Used as S/C propulsion using SRP (Solar Radiation Pressure) exerted on large mirrors (Solar Sails).
- Can increase atmospheric drag at low altitudes, becoming a drag sail.

Inflatables (Fig. 4):

- Failed to inflate. The "jack-in-the-box" deployment method avoids some of the complexity of a multi-panel opening design (i.e. – inflatable boom).

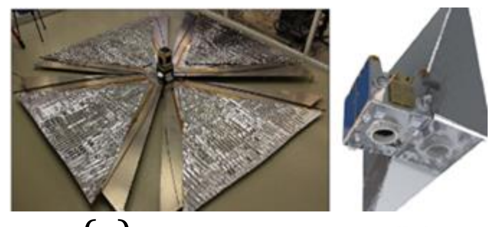

Figure 2: Drag Sail Examples: (a) CanX-7 (b) Icarus-1 (Kramer, "Tech Demo-Sat")

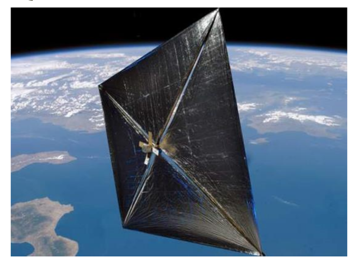

Figure 3: Solar Sail (NASA, "STMD.")

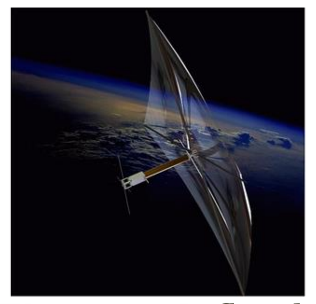

Figure 4: Inflatable Drag Device ("inflateSail, "EO Portal Directory)

Why present new design?

- Current drag sails require complex internal structures to deploy and take up one entire side of the S/C.
- Costly and various parts increase likelihood of failure.

THEORY

Ballistic Coefficient

- Analysis of orbital mechanics and the effects of drag, as seen in Fig. 5, involves consideration of the ballistic coefficient, which is related to drag
- The equation for ballistic coefficient follows:

$$C_B = \frac{m}{C_D A}$$

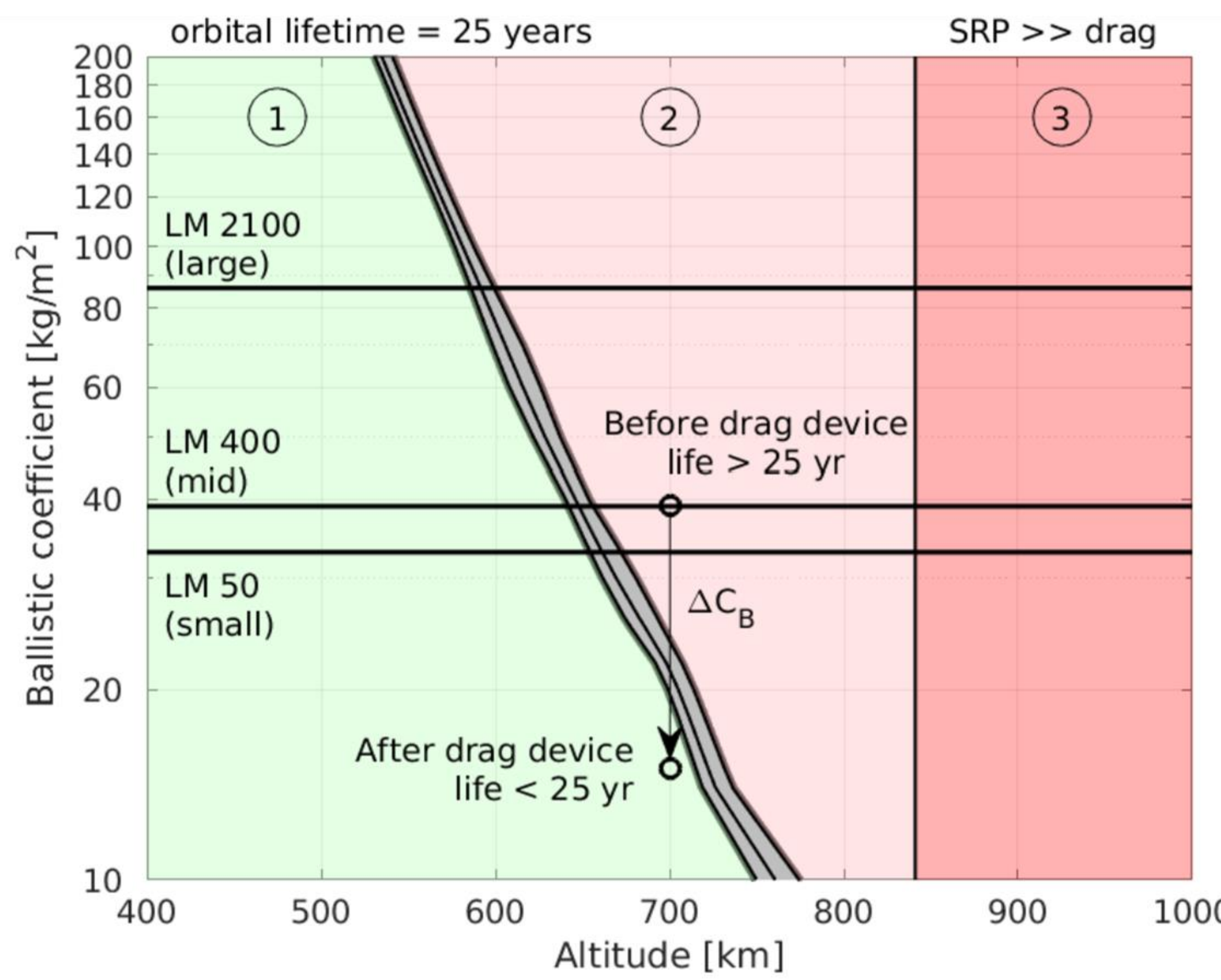

Figure 5: Drag device effect and typical ballistic coefficient for small, mid, and large size spacecraft (Alsup, Katrina P., et al.).

ANALYSIS METHODS

LM-400

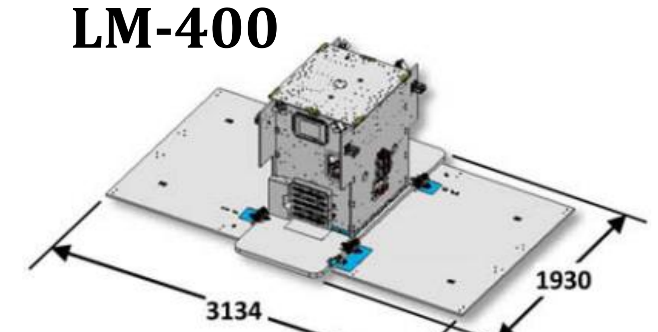

Figure 6: Image from Lockheed Martin showing the scale and shape of the LM-400 bus.

Specifications:

- Mass: 400 kg
- Total Surface Area: 16.5 m^2
- Average Cross-Sectional Area: 3.45 m^2

This research analyzed an LM-400 spacecraft (Fig. 6) at approximately 700 km apogee as these are common examples which serve as a generic demonstration of the drag sail technology. For this research, two main analysis tools were used to model the spacecraft and its orbit: Semi-analytic Tool for End-of-Life Analysis (STELA) from the French Space Agency and Debris Assessment Software (DAS) from NASA.

RESULTS

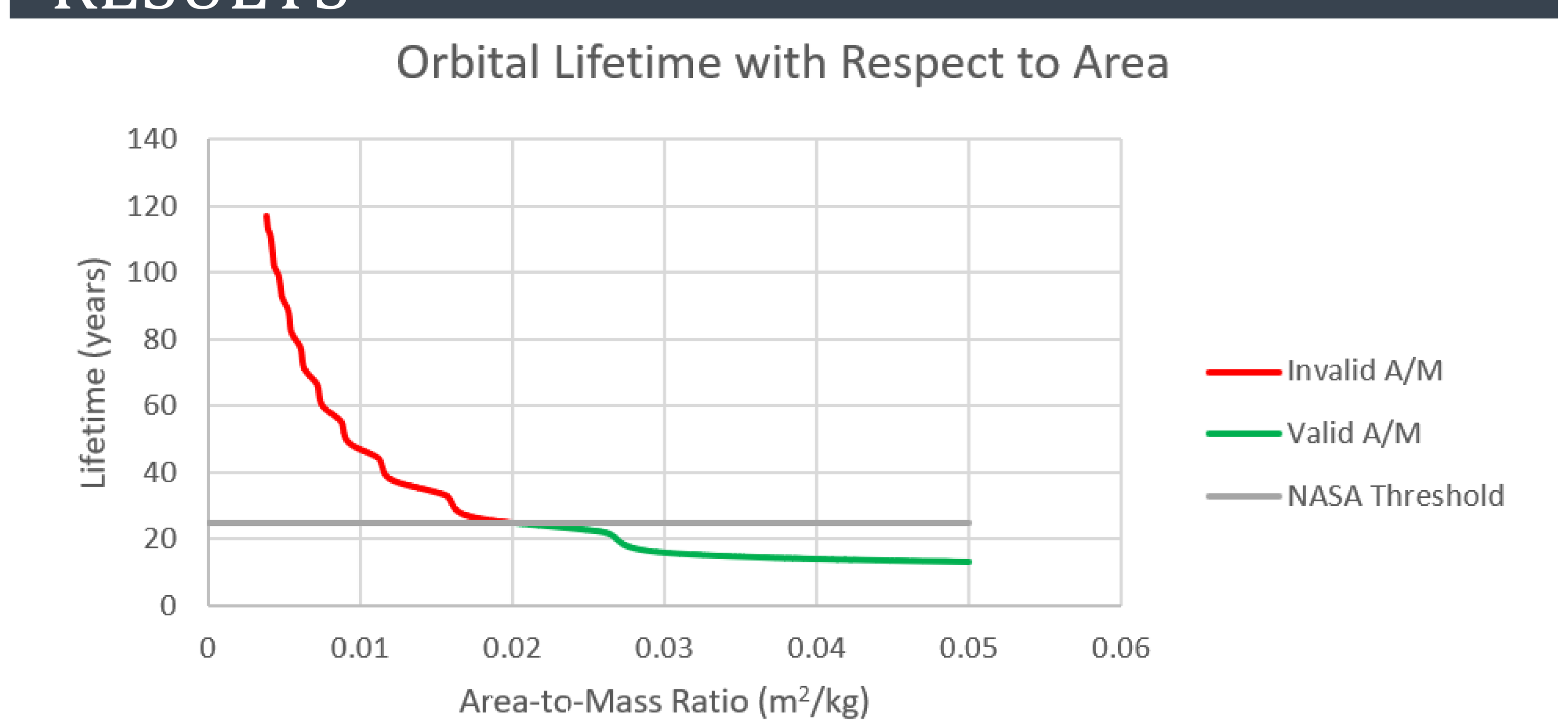

Figure 7: Results from DAS with varying area to mass ratios showing predicted lifetime of EO-1's orbit. The 25-year threshold is also shown in the graph.

Fig. 7 demonstrates the inverse relationship between area and orbital lifetime. Considering the Drag Equation, increased area will decrease the velocity, and thereby altitude and orbital lifetime.

- Current Predicted Orbital Lifetime at 700 km: 56 years
- Minimum Tumbling Cross-Sectional Area: 8.04 m^2
- Minimum Additional Cross-Sectional Area Produced by Drag Sail: 4.59 m^2

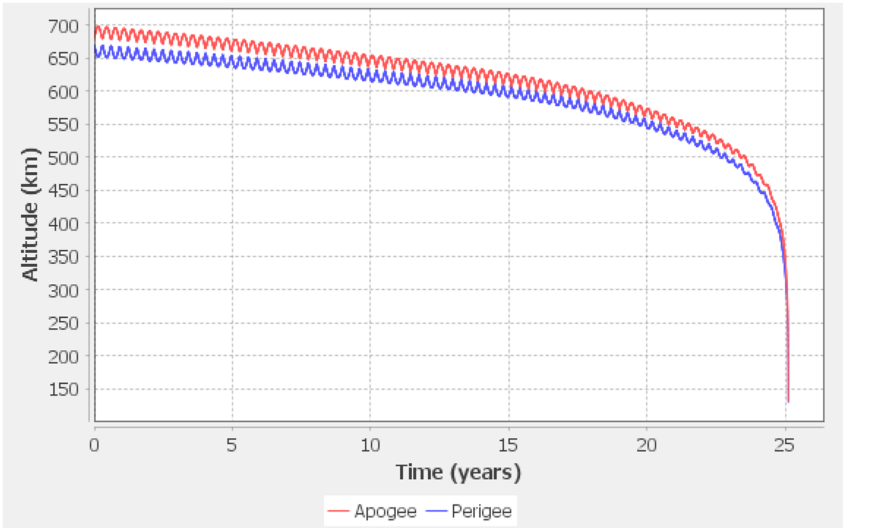

Figure 8: Results with minimum added cross-sectional area of Spacecraft showing orbital decay over 25-year period.

Figure 9: STK Sim of the LM400 with an inclination of 98 degrees.

DESIGN AND MODEL

Drag Sail Design Requirements

- The added area must contribute the minimum cross-sectional area of 4.59 m^2
- The design must be compact throughout the launch and mission lifetime and be capable of extending to a larger area post-mission.
- Before being extended, the design must not obstruct any essential bus components or a significant portion of the surface area.
- Material must be flexible, durable to withstand space weather/atmospheric effects, and have equal or less weight than propulsion fuel used for deorbit operations.

Design Model Analysis

The design model in Fig. 10 is like the shape of an umbrella with similar mechanisms. These four drag sails increase the tumbling cross-sectional area of the LM-400 by 134% to a total of 8.09 m^2. The predicted orbital lifetime is 24.9 years.

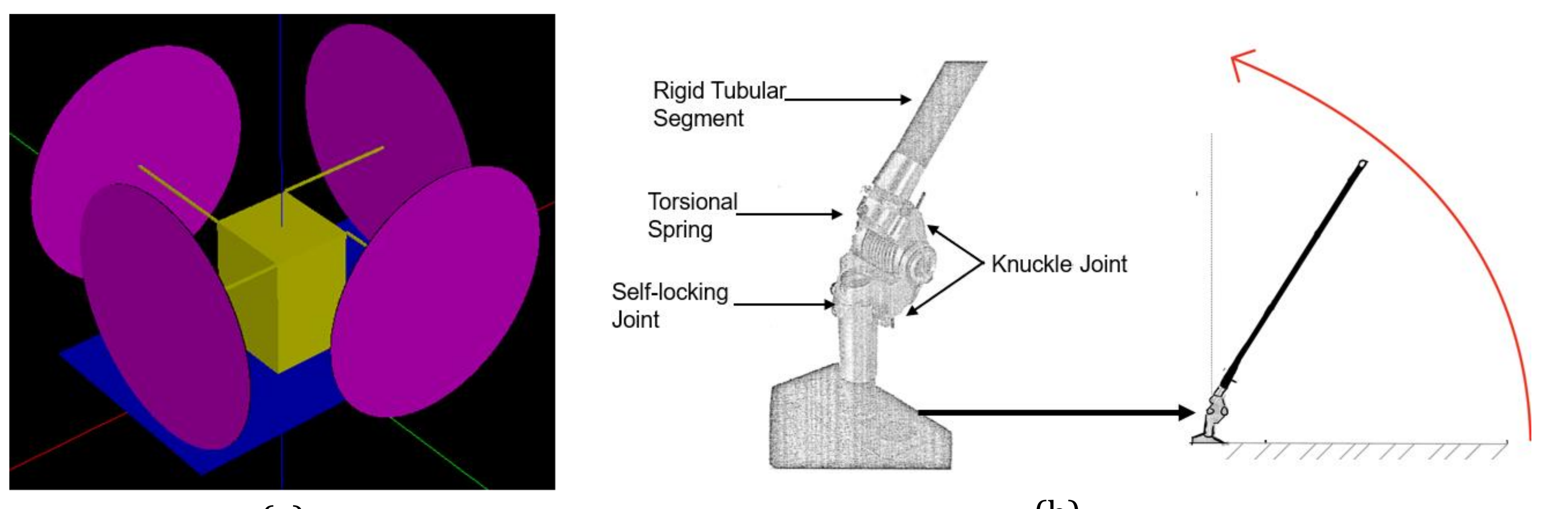

Figure 10: (a) 3-dimensional model of the LM-400 spacecraft with the attached drag sails shaped as umbrellas extended (area analyzed using STELA) (b) Hinge used for whip antennas that may be used to deploy the drag sail from the surface edges of the S/C (AEC-ABLE Engineering Inc.).

REFERENCES

- Akin, David L. *Applications of Ultra-Low Ballistic Coefficient Entry Vehicles to Existing and Future Space Missions.* Space Systems Laboratory, University of Maryland. College Park Maryland. April 2010.
- Alsup, Katrina P., et al. *Drag-enhancing deorbit devices for mid-sized spacecraft self-disposal.* Naval Postgraduate School, 2018.
- "InflateSail," EO Portal Directory, accessed Jan. 2021.
- Kramer H. J.,, "TechDemoSat-1," EO Portal Directory, accessed Jul. 2018.
- NASA, STMD: Tech Demo Missions - Solar Sail Demonstrator, Aug. 2017.
- National Aeronautics and Space Administration. NASA-STD-8719.14B. 2019.
- Tarantini, Vincent, et al. "De-orbit Analysis of a Tumbling Spacecraft." University of Toronto Space Flight Laboratory, 2014.

CONTACT INFORMATION

Corban.Barstow@westpoint.edu
Armande.Naseem@westpoint.edu
Robert.Perezalemany@westpoint.edu
Diana.Loucks@westpoint.edu