

## Drag and Solar Sail for Earth Return (DISPOSER)

Rachael A. Collins, Matthew E. Duchek, and John L. Abrams

Analytical Mechanics Associates, 2460 W 26<sup>th</sup> Ave, Suite 440-C, Denver, CO 80211, United States

### ABSTRACT

The increasing population of CubeSats and small satellites in Low Earth Orbit (LEO) contributes to the accumulation of orbital debris, resulting in a growing potential threat of in-orbit collisions (i.e. the Kessler syndrome). To mitigate this problem, NASA requires future spacecraft in LEO to deorbit within 25 years after end of mission. As many small satellites do not have the propulsive capabilities needed for disposal, low-mass drag augmentation has been introduced to passively accelerate deorbit. These drag devices deploy following the completion of a satellite's operational mission and have sufficient area so that the force from atmospheric drag decays the orbit. Extensive industry innovation in drag augmentation technology has been demonstrated for altitudes up to 1000 km; however, there is not sufficient atmosphere at higher low Earth orbits for timely drag induced deorbiting. Additionally, passive deorbit systems do not have the capability to perform targeted reentry when there are safety concerns regarding satellite components surviving atmospheric reentry.

The Drag and Solar Sail for Earth Return (DISPOSER) system developed by Analytical Mechanics Associates (AMA) is a combined solar and drag sail solution that utilizes solar radiation pressure (SRP) and atmospheric drag respectively to enable CubeSats and small satellites to deorbit from altitudes up to 2000 km. The system includes a ballistic coefficient modulation mechanism to perform precision targeted reentry by controlling the effective area of the sail during approach. Controlled reentry via ballistic coefficient modulation enables safe landing and disposal of the satellite with potential uses for sample return or EDL.

Following end of mission, the DISPOSER sail is deployed from a modular, compact package that is attached to the host satellite using a standard bolt-on interface. The deployment of the sail is controlled in order to limit instantaneous angular accelerations. The deployed square sail consists of triangular quadrants supported by four diagonal tape spring booms that maintain the sail's shape under operational loads while still being flexible enough to allow elastic coiling around a drum for storing. The mass-loading of the sail and booms is minimized in order to minimize the mass of the system and maximize the sail's characteristic acceleration.

At higher altitudes where the force from SRP dominates the force from drag, the solar sail steering law is used to perform orbit lowering maneuvers. This is achieved through active attitude control to orient the sail so that the largest SRP force component acts opposite of the velocity vector. Once drag becomes the dominating force, the sail passively stabilizes in the optimal attitude for maximum drag, with the velocity vector normal to the cross section of the sail. Aerodynamic drag acts as a restoring force when the angle of attack of the sail is non-zero due to the offset between the spacecraft's center of mass (CM) and sail's center of pressure (CP).

In order to perform precision targeted reentry, the effective area of the sail is modulated during approach so that the spacecraft lands in a designated location. The ballistic coefficient profile performed is determined by modeling the predicted spacecraft drag. The drag model accounts for systematic uncertainties and temporal atmospheric variation using Fourier series expansion incorporated into standard Kalman filter techniques for precision orbit determination and landing.

DISPOSER is realized through high-fidelity modeling and simulation tools developed at AMA including models of the solar and aerodynamic forces acting on the sailcraft; six degree-of-freedom attitude dynamics models for deployment, solar steering, drag stabilization, and reentry targeting; and orbit and trajectory simulation for solar/drag deorbit and ballistic coefficient modulated reentry. The results suggest a reliable and robust deorbiting solution that scales to a range of spacecraft systems and mission profiles. DISPOSER's enhanced deorbiting capabilities will enable future missions to comply with end-of-life regulations in order to mitigate the growth of orbital debris.