Multi-Application Survivable Tether (MAST) Experiment

Summary

The "Multi-Application Survivable Tether" (MAST) experiment, will utilize three tethered picosatellites to investigate tether survivability and dynamics in the space environment. The MAST flight hardware is shown in Figure 1 and Figure 2. The three picosatellites will ride into orbit together in a CalPoly P-POD deployer, and be deployed into a 803.0 x 658.5km, 98° inclination orbit. Seven days after ejection from the P-POD, a spring-based separation system will push the tether deployer picosatellite (leftmost in Figure 1) away from the other two picosats, deploying a 1-kilometer long, nonconductive, multi-line tether. After another seven day period, the middle picosatellite will then begin slowly crawling up and down the tether, taking photographs of the tether as it travels. It will transmit these photographs to a ground station to enable analysis of the rate at which the micrometeoroid and orbital debris environment affects the tether structure. Additionally, GPS receivers on all three picosatellites will provide data on the dynamics of tethered satellite formations in orbit.

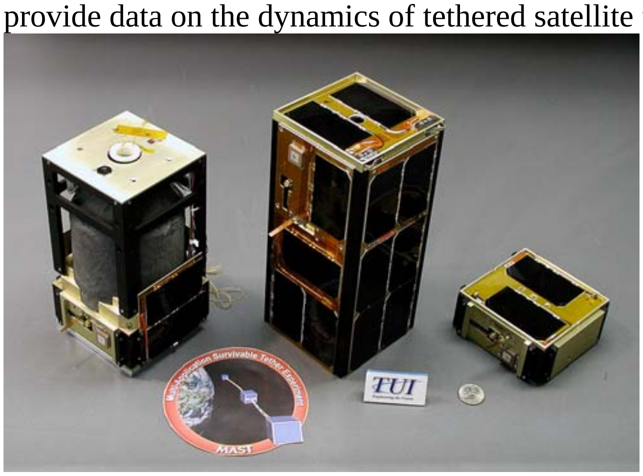

Figure 1. The three picosatellites built for the MAST flight experiment.

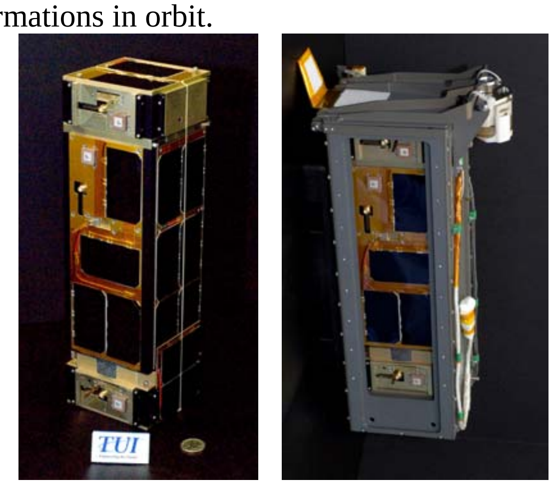

Figure 2. (Left) MAST picosatellites in stacked configuration. (Right) MAST inserted into PPOD deployer (access panel opened for viewing.)

Orbital Debris Mitigation

The MAST experiment has been designed and will be operated in a matter to mitigate the generation of orbital debris. The primary goal of the mission is to validate the multi-strand long-life space tether technology which is a critical element of end-of-life deorbit space tether modules.

The MAST satellite system has been designed to limit the amount of debris released during normal operations. The spacecraft components were assembled in such a manner to minimize the inclusion of any manufacturing and assembly debris, and loose fasteners in the spacecraft. In addition the spacecraft underwent a shake test after being inserted into the P-POD deployer, after which no loose or stray materials were observed.

The MAST experiment consists of three tethered picosatellites which are deployed from the P-POD together, with a Spectra cable looping around the three picosatellites. One week after P-POD deployment, a nichrome wire will heat the cable till the Spectra cable is severed. This process does not generate any particulates, and the two remaining ends of the cable are permanently affixed to one of the satellites.

The MAST experiment has been designed to minimize the probability of accidental explosions during and after nominal mission operations. MAST contains the following energy storage devices which have limited capability to fragment the spacecraft:

- The tether deployer contains four captive springs that are use to initiate a 1 meter per second separation of the spacecraft for tether deployment after the Spectra cable is severed. The mechanism that severs the cable can do so both on command, and redundantly upon watchdog timer expiration, ensuring that the tether is deployed and that the stored spring energy is released.
- Each of the picosatellites contains a lithium-ion battery that is used to power the spacecraft during nominal operations. These battery packages have integrated protection circuitry that detect and prevent overcharge, overdischarge, and overcurrent of a lithium-ion battery during charge and discharge cycles minimizing the probability of an accidental explosion. At the end of nominal mission operations, the batteries will be depleted and placed into a permanently discharged state.
- The heating of the nichrome wire is accomplished by a separate battery. When the mechanism is actuated this battery is used to heat the nichrome wire until fully discharged.

At the end of nominal mission operations, all of the energy sources will be depleted, leaving them in a permanently discharged state.

An assessment has also been made with regards to the probability of collision between the MAST experiment and other cataloged space objects[1]. An analysis was performed comparing the number of conjunctions that the MAST spacecraft will experience as compared to a 10m spacecraft. During the 1-year simulation time, the tether passed within 10 km of 122 objects, while the satellite passed within 10km of 116 objects (Figure 3). From these results, we conclude that deploying a 1-km length tether will result in only a 5% increase in the number of conjunctions of 10 km or less. The MAST operator has assessed and limited the probability of the space station becoming a source of debris by collisions with large debris or other operational space stations.

[1] Hoyt, R., Buller J., "Analysis of the Interactions of Space Tethers with Cataloged Space Objects," JPC 2005. (http://www.tethers.com/papers/MXER_Conjunction_Analysis.pdf)

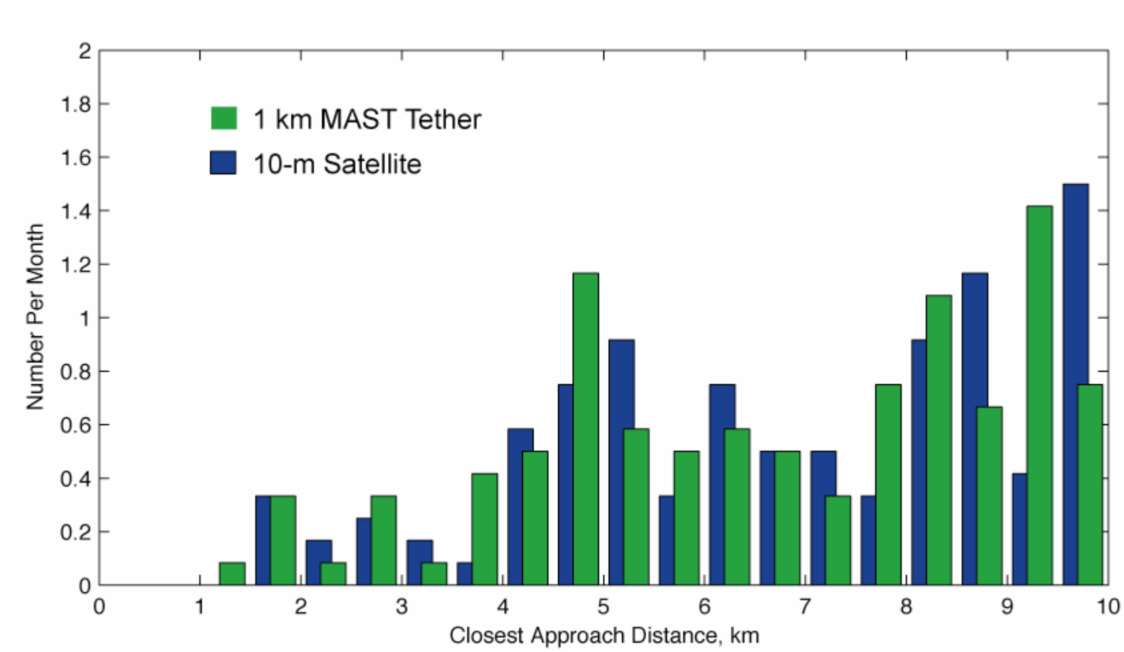

Figure 3. Comparison of the rates at which the MAST 1-km tether and a 10-m satellite will encounter other catalogue objects, as a function of closest approach distance.

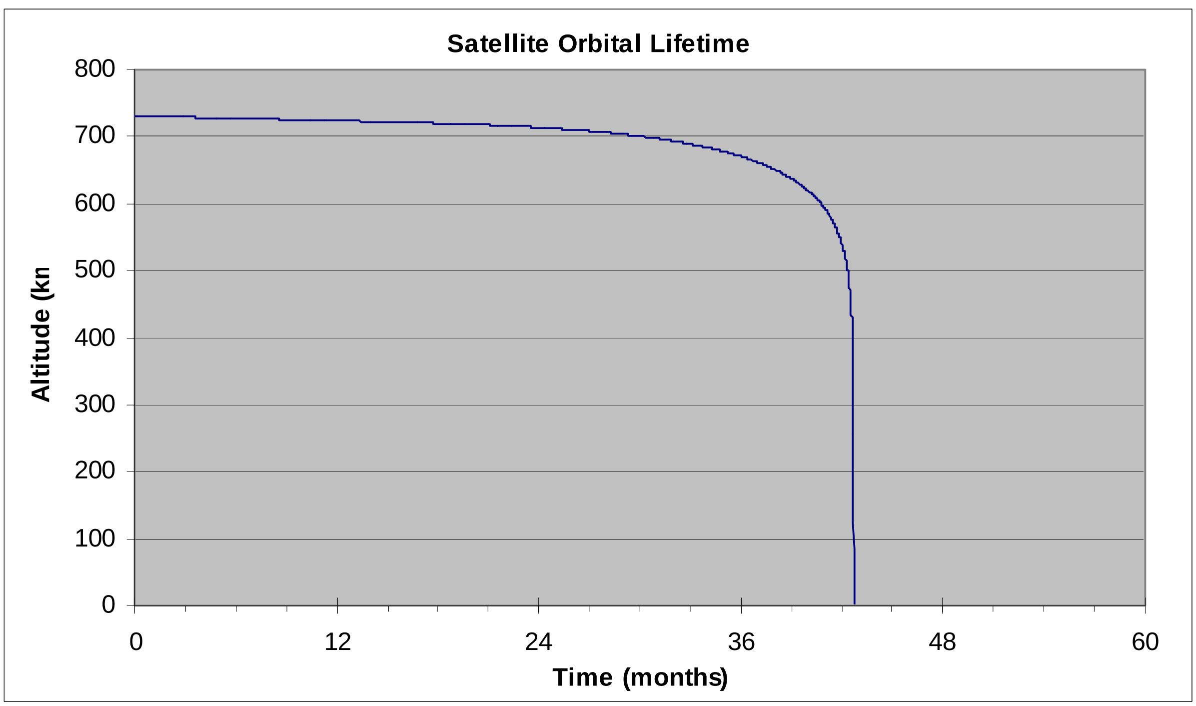

Figure 4. Projected evolution over time of the MAST experiment orbit

The MAST spacecraft does not include any propulsion systems and is not able to maintain or alter its orbit. An assessment of the spacecraft's orbit predicts that the system will have an orbital lifetime of 3.57 years, with the altitude profile depicted in Figure 4. Post-mission, the MAST experiment will be be disposed via atmospheric re-entry. Due to the systems small mass and size, no portions are expected to survive re-entry.

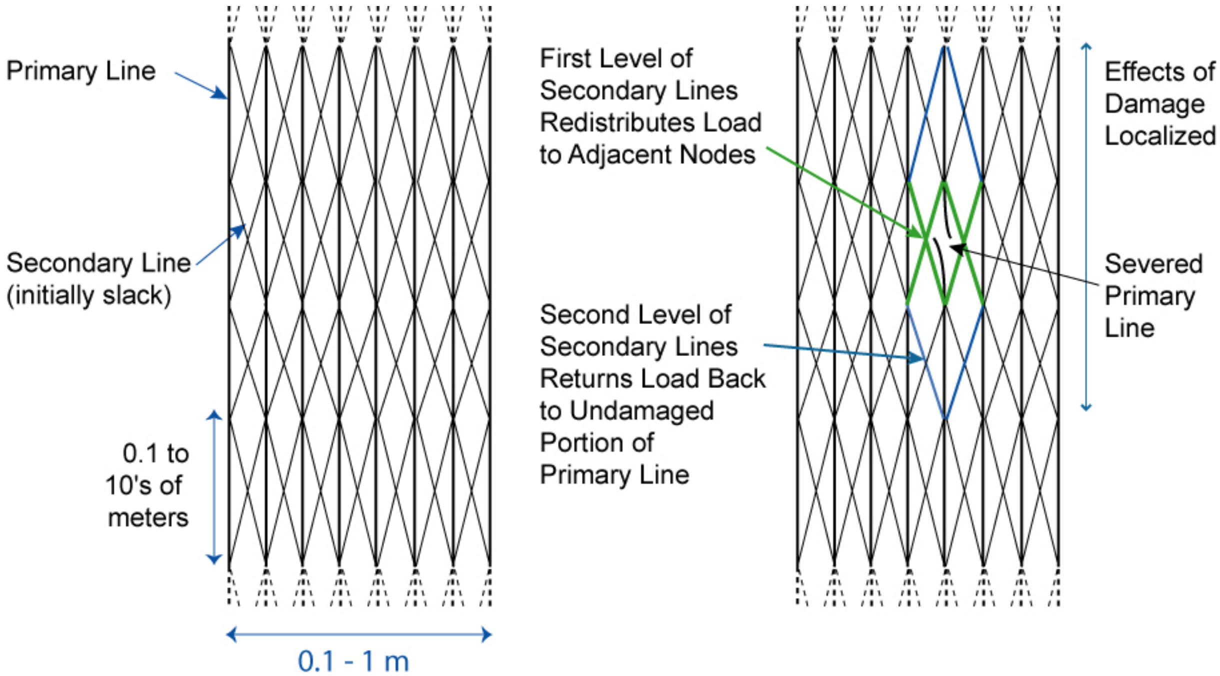

Figure 5. Principal of load-bearing redundancy and damage isolation in the Hoytether™ space tether structure.

Survivable HoyTether™ Structure

The MAST experiment will utilize a TUI-patented multi-line tether structure, called the Hoytether™ (see Figure 5), to ensure that the tether will survive the micrometoroid and orbital debris (M/OD) environment for the duration of the nominal mission operation. Single-line tethers are not suitable for a long-duration mission, because a single cut anywhere along its length by a M/OD particle can sever the tether. The survival probability of a single line tether drops exponentially with time, as illustrated by the red curve in Figure 6. If, however, the tether is constructed of multiple separate lines that are periodically interconnected, so that they provide redundant load-bearing paths, cutting the tether requires either a collision with a single, very large object which can sever all lines at once, or multiple M/OD impacts on one short segment of the tether structure. Physical separation between the lines can be achieved even under loading of the tether through several means, including periodic variations in the braided structure that help spread the lines apart, as well as electrostatic repulsion between charged lines.

In analyzing the survival probability of a Hoytether structure, we must consider both the probability of collisions with large impactors that could sever the entire structure, and the probability of all of the multiple lines on a single segment of the structure being impacted by M/OD particles. Orbital objects large enough to cut the entire tether are extremely rare, and so the survival probability of the tether due to large impacts decreases as a slow exponential. Although the tether will be continually bombarded by M/OD impacts, these impacts will be randomly distributed along the tether length. As a result, the survival probability of a Hoytether™ structure being cut by M/OD is such that the survival probability remains very high for a long duration until it has experienced so many cuts along its length that each segment of the tether has several cut lines. For the predicted 3.6-year orbital lifetime, we estimate that the tether has a 99.5% probability of survival. Details on the method of calculating the survival probability are given in a paper by Forward and Hoyt.[2]

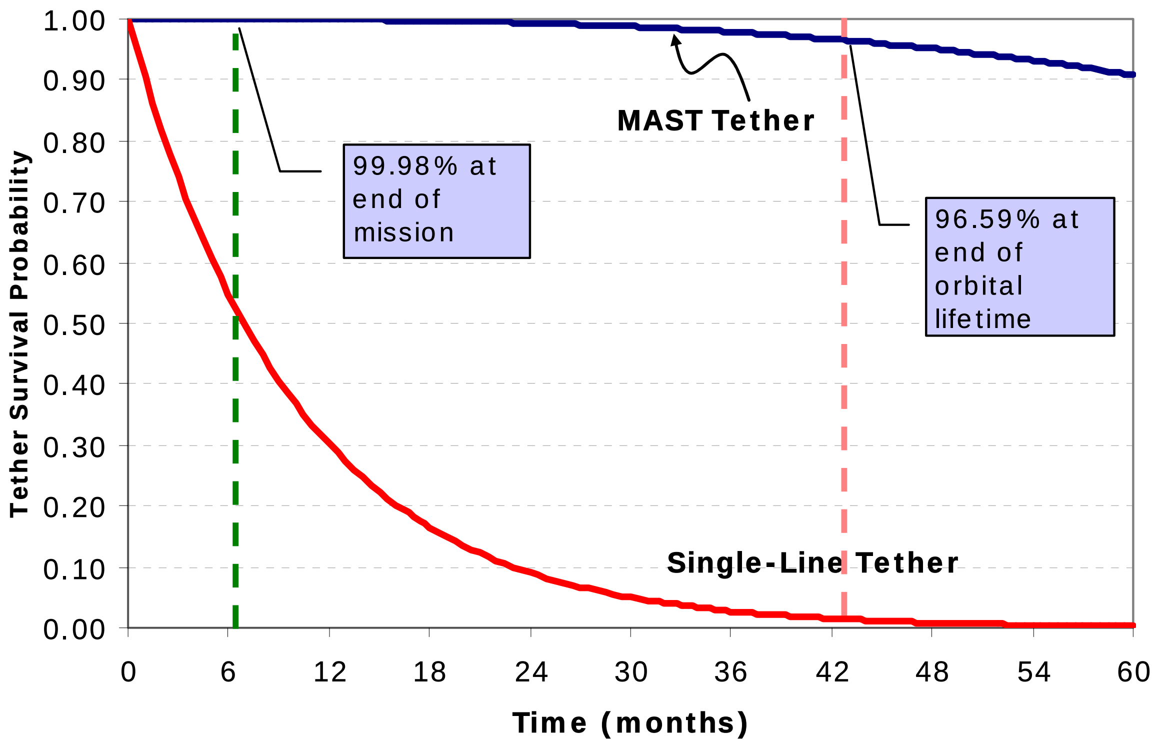

Figure 6. Survival probability of the MAST Hoytether™ structure compared to an equivalent-mass single-line tether.

2. Forward, R.L., Hoyt, R.P., "Failsafe Multiline Hoytether Lifetimes," AIAA paper 95-2890*31st AIAA/SAE/ASME/ASEE Joint Propulsion Conference*, San Diego, CA, July 1995. (http://www.tethers.com/papers/HoytetherLifetimes.pdf)