Testing and Development of NEA Scout Solar Sail Deployer Mechanism

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Abstract

The Near Earth Asteroid (NEA)[1] Scout is a deep space CubeSat designed to use an 86 m^2 solar sail to navigate to a near earth asteroid called VG 1991. The solar sail deployment mechanism aboard NEA Scout has gone through numerous design cycles and ground tests since its conception in 2014. An engineering development unit (EDU) was constructed in the spring of 2016 and since then, the NEA Scout team has completed numerous ground deployments aiming to mature the deployment system and the ground test methods used to validate that system. Testing a large, non-rigid gossamer system in 1G environments has presented its difficulties to numerous solar sailing programs before, but NEA Scout's size, sail configuration, and budget has led the team to develop new deployment techniques and uncover new practices while improving their test methods. NEA Scout's spooled sail and boom design differs from any solar sail design to date: a single square sail membrane spooled upon a non-circular mandrel and the booms are spooled on two separate coils. This configuration was necessitated by the 6U footprint and is not common among other solar sailing missions. The program has planned and completed 3 separate full scale sail deployments to date, with a flight sail deployment test scheduled for FY18. The sail deployment tests have helped mature flight operations plans and developed preliminary off-nominal deployment mitigation strategies. The paper entitled "Design and Development of NEA Scout Solar Sail Deployer Mechanism" [2] was presented at the 43rd Aerospace Mechanisms Symposia. Since then, the system has matured and completed ascent vent, random vibration, boom deployment and sail deployment tests. This paper will discuss the lessons learned and advancements made while working on solar sail testing and redesign cycles.

Executive Summary

In May of 2016, the Near Earth Asteroid (NEA) Scout engineering development unit (EDU) solar sail was prepared for a suite of environmental tests culminating in a full scale deployment at NASA Marshall Space Flight Center's (MSFC) flat floor facility. The full scale deployment would premier a fully machined EDU, flight-like motors, and a developing control system. Numerous half scale deployments and mechanical development efforts were completed in preparation for the full-scale test.

The solar sail development team developed a test suite that would begin with an ascent vent test to simulate the rapid depressurization during ascent on SLS. This test was performed to indicate the viability of the sail folding pattern and verify that the vent paths were performing nominally. The folding pattern and vent paths proved to be acceptable and no sail damage was noted due to trapped air.

After ascent vent the team prepared for a random vibration test. This test was intended to vibrate the system in all 3 axes with intermittent, boom only deployment tests after each axis of vibration. The team

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encountered their first major lesson learned through an undersized stepper motor, which disabled the ability to perform intermittent tests. The team proceeded with the random vibration test with the undersized stepper motor. Post-test, an investigation into the undersized motor commenced. Causes identified included limited design space, improper scaling of half scale loads to full scale designs, and poor assumptions regarding the system's internal friction. The redesign effort required a large system reconfiguration.

Boom-only deployments and retractions were the next tests schedule to be completed. With the new configuration and properly sized stepper motor, the boom-only deployments demonstrated the capability and robustness of the system during nominal operations and risk mitigation activities, such as boom blooming characterization. The team learned several lessons learned that will be highlighted in the extended paper. For example, retraction rates to remove blooming, boom buckling recovery, and deployment shape dynamics.

Once the team was comfortable with the boom deployments, the EDU sails were deployed. Two sails were produced for EDU activities: a mylar sail and a colorless polymer-1 (CP1) sail. Both sails were 86m2 in size, with the CP1 built as flight-like as possible. During the deployments, the team updated procedures with boom support information, electrical inputs, sail attachment methods and mechanical fixturing. These tests proved to be the most eye-opening test to date.

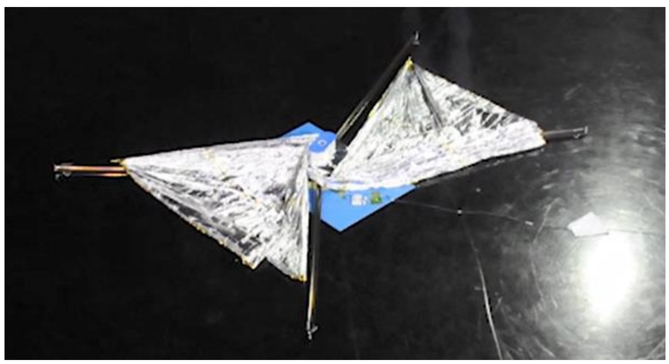

Figure 1. Typical bowtie shape observed during ground deployment tests

Within minutes of initiation, the booms assumed what would come to be known as a "bowtie" configuration, Figure 1. This was due to the single spool, single sail design and the associated unspooling process. As the sail fell and was pulled along the floor, friction pulled the paired boom tips toward one another and away from their orthogonal orientations. A few more minutes in as the booms moved in more acute angles as the booms lengthened, one pair worsened at an alarming rate until a boom buckled. The test was halted as the team investigated and corrected. The test continued and the sail eventually achieved a full deployment, with significant human intervention (Figure 2). These interventions were documented and studied at length in the weeks leading to the full scale EDU test one year later.

Between September 2016 and September 2017, the SSD passed through another redesign process that would incorporate a novel thermal design predicated by laboratory thermal vacuum (TVAC) testing. A lesson learned from TVAC testing the active mass translator, which utilized a small class of stepper motor. Lessons learned will be highlighted in a separate paper titled "Testing and Maturing a Mass Translating Mechanism for a Deep Space Cubesat".

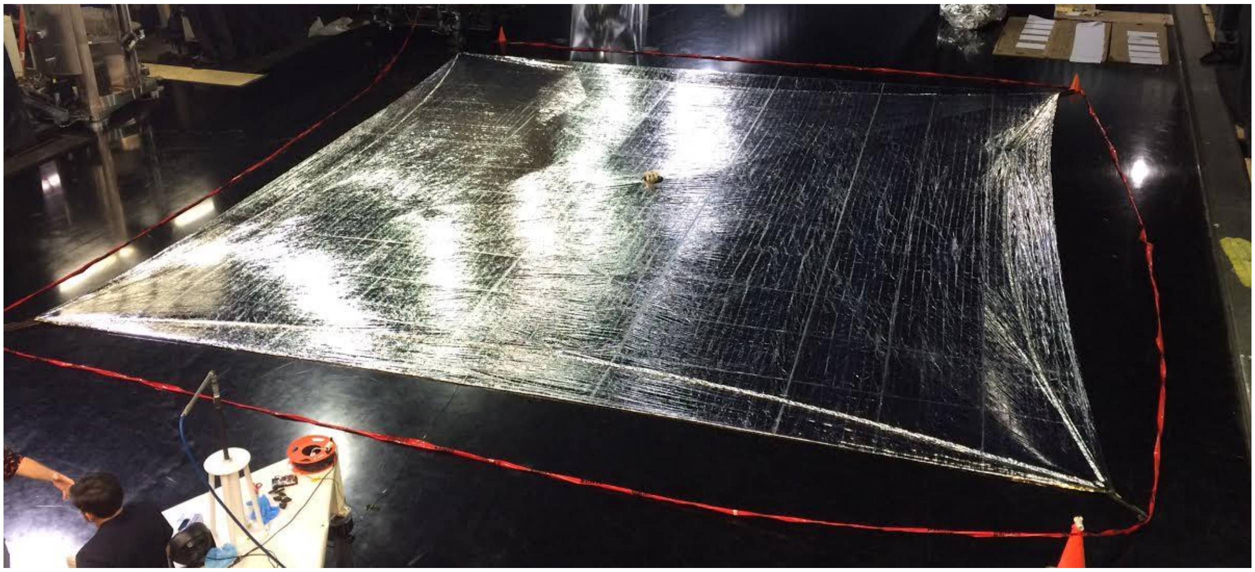

Figure 2. Full Scale CP1 EDU Deployed Sail, August 2016

In September 2017, the NEA Scout team completed its final EDU deployment test. In the weeks prior, the team studied and applied lessons learned to more than a dozen off-nominal deployment cases, characterized the booms and sail in a 1G environment and produced a detailed deployment procedure. This test removed 1G characteristics such as sliding friction forces by 50%, and developed a simple and effective method to gravity offload boom tips. These careful experiments developed a new test scheme that would remove some of the complicating factors present in deploying flexible gossamer structures in 1G and allowed the booms and sail to behave in manners more similar to the 0G flight environments.

In summary, the proposed paper will expound upon several lessons learned in the design, development, and test of the solar sail deployment mechanism. The mechanism encountered design challenges that stretched the team's knowledge and limited resources. The resiliency of the team and novel approaches kept the project aligned with the class-D mission classification while keeping the overall success of the project in mind. The team hopes this paper will provide valuable information for future solar sail mechanism designers.

References

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