

Testing and Maturing a Mass Translating Mechanism for a Deep Space CubeSat

Alex Few¹, Tiffany Lockett², Richard Wilson³, David Boling⁴, and Erik Loper⁵

Abstract

Near Earth Asteroid (NEA) Scout is a deep space satellite set to launch aboard NASA's Exploration Mission 1. The spacecraft fits within a CubeSat standard 6U (about 300 x 200 x 100 mm) and is designed to travel 1 AU over a 2.5 year mission to observe NEA VG 1991. The spacecraft will use an 86 m² solar sail to maneuver from lunar orbit to the NEA. One of the critical mechanisms aboard NEA Scout, the Active Mass Translator (AMT), has gone through rigorous design and test cycles since its conception in July of 2015. The AMT is a two-axis translation table required to balance the spacecraft's center of mass (CM) and solar sail center of pressure (CP) while also trimming disturbance torque created by off-nominal sail conditions. The AMT has very limited mass and volume requirements, but is still required to deliver a large translation range—about 160 x 68 mm—at sub mm accuracy and precision. The system must accommodate and protect a shielded wire harness and coax cables during translation. Lastly, the system has been constrained to operate in complete exposure to space with limited power and data budgets for mechanical and thermal needs. The NEA Scout team has developed and carried out a rigorous test suite for the prototype and engineering development unit (EDU). These tests uncovered numerous design failures and lead to many failure investigations and iteration cycles. This paper will site each discovery and discuss at length the most surprising and difficult failures to date as the NEA Scout AMT moved through functional, random vibration, thermal vacuum, harnessing, and design life verification testing. A paper was previously presented at the 43rd Aerospace Mechanisms Symposia entitled, "Development of a High Performance, Low Profile Translation Table with Wire Feedthrough for a Deep Space CubeSat". This paper will make note of specific lessons learned from the test activities: testing ideologies for high-risk missions, thermal mitigation design for small mechanisms, non-flight qualified stepper motor accommodation, harnessing volume allocation/design, and ground testing of mechanisms developed for zero-g environments.

Executive Summary

As the Near Earth Asteroid (NEA) Scout Active Mass Translator (AMT) passed through Critical Design Review in July 2016, the engineering team planned and prepared test procedures, facilities and a rigorous test schedule. The NEA Scout AMT EDU first iteration was completed in November 2016 and quickly began testing. Functional and workmanship random vibration tests passed with no noted cautions or failures. In December of 2016, the AMT entered thermal vacuum (TVAC) testing.

¹ George C. Marshall Space Flight Center, 256-544-6490, alexander.c.few@nasa.gov

² George C. Marshall Space Flight Center, 256-961-1304, tiffany.lockett@nasa.gov

³ Jacobs Technologies, George C. Marshall Space Flight Center, 256-544-4079, richard.d.wilson@nasa.gov

⁴ Jacobs Technologies, George C. Marshall Space Flight Center, 256-544-8648, david.a.boling@nasa.gov

⁵ George C. Marshall Space Flight Center, 256-544-2668, erik.r.loper@nasa.gov

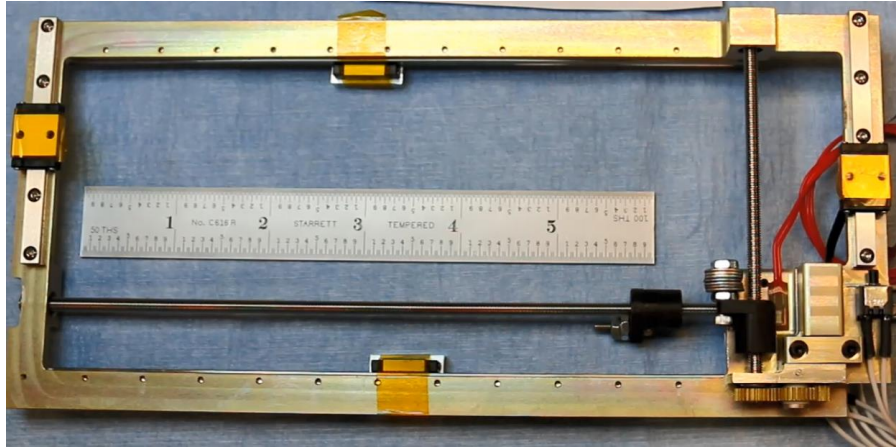


Figure 1. Active Mass Translator engineering development unit

The AMT uses two stepper motors to drive a leadscrew along the X and Y axis (Figure 1). During the first TVAC test, one of the motors failed within seconds of operation in the vacuum environment. After consulting with vendors, deconstructing the mechanism and conducting a root-cause failure investigation, the mechanical design team uncovered a few contributors to the motor's failure: motor overcurrent, faulty thermal design and incorrect assumption of the motor's thermal path created a large heat source with insufficient conductive surfaces to reduce the motor coil temperature. During this time, the mechanical engineer began working closely with the motor vendor to determine the best way to redesign the mechanism to include a satisfactory thermal path.

After the failure investigation and redesign process, the AMT reentered TVAC testing and would uncover more thermal design failures. In May 2017, the test team entered the TVAC test facility with an updated test procedure and motor controller algorithm aimed to collect more precise thermal data and run each motor at a lower power. Even with the mechanical and controller design changes, the AMT motors still failed in vacuum. The collected thermal data taken from numerous locations on the AMT noted that the motor temperatures rose much more slowly and peaked well below the motor max survival temperature. Though this data would indicate an improved thermal design, the motors exhibited the same failure mode. With the disparity between collected thermal data and failure mode, the team investigated the motors' internal design and eventually determined that the motor's internal heat path was yet again different than anticipated and would require only a small modification to remedy.

Date	Time	Xa		Xb		Ya		Yb	
		R[Ω]	T[°C]	R[Ω]	T[°C]	R[Ω]	T[°C]	R[Ω]	T[°C]
July 20, 2017	Pre test	120.7	26.0	121.4	26.0	120.6	26.0	121.1	26.0
	3:01 PM	144	75	137.8	61	122.8	31	121.6	27
	3:05 PM	122	29	122	27	122	29	122	28
	3:28 PM	123.5	32	124.2	32	152	93	152	91
	3:32 PM	122.8	30	123.4	30	122.9	31	123.1	30
July 21, 2017	1:02 PM	120.4	25	120.9	25	120.2	25	120.6	25
	1:29 PM	122.3	29	122.9	29	147	82	147	81
	1:53 PM	148	84	140	65	122.9	31	122.2	28
	1:57 PM	122.3	29	123	29	122.3	30	122.6	29
	2:20 PM	153	95	145	76	148	84	149	85
	2:23 PM	124.5	34	125	34	124.7	35	125	34

Figure 2 Internal coil temperature data of stepper motors collected during TVAC test

The team entered the TVAC test for a third time in July 2017. This test was constructed to determine the operational range of the AMT with the new thermal design. Since the thermal data was not indicative of the internal motor temperature, the team employed a new method to measure the motor coil temperature

immediately after running (Figure 2). This was used to construct a data set that would determine the ambient environment to motor coil temperature relationship and help the team bound a realistic operational temperature range. The July test was the first time the AMT was tested in vacuum at various temperatures, running from -35C to 50C at 5-10 degree increments. The AMT motors performed nominally, but the team noted translation capability degradation at around -10C which worsened until the lower bound. This investigation is currently ongoing, but there have been recent discoveries that the bearings could not operate at low temperatures and that the lead screws were not properly designed to accommodate the CTE differences over that temperature ranges. The mechanical designer is currently reconfiguring the AMT to remedy these problems and is working towards a fourth and final EDU TVAC test in October 2017.