DETECTOR ARRAY ASSEMBLY DEVELOPMENT FOR THE ATLAS INSTRUMENT ON THE ICESAT-2 MISSION

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ABSTRACT

This paper describes the development of the Detector Array Assembly (DAA) structure for the Advanced Topographic Laser Altimeter System (ATLAS) on the ICESat2 Mission built at NASA Goddard Space Flight Center (GSFC). It describes the challenges faced in designing a structure to protect sensitive detectors with limited data available for the detectors and the environment, including shock. The paper shows the successful re-design and testing that was performed to allow for a design to handle launch, shock and thermal environments with flexibility to incorporate design changes.

1. INTRODUCTION

The ICESat-2 mission is one of the earth science decadal survey missions, a continuation of the science done by ICESat. The objective of the ICESat-2 mission is to measure changes in the land ice, sea ice, and vegetation canopy height over a three year duration. The ICESat-2 spacecraft is shown in Figure 1.

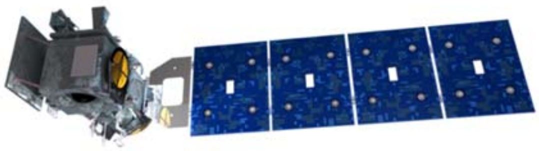

Figure 1. [1] ICESat-2

ATLAS is a multiple-beam laser altimeter. It illuminates the ground, collects and detects light, processes signals related to the detected light, and sends the resulting data to the spacecraft and the ground system. Two signals are used to measure time of flight of each received photon: a pulse generated at the time photons are emitted and a pulse generated each time a photon is detected. The time interval between the two pulses is the measured time of flight. Photon counting is performed by the Detector Array Assembly. The ATLAS Instrument is shown in Figure 2.

The DAA consists of a Detector Optics Module (DOM) and a Detector Electronics Module (DEM). The DOM, which consists of Optics Tubes for signal input, Photo-multiplier Tube (PMT) detectors, and a mechanism for redundant PMT selection (all provided by the GSFC development teams), receives the optical input and generates a digital pulse to be used in generating the time of flight histogram.

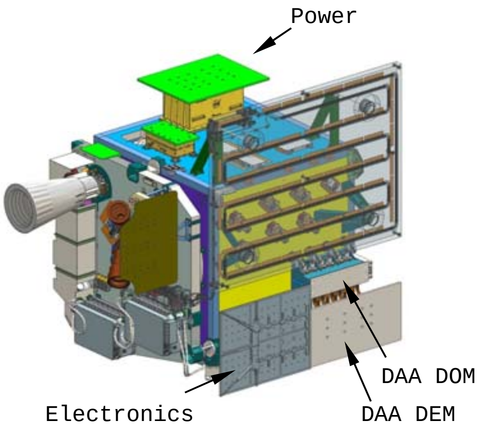

Figure 2. [2] ATLAS

ATLAS Instrument and ICESat-2[2] mission information is provided in the table below.

ATLAS Instrument Information	
Mass	500 kg [2]
Power	686 W [2]
Data volume	577 Gbits/24h [2]
Laser	532nm 10 kHz [1]
Number of beams	6 [1]
ICESat-2 Mission Information	
Launch year	2016 [1]
Launch vehicle	Delta II [1]
Mission Duration	3 years [1]
Mission class	C [2]
S/C vendor	Orbital Sciences Corporation [2]

2. DESIGN CONSIDERATIONS

The DAA development presented the Team with some interesting challenges. As a system that takes an optical input and produces an electrical output it requires the expertise of and the accommodation for a number of various discipline teams. In addition to the Core Mechanical DAA Team an Optical, Detector, and Mechanism Teams were part of the development. Schedules and resource limitations had to be taken into account for all. In addition, considerations for vendor-supplied components limited the design space. The Detector Electronics Module chassis, for example, was already designed by a vendor and had to be accommodated.

Initial mechanical analysis efforts for the DAA faced several fundamental challenges. First, the design process had to proceed prior to launch vehicle selection. Additionally, spacecraft design elements such as deployable actuator selection were still maturing. Consequently, final launch environments and shock loads were unknown during the design phase. Similar uncertainty surrounded the capability of the PMT detectors. While some specifications did exist, their true load handling capability and exact vulnerability was unknown. A comprehensive test program to obtain this information was prohibitively expensive. In short, the Team was initially faced with designing a system with unknown capability being exposed to unknown loads.

Due to programmatic needs, the DAA was originally developed to consist of a separate DOM and DEM mounted on a single plate. This initial design presented a number of concerns.

The mechanism for cycling between primary and secondary detectors was found to need simplification. Coefficient of Thermal Expansion mismatch between the baseplate and the composite panel of the structure resulted in loads that were too high. Thermal isolation between the DAA and the deck was insufficient partially due to the fact that the number of interface fasteners was high. The structure consisted of multiple parts, was not rigid enough and required sequential assembly with participation from multiple discipline teams. A redesign was initiated to address these concerns.

Major factors that shaped the development were: maintaining optical alignment precision, modularity for parallel development by the different teams with possibility of changing the assembly sequence, response to findings from the initial design, designing a structure within existing constraints, staying on a tight schedule and budget and protecting detectors in an unknown environment.

3. DAA DESIGN

The DOM was redesigned to consolidate multiple components into a rigid aluminium housing with vibration isolators interfacing directly to the ATLAS structure. Compliance with structure loads, thermal isolation and vibration isolation requirements was achieved. The existing DEM was retrofitted onto a flexured frame that interfaces to the ATLAS structure. The flexured frame resolved CTE mismatch issues and the titanium flexures met thermal isolation requirements. This resulted in a simplified robust modular design with parts adaptable to changes incurred throughout the DAA development, integration, and test program.

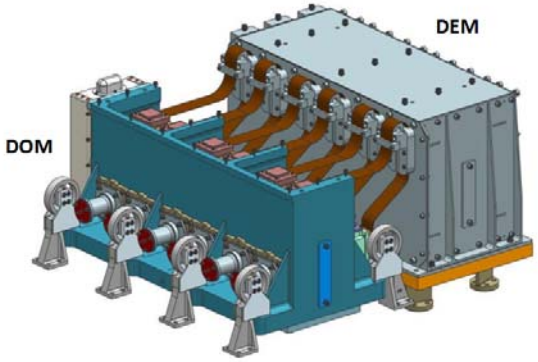

Figure 3. [3] Final Detector Array Assembly Design

3.1 Detector Optics Module

The DOM is comprised of a six-channel housing and eight Moog-CSA Engineering vibration isolators. Each channel consists of an optical tube assembly, primary and redundant detector assemblies and a detector select mirror (on a common shaft controlled by the detector select mechanism). The module housing is a single-piece component machined from aluminium alloy 6061-T651.

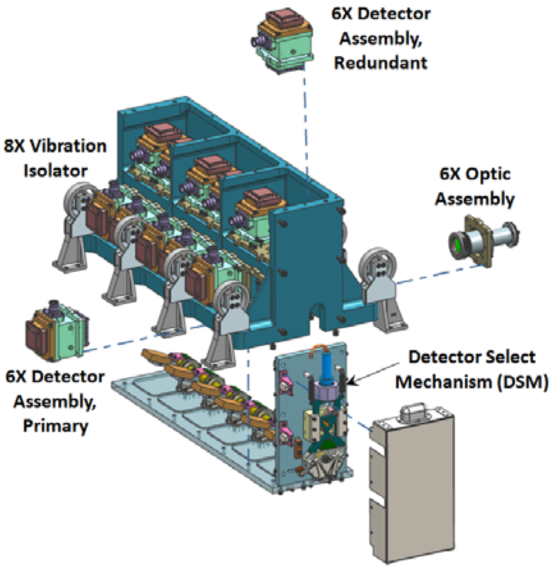

Figure 4. [3] Detector Optics Module

The monolithic housing design permitted tuning (stiffness, weight and GC) of the DOM to the custom vibration isolators for protection of the sensitive detectors. Steel pins in the module housing maintain alignment between the detectors, optics and detector select mirrors. Additional pins provide robust structural connection to the vibration isolators. Each component is independent of the assembly and can be replaced without disturbing the others. The subsystem components were developed in parallel by independent teams working to an interface document specifying component alignment and tolerance requirements. To assure optical alignment requirements could be met, the DOM design incorporated adjustability utilizing spacers, adapter plates, shims and liquid pinning at various levels of the assembly process. Three versions of the DOM were developed; a mass simulator for development of the vibration isolators, an Engineering Test Unit (ETU) for vibration test, and the Flight unit for delivery to ATLAS.

3.2 DAA Interface to ATLAS Structure

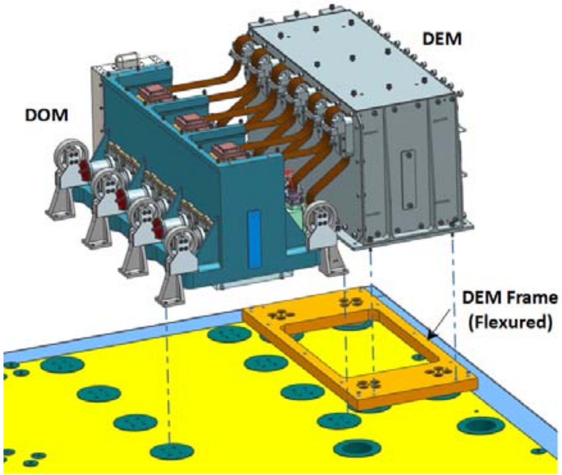

Figure 5. [3] DAA Interface to ATLAS Structure

The ATLAS structure (supplied by GSFC) is a box geometry constructed of six composite sandwich panel assemblies. Each composite panel is comprised of an aluminium honeycomb core with carbon-fiber facesheets. Component attachment to the structure is accomplished via titanium inserts bonded to the composite sandwich panels. The box interior is not accessible; all component attachment must be performed from outside of the box. There are twelve individual DAA interfaces to the structure (eight DOM and four DEM). They are considered highly loaded, requiring rigorous structural and environmental testing. Individual panel inserts were sized for weight and material demise restrictions. Attachment of the DAA to each structure interface requires tensile and shear components accomplished with screws and pins. With this design approach, precise location of the bonded inserts is necessary to assure the DAA fit to the structure. The DOM attachment to the structure is a conventional interface at the panel exterior surface. The eight DOM vibration isolators connect to eight individual panel inserts. The importance of precise insert location became evident when a DOM fit-check to the structure revealed some of the panel insert positions were out-of-tolerance. The DOM could be installed, but the risk of bending pins and difficulties of maneuvering the DAA during future installation and removal operations drove a need for corrective actions.

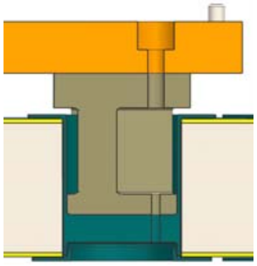

Figure 6. DEM Isolator Interface to Structure

The DEM interface to the structure presented a greater design challenge. The DEM flexure had to be recessed into the structure panel, to minimize the increase in height due to the DEM adapter plate. In addition, installation could only be performed from outboard of the box structure. To accommodate this requirement, the flexure mount flanges were designed as cylindrical geometry with close tolerance fits to achieve a shear connection at the structure insert interface. The shear connector rotational component was satisfied with dowel pins in the frame-to-flexure interface. Fastener installation and tooling access are accomplished sequentially. Tool access to smaller screws used in the flexure-to-insert connection is accomplished through larger screw interfaces in the frame-to-flexure connection. The installation of the DEM flexure frame assembly to the structure was very successful. The plate assembly was used to correctly position the structure inserts.

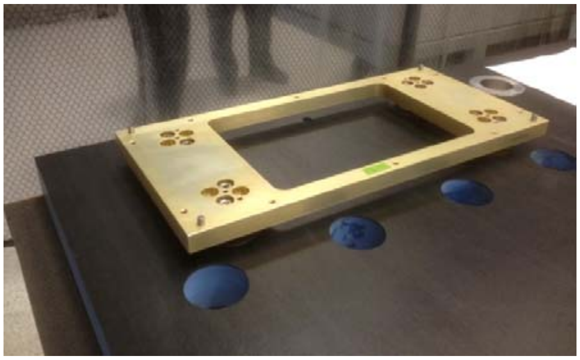

Figure 7. DEM Frame Used to Position Structure Panel Inserts During Bonding Process (photo taken at NASA GSFC)

4. ALIGNMENT VERIFICATION

Due to the need to provide a stable and precise alignment of the optics the DOM housing is designed to be monolithic and serve as a stable base for alignment with minimum tolerance build-up and high thermal stability. All the modules can be installed and removed without disturbing the optical alignment of the rest of the system.

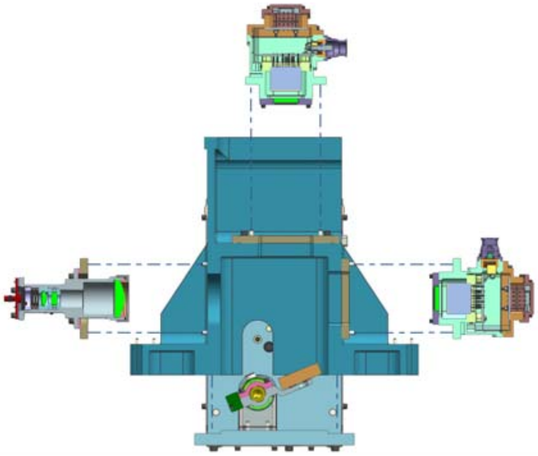

Figure 8. [3] DOM Module Alignment

The Optics Tubes were delivered pre-aligned for plug-and-play installation and modularity, with the ability to fine adjust image center if required. Precision features on the DOM housing are used to position the tubes, detector modules and select mechanism. A cross-hair plate and alignment scope are used to position the Optics Tubes without having the detector modules in place. The secondary (redundant) detectors are installed on adapter plates (mounted to the housing) that were aligned to the optical path. This, again, allows the alignment to be done separately and results in a plug-and-play module installation. Once the adapter plates are aligned the Optics Tubes and the Detector Modules can be removed and replaced without the need to realign.

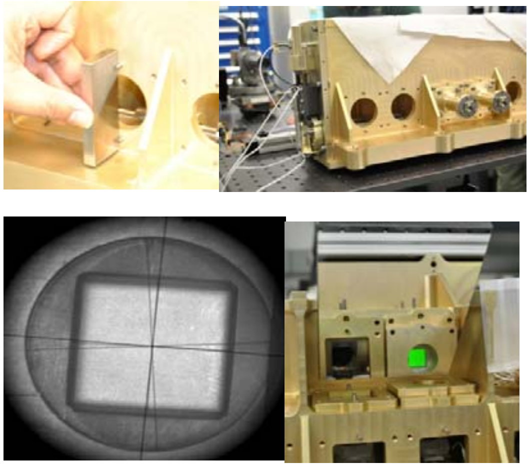

Figure 9. DOM Optical Alignment (photo taken at NASA GSFC)

5. ANALYSIS AND TESTING

The Team endeavoured in their design efforts to make the DAA as robust and as flexible with respect to design changes as possible. While a direct attachment of the DAA structure to ATLAS was favored due to its low cost, simplicity, and minimal envelope, the combined uncertainty of loads and detector capability clearly showed the need to reduce PMT response to the greatest extent practical. The Team turned to Moog-CSA Engineering to provide a vibration isolation system at the DAA interface. Without this system, the DAA would be at the mercy of whatever the final ATLAS interface forces happened to be.

Obviously, tuning the isolation system's suspension modes to a frequency range in which the PMT was vulnerable would be a not desirable. Thus, the Team ventured to learn, at the very least, some basic knowledge of the Detector's modal behavior. The Detector is small enough that traditional accelerometers are too large to employ. In addition, the detector is sealed making the internal structure inaccessible during testing. However, the Detector is constructed with a glass exterior. This allowed for a modal test to be performed with a laser vibrometer aimed onto the inner detector structure. Additionally, deconstruction of a sacrificial PMT allowed for rudimentary FEM analysis of the inner structure. Vibrometer test results and simplified FEM analysis showed good agreement on the first mode. It was still unknown if this first mode was of particular vulnerability for the PMT, however, it allowed some confidence in tuning the isolation system to reduce response at this frequency and above. The structure above the isolators, meanwhile, was designed to be very stiff (modal frequencies far exceeding the tuned suspension modes of the isolators). This benefited isolation performance as structure modes would not be amplified, and in fact, input would be greatly reduced at their frequency.

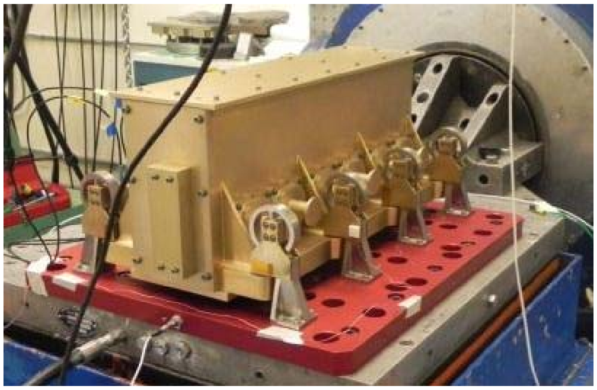

Figure 10. DAA test configuration showing isolator orientation. (photo taken at Moog-CSA Engineering Facility)

Engineers at Moog-CSA Engineering provided early recommendations on preferred isolator orientation and positioning. However, design considerations at the ATLAS interface, including available area, drove a specific orientation which placed all isolators essentially in parallel, as shown in Figure 10.

This was a somewhat unconventional arrangement compared to previous applications using similar isolators. These vibration isolators employ a visco-elastic material (VEM) which typically performs best under shearing motion. As a result of the parallel isolator arrangement, load along one specific coordinate axis would be normal to the VEM pads on all isolators – inducing more of a tension or peel effect on the VEM. During the first random vibration test, with load applied in this specific axis, the VEM pads delaminated. The Moog-CSA Engineering's resourceful engineers rose to the challenge of redesigning aspects of the isolator such that it performed excellently in its required orientation. The well-understood isolator FEM, when coupled to the DAA FEM, provided analysis predictions that closely matched test results, as shown in the random vibration test data in Figure 11. Even without a predetermined launch vehicle, use of GSFC's General Environmental Verification Specification (GEVS) loads showed the isolation system capable of reducing the PMT response to comfortable levels at frequencies of potential vulnerability.

Another aspect of the isolator VEM which had to be taken into account in DAA test verification is the frequency-dependent nature of the VEM stiffness. Not only does the VEM stiffness increase significantly under dynamic load as opposed to purely static load, but the latter, at certain load and duration, can induce a damaging creep effect in the VEM. DAA structural analysis requirements included static load based on a mass-acceleration curve (MAC), but this load, if applied in a purely static manner, could damage the VEM. GSFC dynamics analysts were able to carefully tailor an appropriate test program by evaluating the environments of several launch vehicle candidates (once again, a single vehicle had not been selected). Enveloping multiple vehicles, analysts parsed the vehicle's dynamic content versus true static acceleration and planned test durations based on the timing of flight events (time to MECO, etc). This frequency-dependent nature of the VEM also raised interesting considerations in the selection of test methods. For instance, load applied in a static pull-test facility, may hypothetically cause a failure, while the same magnitude of load applied in a sine burst test (a quasi-static test run at low frequency) may show ample margin.

Another aspect of the DAA analysis challenges was uncertainty in the expected flight shock loads based on final actuator selection. Since Moog-CSA Engineering's facilities included the capability to perform shock testing, the DAA Team provided a flight-like DAA which could be used to characterize the shock response behavior of the system (DAA including isolators). Moog-CSA Engineering was able to determine base shock allowable by tailoring arbitrary shock inputs applied at the base of the isolators and measuring responses at the simulated detector locations. The base allowable input was determined once the measured detector response matched the detector's allowable shock specification. This information could then be flowed to ATLAS systems engineers, as it illustrated that if future shock loads would exceed the base allowable, further implementation of shock mitigation within ATLAS would be required.

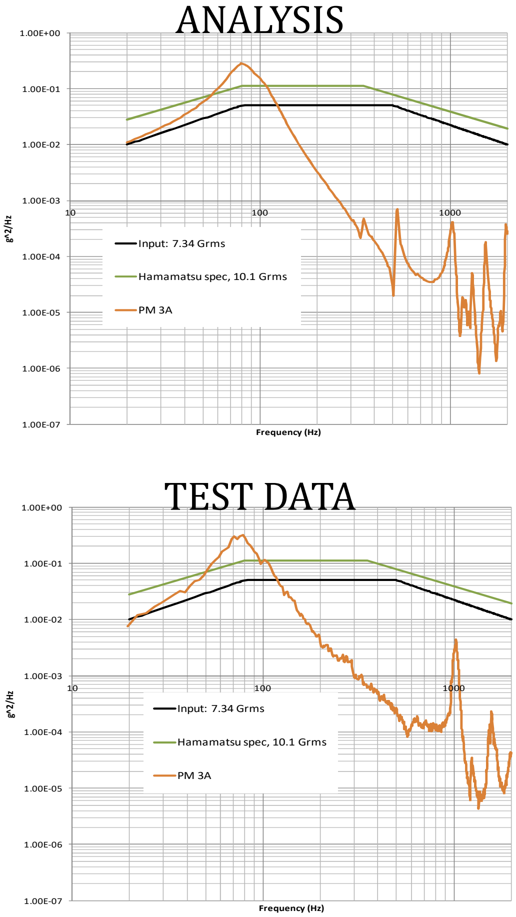

Figure 11. [3] Example comparison of DAA random vibration data to analytical predictions.

6. FINDINGS

Creating a modular design proved very valuable. The ability to have parallel development efforts and to change integration and test sequences resulted in schedule and cost savings to the program.

Procuring ETU parts with Flight paperwork and treating them as such provided valuable "spares" that could stand in for Flight parts when needed. Additionally, avoiding changes to such ETU parts allowed them to be used as Flight, reducing the cost of additional fabrication. Choosing expensive ETU parts as the anchors of the design, with this approach, produced significant schedule and cost savings.

Designing the DOM housing with the capability to compensate for mass changes in attached subcomponents enabled us to procure vibration isolators early. This approach mitigated a schedule hit when the initial test of the isolators had a failure. Having a flexible mass-spring design allowed early development and "anchored" the rest of the components.

In the initial test of the isolators, the proven design was forced into a less than conventional application (orientation) and had an unexpected failure. Trusting a proven design did not initially guarantee success.

We encountered difficulty during installation of the DOM on the flight structure due to out-of-tolerance pins. Also, some minor interference issues were found between the DEM Box and Radiator when an early fit check was performed. This highlighted the need for a spare unit or controlled precision-machined template to mitigate such issues. Relying on interface control drawings between separate teams, without early fit-checks, led to potential issues.

Making an adapter plate for the DEM box did not interrupt the development of the electronics and proved to be a useful mitigation of a CTE issue. Recessing flexures into the structure successfully minimized volume impact from the plate addition. This adapter plate also allowed the team to proceed with environmental testing using a mass simulator without the actual DEM chassis being available for it. Using an adapter helped to solve a technical issue without interrupting the programmatic schedule.

The design intent was to make the DAA as robust a system as practical. Selecting the vibration isolation system had the unintended consequence of protecting the hardware during a DAA test anomaly. A non-flight test version of the DAA was undergoing random vibration testing when the shaker amplifier at one facility experienced a hard shutdown. This had the effect of introducing an unintended shock load to the hardware as the table motion abruptly seized. When data collected during this accidental occurrence was analysed, it was determined that hardware had not been damaged. Had the flight detectors experienced this event without isolators present, failure would have been possible. In this case, the robust design intent and "test as you fly" approach helped to protect the hardware.

In lieu of a standard pass/fail test the isolators were shock tested to verify capability before the shock input was determined. This allowed us to determine a "transfer function" that gave us indication of the maximum protection provided by the isolators. Defining this capability was a useful tool in quickly determining system susceptibility at a future date.

Overall, the development proved to be challenging, but minimizing the number of parts and allowing for flexibility from the technical and programmatic standpoints proved to be the key to success.

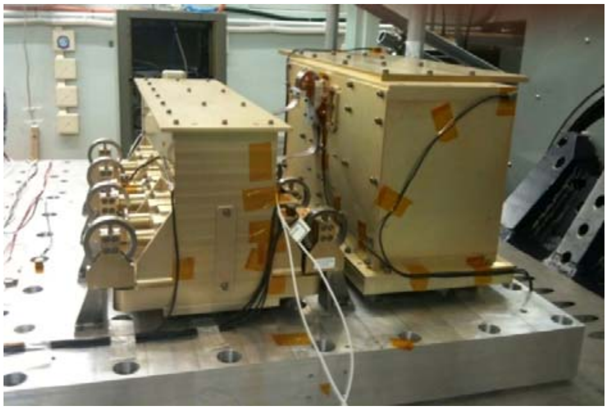

Figure 12. DAA ETU Test (photo taken at NASA GSFC)

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