DEVELOPMENT OF NON-PYROTECHNIC HOLD DOWN AND RELEASE MECHANISMS FOR THE JAMES WEBB SPACE TELESCOPE

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ABSTRACT

Working closely with our NASA and industry customers, Ensign-Bickford Aerospace & Defense Company (EBAD) developed, qualified, and delivered a total of 178 ea. Hold Down and Release Mechanisms (HDRM's) for the James Webb Space Telescope (JWST). EBAD's NEA® HDRM's were critical in over twenty (20) system deployments performed over a two-week period that began with the release of the solar panels and ended with the release of the primary and secondary mirror assemblies.

The demonstrated reliability and low shock output of EBAD's HDRM technology addressed key system requirements, however, JWST pushed the envelope in terms of load levels and environmental requirements, including operation at temperatures down to 28°K.

1 INTRODUCTION

Shortly after its Christmas Day 2021 launch, the transformation of JWST from its launch configuration into a fully commissioned space telescope began with deployment of the spacecraft solar arrays. Over the next two weeks, fifty (50) major system level deployments would be performed, over twenty of which relied on NEA® HDRM's.

The timeline for the major deployments is shown in Fig. 1 below. With the exception of fairing separation and launch vehicle (LV) separation, all of the deployments shown in Fig. 1 utilized NEA® HDRM's manufactured by EBAD.

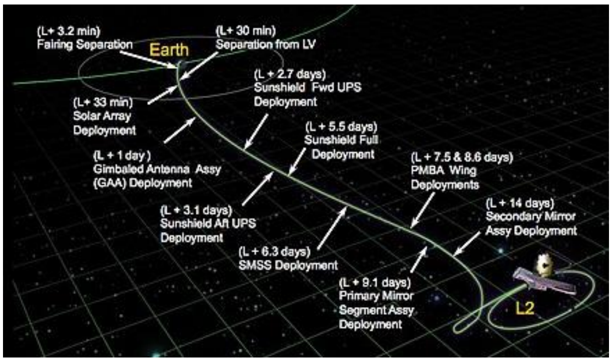

Figure 1 – JWST Deployment Events

2 BACKGROUND

EBAD is the global leader in non-pyrotechnic HDRM's, which are also referred to herein as NEA® release mechanisms.

Our NEA® HDRM products (see Fig. 2) are electrically initiated, one-shot devices that have the capability to carry a very high tensile preload until commanded to release. The preload is applied through a release rod held in place by separable spool halves which are in turn held together by a tightly wound restraining wire. The restraining wire is held in place by redundant electrical fuse wires. Actuation of either fuse wire allows release, providing redundancy of initiation. When sufficient electrical current is applied, the restraining wire unwinds allowing the spool halves to separate over timeframe measured in tens of milliseconds, gradually releasing the load such that the associated shock output is quite low, generally less than 1000 g's.

Figure 2 – NEA® HDRM

The low shock output of the NEA® HDRM's distinguish them from pyrotechnic separation nuts, which can produce 10X to 30X higher shock output levels. The NEA® HDRM's, therefore, are ideally suited for satellite and spacecraft applications. Because electrical properties, such as actuation and no-fire current levels are similar to pyrotechnic initiators, NEA® release mechanisms are compatible with pyrotechnic initiation circuitry.

Unlike pyrotechnic separation nuts, NEA® HDRM's can be refurbished by replacing the fuse wire, restraining wire, and a few other parts.

3 JWST RELEASE MECHANISMS

Prior to JWST, EBAD's NEA® HDRM product line, as measured by the release rod diameter, ranged from 6 mm to 16 mm, with corresponding release load capability of approximately 18 kN to 142 kN.

For the JWST program, EBAD developed both smaller (3 mm) and larger (19 mm) release mechanisms, expanding prior product heritage to meet the specific program requirements that were driven by size constraints and load requirements. Four unique SSD9100 (3 mm) device designs were developed, including an SSD9100 release mechanism variant for deployment of JWST's sunshield. A total of 107 SSD9100 HDRM's were used to pin the sunshield in place for launch and were subsequently released over a three-day period to deploy the 21 m x 14 m sunshield. Like every one of the NEA® HDRM's on JWST, each SSD9100 HDRM represented a potential single point failure for the mission.

JWST's Deployable Tower Assembly (DTA) separated the upper section of the observatory from the spacecraft bus and simultaneously provided room for the sunshield membranes to unfold. Due to envelope constraints, the DTA was to be supported by four HDRM's. Since load requirements exceeded the 142 kN capability of EBAD's 16 mm SSD9106 release mechanism, EBAD needed to develop the 19 mm SSD9107 release mechanism specifically for JWST. As will be described in a following section, this development effort became one of the most significant technical challenges on the program.

4 SCOPE OF WORK

The SSD9100 variant for deployment of the sunshield and the 19 mm SSD9017 release mechanisms were only two (2) of a total of seven (7) unique release mechanisms to be qualified for the JWST program. Qualification testing included various electrical tests (resistance, dielectric strength, insulation resistance, grounding, and no-fire current), mechanical proof load testing, output shock, random vibration, thermal cycling, external (input) shock testing, and functional, or actuation testing. Since NEA® HDRM's are designed to be refurbishable, life testing was also conducted to demonstrate that the release mechanisms were capable of being actuated under load, refurbished, and then actuated again for up to a total of ten (10) actuations.

Although the type of qualification tests were typical for NEA® HDRM's, JWST test levels exceeded prior product heritage and imposed some challenges due to the unique spacecraft and mission requirements. This paper addresses a few of those specific challenges, including release mechanism operation over a temperature range of 28°K to 433°K and shock output of less than 700 g's when functioned under loads exceeding 200 kN.

5 TEST RESULTS

5.1 Cryogenic Testing

Due to the location of several 6 mm (SSD9102) and 10 mm (SSD9103) release mechanisms on the spacecraft, the operational temperature range requirements for these particular devices represented both the coldest and hottest extremes of all of the JWST HDRM's with a specific operational temperature range of 28°K to 433°K, while operating in a vacuum environment.

The typical operational temperature range for NEA® HDRM's is 138°K to 408°K, so the departure from heritage was a particular challenge at the JWST cold temperature extreme of 28°K. Simultaneously, JWST required a maximum actuation time similar to the 50 ms function time for standard NEA® HDRM' at a modest current level of 3 A.

Fig. 3 below shows the relationship between actuation current and actuation time at ambient temperature, i.e. 295°K. While actuation under vacuum is somewhat faster than at ambient pressure due to reduced thermal conduction the 3 A current level is approaching the actuation current level where the function time starts to increase asymptotically as the current is reduced, as seen in the graph below. Note that the entire curve shifts to the right as temperature is reduced.

Thermal vacuum testing was performed at NASA Marshall Space Flight Center (MSFC) in Huntsville, AL with support from EBAD, our government prime contractor customer, and NASA since MSFC had unique capabilities to perform this testing at cryogenic temperatures down to 28°K.

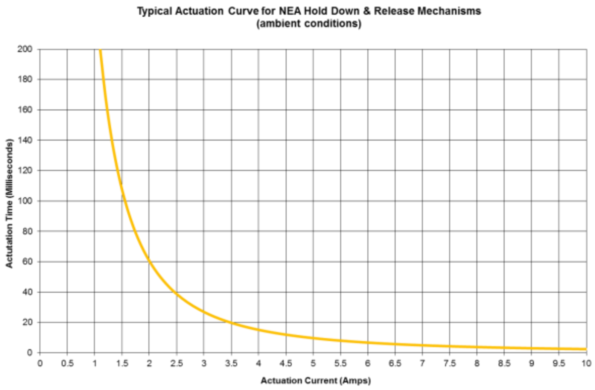

Figure 3 – NEA® HDRM Actuation Time as a Function of Actuation Current at Ambient Temperature

Test results are shown in Tab. 1 below for the 6 mm SSD9102 release mechanism. Note that nine (9) units total were tested, including five (5) at a maximum preload level of 19 kN and four (4) at a minimum preload level of 0.44 kN. In all cases, the actuation current was 3 A.

Table 1 – Thermal Vacuum Cold Actuation Test Data

Serial Number	Preload (kN)	Current (A)	Actuation Time (ms)
201	19	3	38.7
202	19	3	38.7
203	19	3	38.1
204	19	3	39.8
205	19	3	38.2
206	0.44	3	39.2
207	0.44	3	37.8
208	0.44	3	39.4
209	0.44	3	39.1

Note that the actuation time is very consistent and is not significantly affected by preload level. Although actuation times are somewhat longer at the 28°K temperature, as would be expected, they were well within the pertinent 50 ms requirement.

5.2 Shock Output Testing

All NEA® release mechanisms being developed for JWST shared a common technical requirement for a maximum shock output level of 700 g's or less.

This test is conducted by mounting the unit under test in the center of an aluminum plate with accelerometers positioned at several fixed positions on the plate. The plate is suspended from the ceiling using bungee cords attached to each of the four corners, as shown in Figs. 4 and 5. Accelerometers locations are shown in Fig. 6.

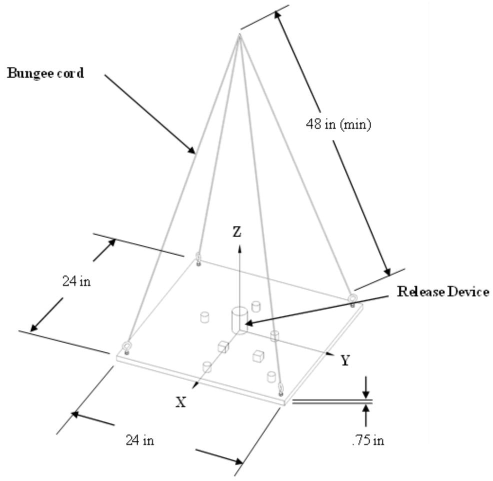

Figure 4 – Shock Output Test Setup

Figure 5 – Pin Puller Mounted on Shock Output Plate with Accelerometers

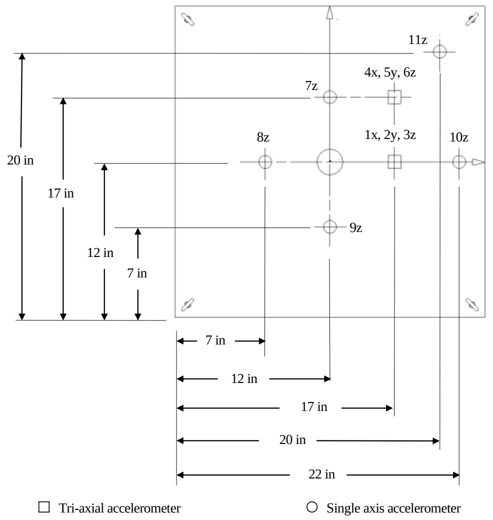

Figure 6 – Accelerometer Locations on Shock Plate

Representative test data from the JWST Pin Puller (one of the 3 mm release devices) shock output test is shown in Fig. 7 below, with data from all accelerometer locations and axes falling within specification limits.

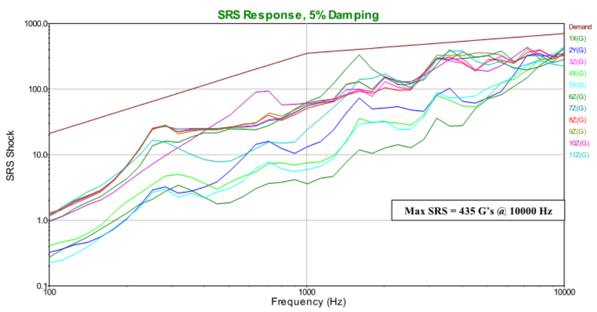

Figure 7 – Shock Response Spectrum from Pin Puller Shock Output Test

5.3 High Load Release Mechanism

As noted previously, one of the significant engineering challenges presented by JWST was the development of the SSD9107 (19 mm) release mechanism, which was designed to meet a preload requirement of 205 kN while simultaneously complying with the same 700 g maximum shock output requirement as applied to the other JWST release mechanisms.

For the SSD9107 HDRM, Fig. 8 shows representative test data at an actuation current of 4 A and preload level of 160 kN. For this test, the fuse wire burn time was 42.7 ms and load drop time was approximately 130 ms.

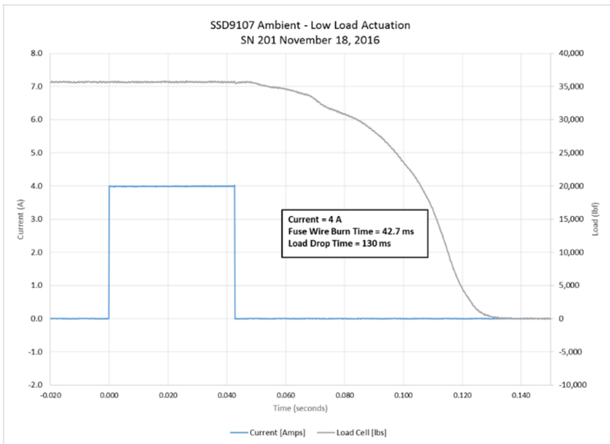

Figure 8 – SSD9107 Functional Test Data

During initial development of the SSD9107 release mechanism, it was observed that the restraining wire that held the two spool halves together would break early in the unwinding process, resulting in sudden separation of the spools and an almost instantaneous load drop. The sudden load release led to a very high shock output event, typically greater than 2000 g's, as shown in Fig. 9.

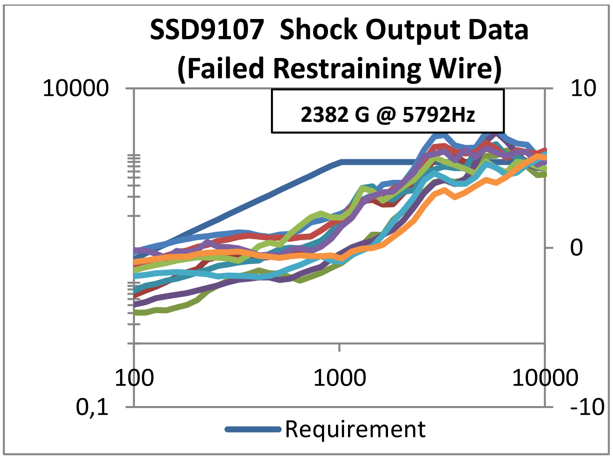

Figure 9 – SSD9107 Typical Shock Output Test Result When Restraining Wire Fails During Actuation

After several iterations, a combination of fuse wire diameter and restraining wire diameter was found that met all pertinent requirements for all-fire and no-fire characteristics, load capability, and shock output.

Shock output test results are shown in Fig. 10 below.

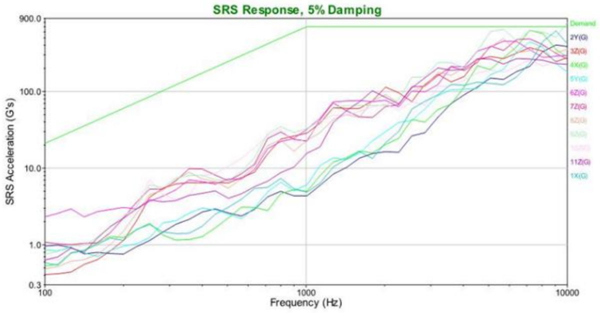

Figure 10 - SSD9107 Shock Output Test Data After Optimization of Fuse Wire & Restraining Wire Size

6 CONCLUSION

It's hard to believe that only roughly one year has passed since the James Webb Space Telescope was commissioned on 11 July, 2022 given the scientific accomplishments to-date, including observation of some of the most distant and oldest galaxies recorded.

EBAD successfully developed seven (7) different NEA® release mechanism configurations that were designed for use in 178 independent releases facilitating more than twenty (20) major system level deployments of the JWST.

The design campaign involved the development of new capabilities for heritage EBAD devices. It required management of many risks associated with the fact that each device represented a possible single point failure within the overall system. Teams were required to work together very closely across EBAD, the prime contractor, and NASA Marshall Space Flight Center (MSFC).

EBAD's NEA® non-explosive release mechanisms performed flawlessly from the initial deployment of the spacecraft's solar arrays, through the critical actuation of 107 mechanisms used during the telescope's sunshield deployment, and finally to the release of the secondary and primary mirror assemblies. EBAD worked closely with our NASA and industry customers to validate and qualify these mechanisms to extremely harsh environments to assure mission success of JWST.

In the end, the development and qualification of multiple NEA® release mechanism designs for the JWST program resulted in a completely successful launch and deployment of the JWST system which is now completely operational and expected to provide valuable scientific discoveries that will benefit the entire world!

Ensign-Bickford Aerospace & Defense Company (EBAD) is extremely proud to have been part of the JWST team and to have played a key role in the program with our NEA® release mechanisms.