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MSL PYROSHOCK DEVELOPMENT TEST PROGRAM FOR SHOCK MITIGATION

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Abstract

The Mars Science Laboratory (MSL) is a NASA rover scheduled to launch in December 2009 and perform a precision landing on Mars in October 2010. This rover will be three times as heavy and twice the width of the Mars Exploration Rovers (MERs) that landed in 2004.

The MSL Spacecraft makes extensive use of pyrotechnic devices to enable mission-critical separation and deployment events. Several of the devices employed generate high shock levels that are potentially damaging to shock-sensitive equipment on the spacecraft. Early on in the project, it became critical for mission success to characterize the shock-induced environments and minimize their impact on sensitive hardware. This paper describes the JPL development test program undertaken to investigate shock mitigation and isolation techniques, and ultimately to refine early pyroshock environmental estimates.

Testing consisted of live-firings of pyrotechnic devices, mainly 5/8" separation nuts, attached to various development test hardware. Multiple firings were performed of each test configuration to assess firing-to-firing repeatability. Candidate isolation techniques were screened using a simple 3 ft. by 3 ft. by .60 in. Aluminum square plate. The effectiveness of select isolation techniques were then verified on high-fidelity mockup hardware of the Rover top deck and instrument panel, and of a Descent Stage (DS) hex and outrigger panel. Isolation approaches at the box level and device level were explored. Through a combination of source mitigation and victim isolation, order-of-magnitude reductions of the shock levels were achieved at key locations.

As a result, critical telecommunications equipment with known susceptibility to shock levels as low as 500 G Shock Response Spectrum (SRS) did not need to be re-designed, and various other heritage hardware avoided having to be re-qualified to higher shock levels. By addressing pyroshock issues early on in the program, the MSL project avoided unnecessary rework of hardware and attendant schedule delays.

1. INTRODUCTION

The Mars Science Laboratory is a NASA rover scheduled to launch in December 2009 and perform a precision landing on Mars in October 2010, Figure 1. This rover will be three times as heavy and twice the width of the Mars Exploration Rovers that landed in 2004. MSL will be a long-range, long-duration mobile lab. Its mission will be to continue the study of Martian geology from the surface. The lab will be delivered to Mars on the first of a new generation of smart landers. Instead of using airbags to cushion the spacecraft during landing, this next-generation lander will use precision landing and hazard avoidance to touch down on promising but difficult-to-reach sites of scientific interest.

The MSL spacecraft makes extensive use of pyrotechnic devices to enable mission-critical separation and deployment events. A wide assortment of pyro devices are used including separation nuts, pin pullers, pyrovalves, cutters and clamp bands. Several of the devices employed generate high magnitude, high frequency shock that can damage nearby shock-sensitive equipment. Early on in the project, it became critical for mission success to characterize the shock-induced environments and minimize their impact on sensitive hardware. One of the equipment items found to be most sensitive to pyroshock is the telecom Traveling Wave Tube (TWT) used in the critical descent phase. This paper describes the JPL development test program undertaken to investigate shock mitigation and isolation techniques, and ultimately to refine early pyroshock environmental estimates.

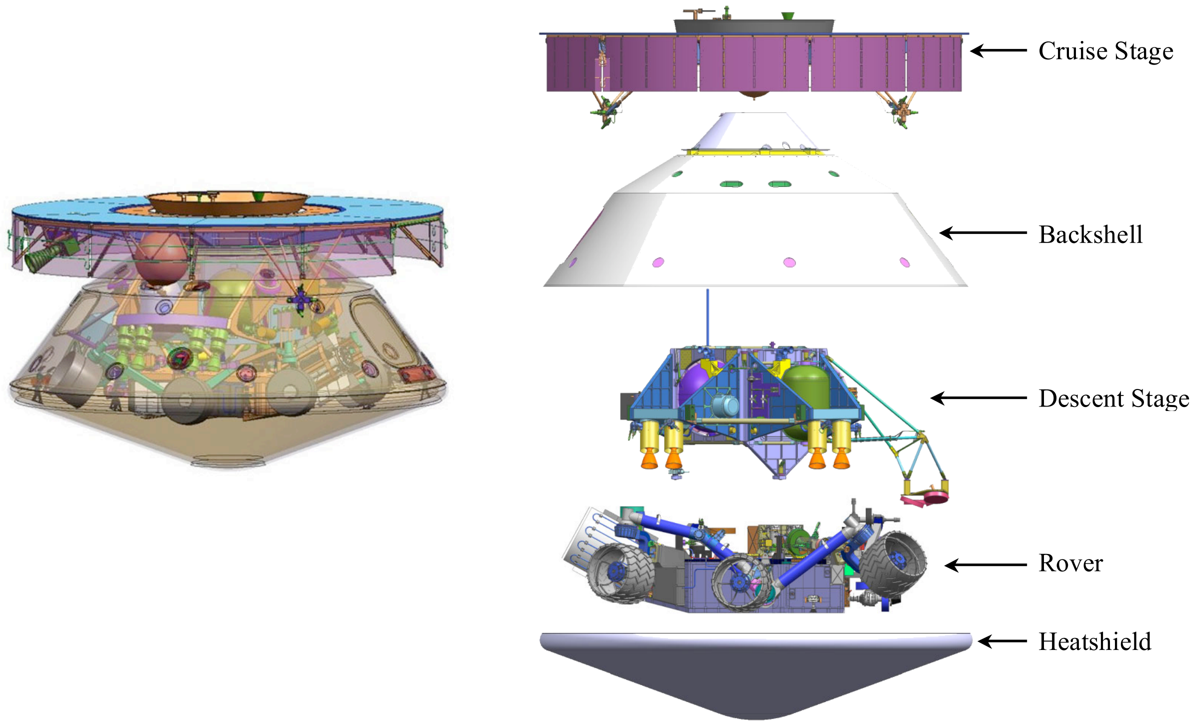

Figure 1. Mars Science Laboratory

2. PYROSHOCK MITIGATION SCREENING TESTS

Pyroshock mitigation at the box and device level was first evaluated using a simplified test setup. The primary objective was to screen out candidate shock mitigation approaches and select a subset for continued development testing on higher fidelity MSL mockup hardware. All pyroshock development testing was conducted at JPL's Environmental Test Laboratory.

2.1 Test Setup

The test configuration consisted of a simple 3 ft. by 3 ft. by .60 in. Aluminum square plate, henceforth referred to as the base plate, and a second smaller plate attached to the base plate via four elastomeric shock mounts. The smaller plate with an attached weight represented a gross mockup of the MSL telecom plate. The base plate was suspended by four steel cables attached at each corner as shown in Figure 2.

Among the various MSL pyrotechnic devices, the 5/8" separation nuts, or sep nuts, were identified as generating the highest shock loads and therefore became the focus of early testing. A hole was drilled through the base plate for attaching the 5/8" sep nut, which was located slightly off-center about a foot from one edge of the plate. The custom made 5/8" steel bolts used with the sep nuts had internal built-in strain gages that allowed for direct measurement of the applied preload. In all cases, save for one, the sep nut bolt was tightened to a nominal preload of 32,000 lb.

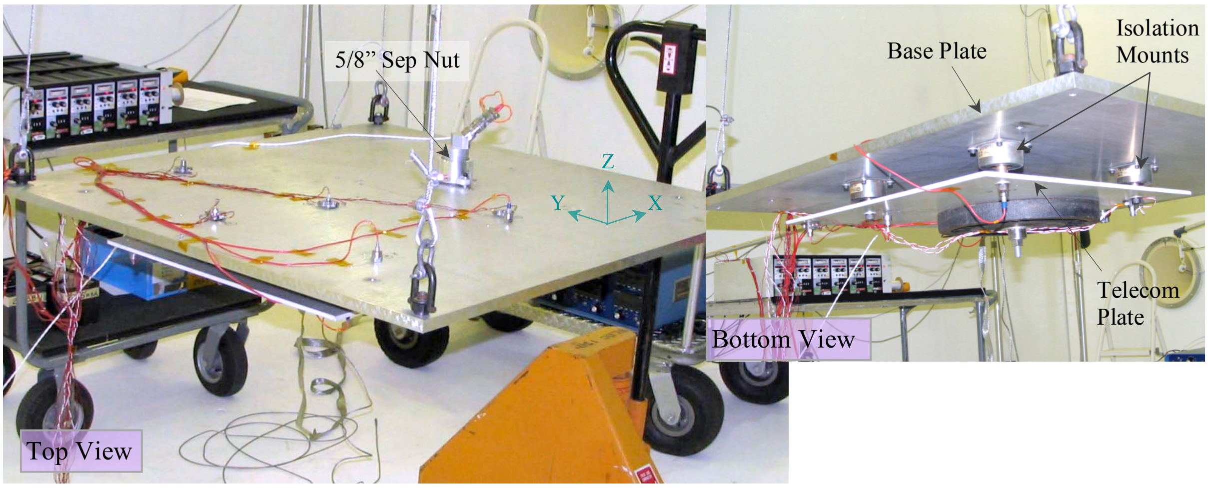

Figure 2. Setup of Simple Screening Test Plate

2.1.1 Source Mitigation Approach

Mitigation of the source shock involved the concept of using a "Floating" sep nut as illustrated in Figure 3. When released the sep nut body is free to slide up and down within a modified flange having an extended cylinder. Various mechanisms were incorporated into the "Floating" sep nut assembly to evaluate their pyroshock mitigation performance during sep nut release, mainly: wave washers, rubber washers, crushable honeycomb ring and Met-L-Flex bushings. Figure 3 shows the "Fixed" versus two "Floating" sep nut configurations.

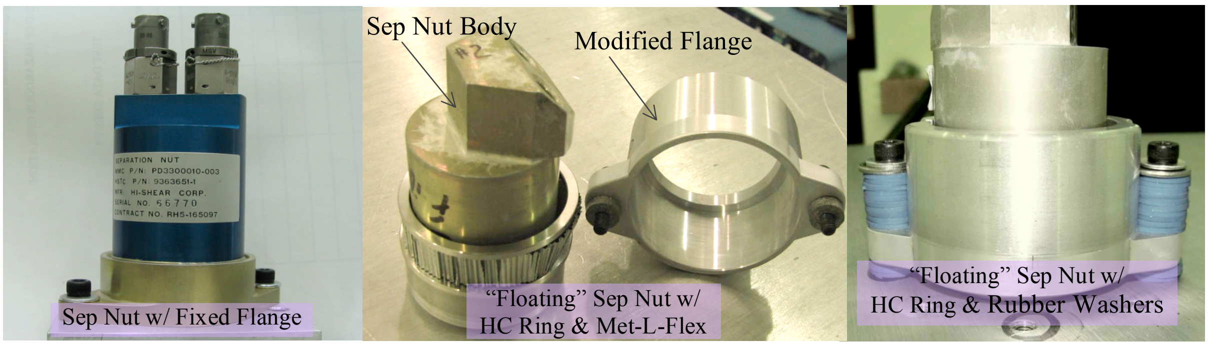

Figure 3. "Fixed" versus "Floating" Sep Nut Configurations

2.1.2 Equipment Isolation Approach

The approach for shock isolation of sensitive equipment involved the use of isolation mounts. Specifically, the telecom plate was targeted for the use of isolation mounts to help protect the shock-sensitive TWT component. Following their successful implementation on the MER mission, standard off-the-shelf elastomeric shock mounts from Barry Controls were selected for evaluation. While the mounts previously had provided excellent shock isolation on MER, their application to MSL required characterizing their performance while supporting a mass six times that of MER (2.5 vs 16 kg). A stiffer mount than that used on MER was selected to support the heavier MSL telecom payload and to avoid coupling with significant spacecraft modes. The fundamental frequency of the telecom plate on mounts is about 50 Hz.

2.1.3 Data Acquisition and Processing

Multiple shock accelerometers were stud-mounted to the test unit to measure shock levels in three axes. ETL's Piranha data acquisition system was used to record all acceleration time history data. The system recorded data continuously during all firings and used a sampling rate of 100 kHz to provide a minimum of 10 kHz frequency resolution of the data.

Time history data was reduced in terms of the Shock Response Spectrum (SRS). All channels were reviewed to flag accelerometers exhibiting anomalies such as a zero-shift or DC offset. Those channels that could not be corrected were excluded from further evaluation.

2.2 Test Results

Two test series were completed covering a total of nineteen 5/8" sep nut firings. Two firings were completed for each test configuration to evaluate firing-to-firing repeatability. Sep nut assemblies were inspected after every firing and parts were replaced or refurbished as needed.

2.2.1 Device Mitigation

The sep nut configuration with fixed flange and no isolation, i.e. "Fixed," generated the highest shock levels and became the baseline against which the relative efficacy of the various mitigation approaches was judged. SRS acceleration response data from a "Fixed" sep nut firing are plotted in Figure 4. A plateau of 4,000 g SRS reasonably bounds the shock responses at frequencies above 1,500 Hz.

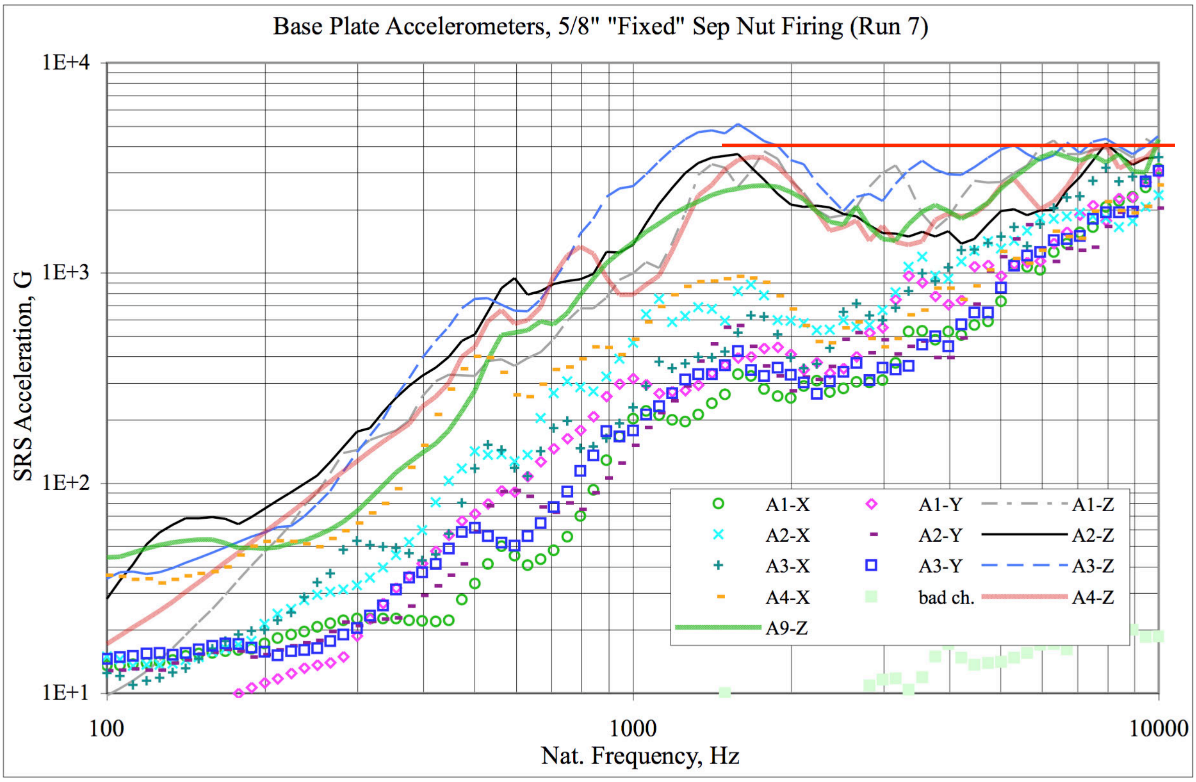

Figure 4. SRS Data for "Fixed" Sep Nut Firing on Simple Plate

Clear differences are seen in the characteristics of the in-plane (XY) responses compared to the normal responses (Z). Acceleration responses measured normal to the plate are noticeably higher with a distinct “knee” at 1,500 Hz, whereas the in-plane responses rise at a near constant slope past 10,000 Hz. Subsequent comparisons are made using only Z-axis measurements as they bound the bulk of the data over the frequency range of interest.

A summary plot of Z-axis shock response data from all test firings is shown in Figure 5. The performance of the various mitigation approaches can be compared relative to the “Fixed” sep nut configuration, which provides a baseline for shock loads with no mitigation applied. Surprisingly, the sep nut configurations with HC ring (S1 R3-4) and wave washers (S1 R5-6) actually amplified the shock levels over the baseline at a frequency of 1,800 Hz.

Overall, a factor of two reduction of the shock levels was obtained for most configurations, but the best performing was the sep nut with tall rubber stack and HC ring (S2 R5-6). However, the Met-L-Flex offered installation and performance advantages for space flight applications over the rubber washers and thus was selected in combination with the crushable HC ring for further evaluation on higher fidelity MSL mockup hardware.

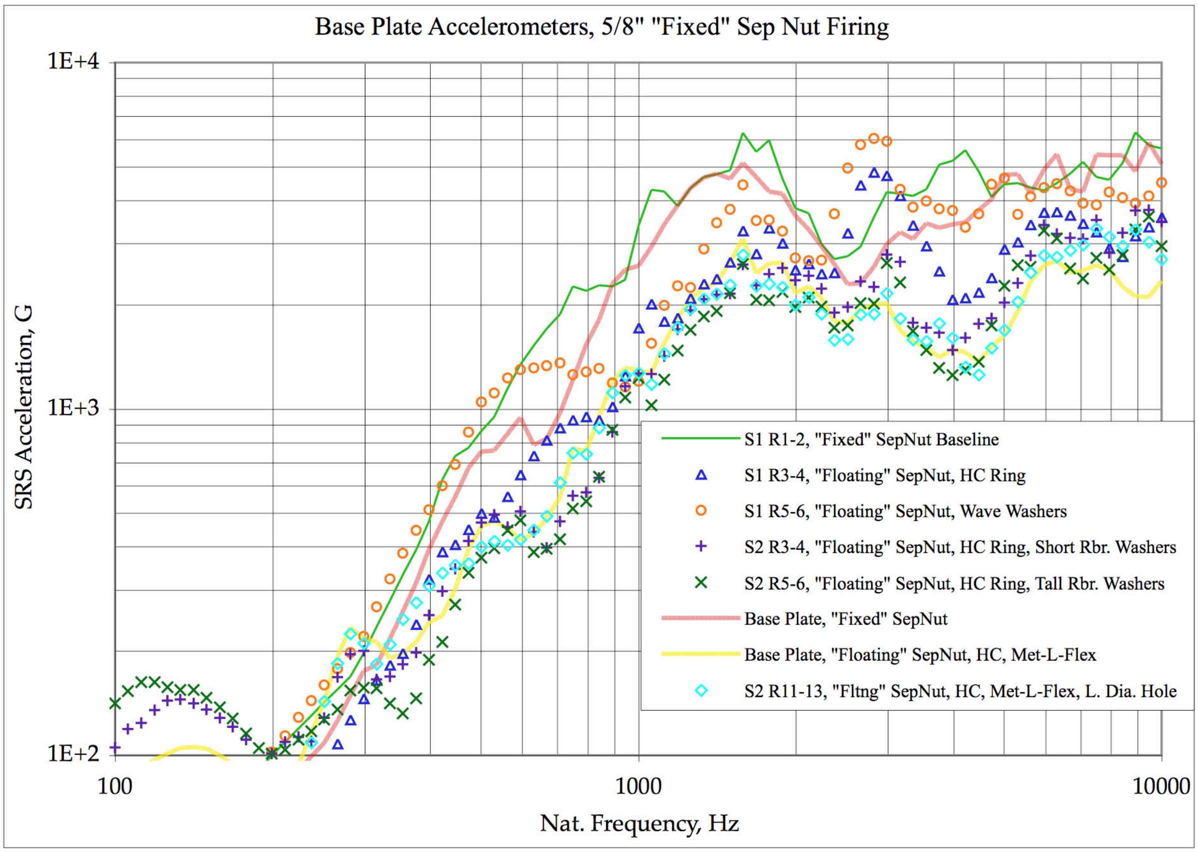

Figure 5. SRS Data Envelopes for Multiple Sep Nut Configurations on Simple Plate

2.2.2 Component Isolation

The shock isolation effectiveness of the elastomeric mounts was gauged by comparing accelerometers located on the base plate with those on the telecom plate mockup. Response envelopes of the base plate and telecom plate are shown in Figure 6 for a “Fixed” versus a “Floating” sep nut firing. Significant shock attenuation occurred at frequencies above 900 Hz, but little if any at lower frequencies. The shock attenuation performance of the shock mounts is clearly superior to that of the “Floating” sep nut.

A target flight level of 400 g SRS was set for the telecom plate due to known pyroshock susceptibility of the TWT to levels as low as 500 G SRS. The isolation mounts alone were not sufficient to achieve the target, but a combination of source mitigation and victim isolation resulted in roughly a factor of ten (10) reduction of the shock levels, which brought the levels at the TWT down to about 400 G SRS, Figure 6.

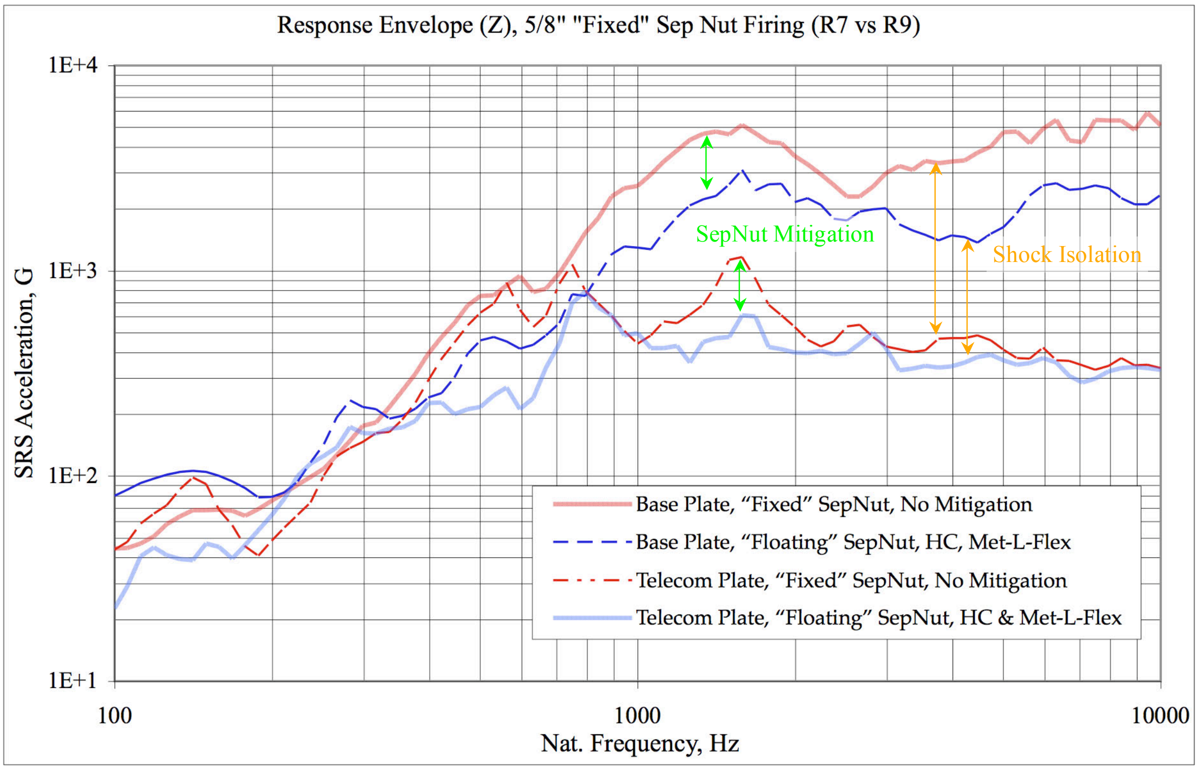

Figure 6. Shock Attenuation at Telecom Plate

3. DESCENT STAGE MOCKUP DEVELOPMENT TESTS

Pyroshock development testing was completed on high fidelity mockup sections of the Rover and Descent Stage susbsystems. Results are presented herein only for pyroshock testing of the DS Hex Panel and Outrigger Panel Assembly. Primary test objectives were to verify the effectiveness of shock mitigation techniques and to gather shock data to help refine pyroshock environmental estimates for DS mounted hardware.

The shock induced from cruise stage, descent stage and rover separation events were simulated. Multiple firings of the 5/8" sep nuts were conducted to characterize the shock propagation across the hex and outrigger panel and to the telecom and avionics plate. A total of sixteen (16) firings were completed with bolt preloads ranging from 20,000 lb to 33,255 lb. The "Floating" sep nut with HC ring plus Met-L-Flex bushings was used for all firings.

3.1 Test Setup

Figure 7 depicts one of three DS test configurations. One hex panel and one outrigger panel were assembled along with various mass models to simulate a portion of the descent stage. The first configuration incorporated the telecom plate simulator, shock mounts, and seven telecom mass models, the second included the avionics plate simulator and various mass models, and the third was a combination of the first and second. All tests included a bar mounted to the top of the hex panel to simulate the Backshell Interface Plate (BIP) local interface and to provide the structure with a more flight-like stiffness.

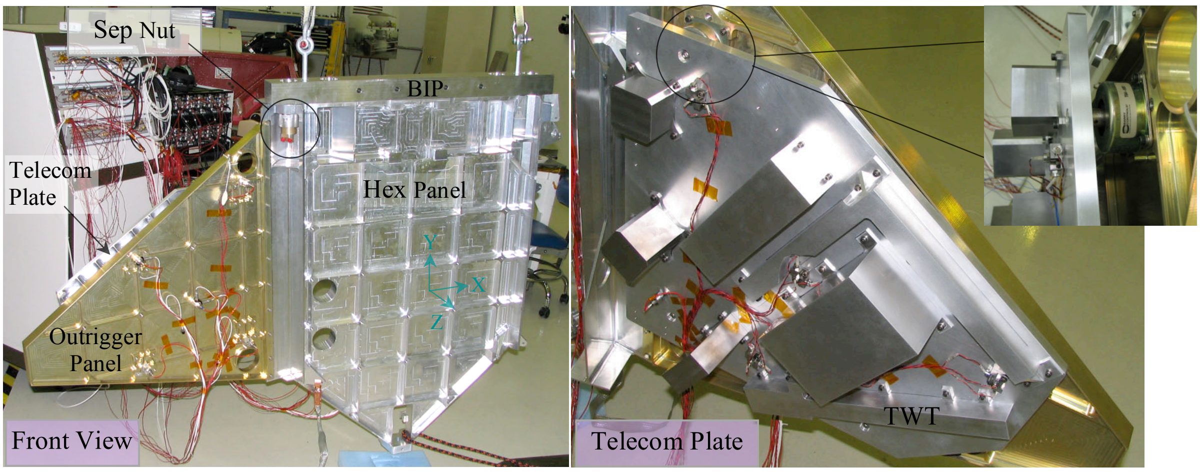

Figure 7. Descent Stage Hex and Outrigger Panel Assembly, Telecom Test Configuration

3.2 Test Results

Baseline shock response levels for the “Fixed” sep nut with no mitigation are shown in Figure 8. The data distinctly shows the dominance of the in-plane (XY) responses in sharp contrast to the test results using the simple plate, which is attributed to the differences in the sep nut mounting configuration between the two tests. For the simple plate test the sep nut was mounted normal (Z) to the plate whereas it was mounted in-plane (Y) for the hex panel test.

Implementation of the “Floating” sep nut to mitigate the shock levels resulted in a two-fold reduction of the shock levels over the baseline thereby providing verification of the earlier results on the simple test plate. Likewise, the levels at the critical TWT were marginally over the target 400 G SRS confirming close to an order of magnitude reduction of the source levels with both shock source mitigation and victim isolation mechanisms in place, Figure 9.

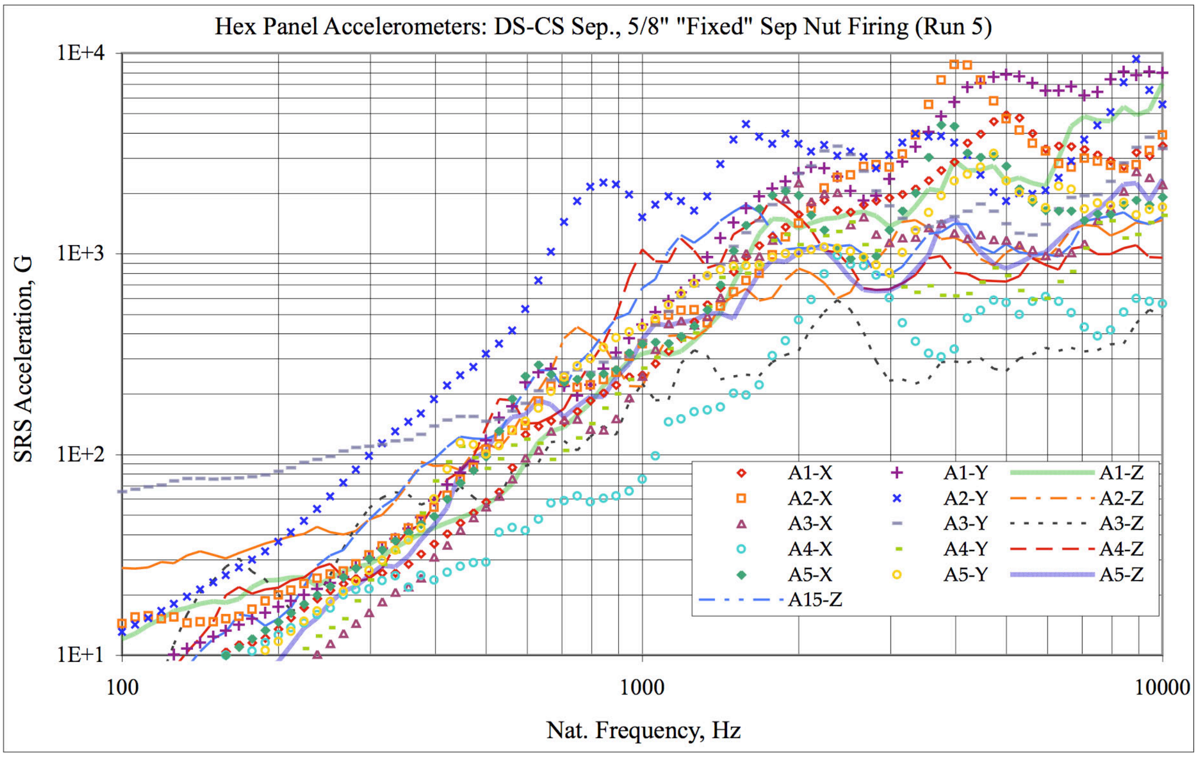

Figure 8. SRS Data for “Fixed” Sep Nut Firing on DS Hex Panel

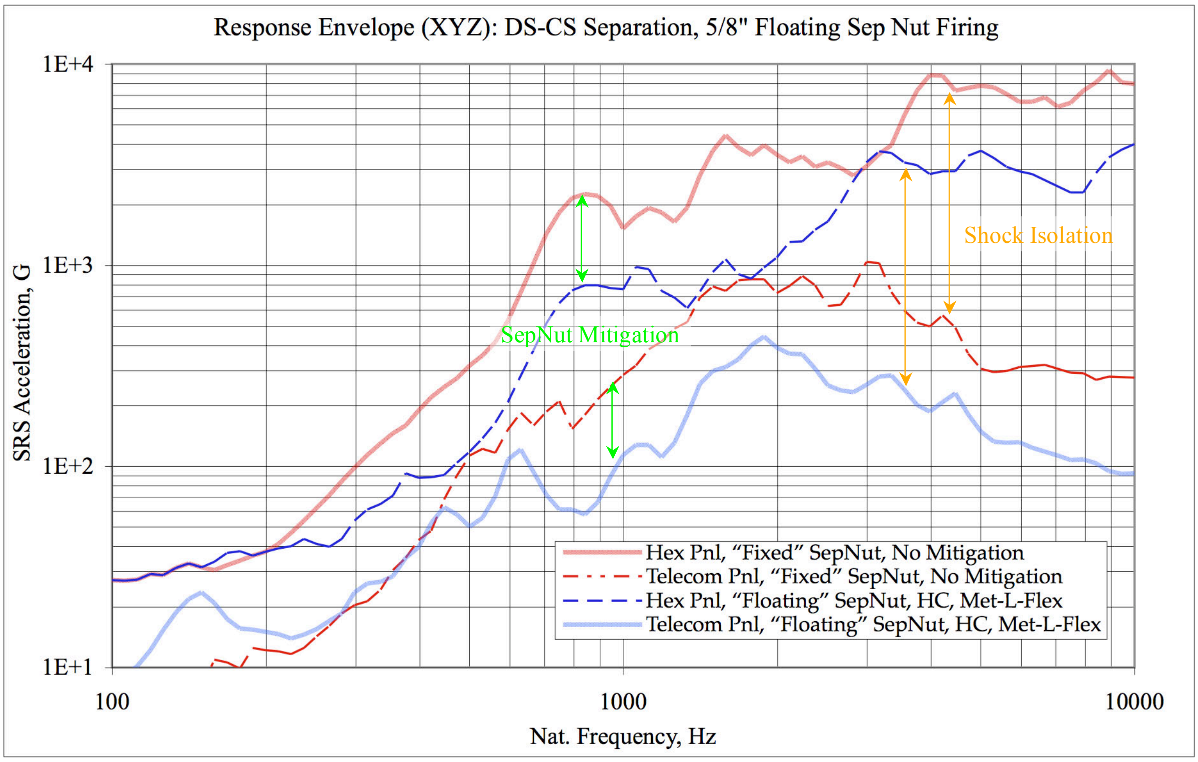

Figure 9. DS Telecom Configuration, Shock Attenuation at Telecom Plate

5. SUMMARY

Candidate shock mitigation/isolation techniques were screened using a simple test plate. The most promising approaches were selected and their effectiveness verified on high-fidelity mockup hardware of sections of the Rover and DS subsystems. Through a combination of source mitigation and victim isolation techniques, order-of-magnitude reductions of the shock levels were achieved at key locations, mainly the telecom plate.

As a result, critical telecommunications equipment with known susceptibility to shock levels as low as 500 G Shock Response Spectrum (SRS) did not need to be re-designed, and re-qualification of various other heritage hardware to higher shock levels was avoided. By addressing pyroshock issues early on in the program, the MSL project avoided unnecessary rework of hardware and attendant schedule delays.

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