# DEVELOPMENT OF A DUAL RELEASED LANYARD CONNECTOR FOR SPACE APPLICATIONS

**Brandon Hill**

*Eaton, 750 W. Ventura Boulevard, Camarillo, CA 93010, USA, brandonhill@eaton.com*

## ABSTRACT

Lanyard released connectors are used in military and space for electrical separation during payload release and stage separations. The problem with standard, military specified lanyard connectors is the high number of single point failures within the mechanism. For increased reliability and redundancy, a Dual Released Lanyard (DRL) Connector was designed and developed to support the extreme requirements of manned spaceflight vehicles. The most critical of these environments are the high vibration and mechanical shock levels. The challenge around designing a redundantly released lanyard connector, while maintaining low separation forces, is balancing the mass and latching force to the in-axis vibration and shock environments. Out of balanced connectors cause premature separation or high separation force failure modes. This paper describes the unique design constraints of a redundant lanyard connector, development test results, and lessons learned for the Dual Released Lanyard Connector.

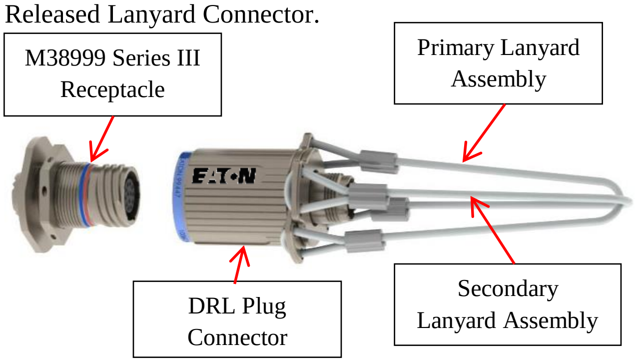


*Figure 1 Dual Released Lanyard Mated Connector Set*

## INTRODUCTION

Lanyard connectors are the primary means of electrical connect and disconnect in harsh environments due to the quality and reliability that MIL-DTL-38999/31 provides. These connectors are threaded on and pulled off at low release forces via segmented threads as shown in Fig. 2.

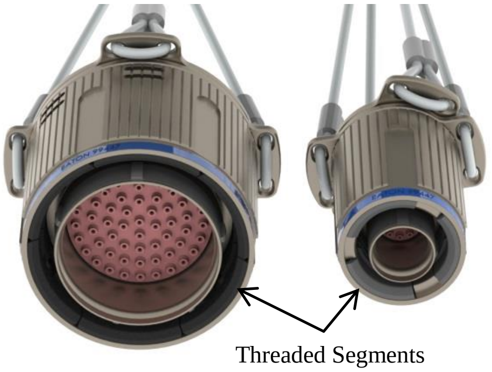


*Figure 2 Threaded Segment Design of size 25 and 11 Dual Release Lanyard Connector Plugs*

The primary concern, specifically for space applications, is that the connector is riddled with single point failure modes that may result in the connector not separating. A failure in the lanyard, one of the lanyard swages, the lanyard ring or the lanyard retaining ring will cause the connector to fail to separate. Each of these failure modes is non-redundant and completely eliminates the entire usefulness of the connector. It is difficult for systems engineers to propose a connector design that does not meet their zero fault tolerance design criteria, especially for manned space flight missions. Human-rating requires "[t]he space system [to] provide failure tolerance to catastrophic events, with specific levels of failure tolerance and implementation" [1]. The DRL connector design has been deemed to meet the human-rating requirements for manned space flight.

The Dual Released Lanyard (DRL) connector eliminates all of the single point failures of the M38999/29 style connector and replaces them with a "loss of redundancy" failure mode. This is demonstrated by Fig. 3. The DRL establishes a redundant load path through the entire connector until it reaches the connector threaded interface. A detailed description of the function of a dual lanyard connector may be found in *US Patent 9,481,461* [2].

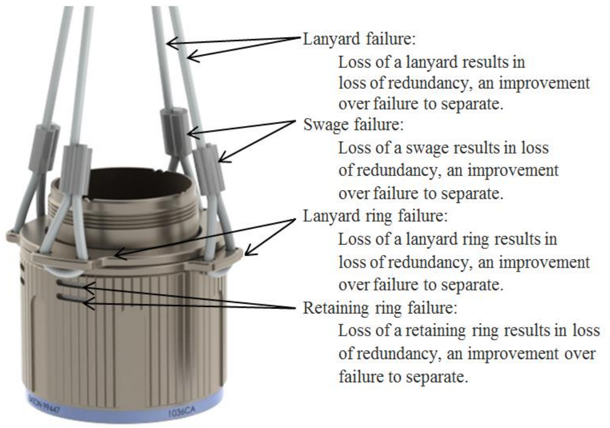


*Figure 3 Redundancy Features of the DRL*

In addition to providing redundant load paths, lanyard released connectors for space applications are required to handle significantly higher vibration and shock load cases compared to what is traditionally required for M38999 lanyard connectors. Human-rated space vehicles include launch abort fail safes which propel the payload away from the launch vehicle if a launch failure occurs [1]. The DRL connectors are expected to survive and function throughout environments that are +6db higher than M38999 vibration environments. This becomes increasingly difficult when trying to maintain low forces during separation and not exceeding the envelope of a Type 1 M38999/31 lanyard connector.

## Environments

DRL connectors are used throughout all separation stages of a launch vehicle and payload. The most extreme of these separation stages in terms of vibration load case is the launch abort system. Launch vehicles seeking human-rated certification are required to "provide abort capability from the launch pad until Earth-orbit insertion" [1]. For separation connectors located near the launch abort engines, the loads can be intense.

The DRL's will be qualified to the vibration profiles shown in Fig. 4 and Fig. 5. These levels are representative of the vibration levels of a Launch Abort Failsafe System. The levels of particular concern for the DRL connectors are those in-line with the central axis of the connector (normal) as these are the loads that could potentially cause the connector to prematurely separate via the latching mechanism.

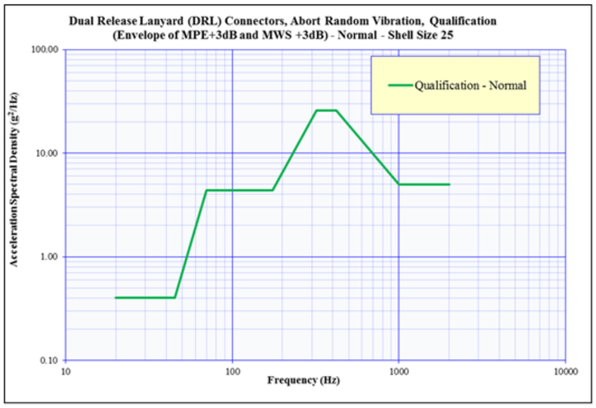


*Figure 4 Typical Launch Abort Vibration Environment (Normal)*

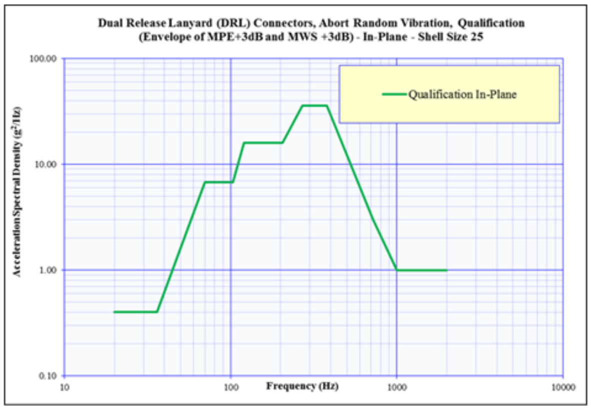


*Figure 5 Typical Launch Abort Vibration Environment (In-Plane)*

The DRL's will also be qualified to the SRS shock levels shown in Fig 6. To reduce program cost and schedule, a mechanical shock setup that enabled a high number of test iterations was developed to greatly reduced setup and configuration time in comparison to pyro shock testing.

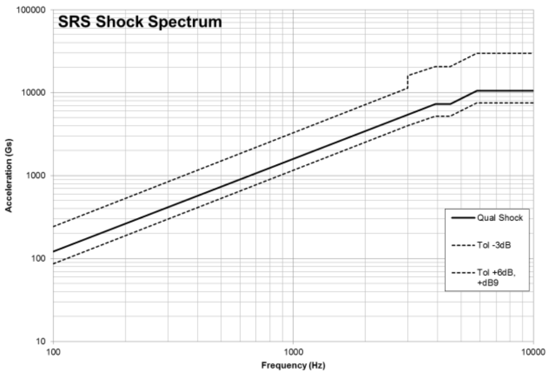


*Figure 6 SRS Shock Test Levels*

## DEVELOPMENT TESTING

Extensive development testing was performed on the DRL connectors to validate functionality and performance during launch abort vibration environments. Connectors were verified for workmanship through pre-flight testing (acceptance testing) to ensure that proper run-in was achieved for lubricated surfaces and springs prior to abort vibration testing. The connectors functioned as expected for all in-plane vibration profiles; however, they experienced a premature separation failure mode during the normal vibration profile and the normal shock profile.

### Vibration Test

The vibration was controlled via a .85mV/G shock accelerometer located on the vibration cube and a response was measured on the opposite side of the connector mounting plate using a triaxial accelerometer, shown in Fig. 6. The connector was monitored for electrical discontinuities greater than 1 µsec throughout testing. In order to ensure the vibration profile met the test tolerances, the profiles was ramped up to full levels in 3dB increments for five seconds, starting at -9dB. A total of five connectors were tested.

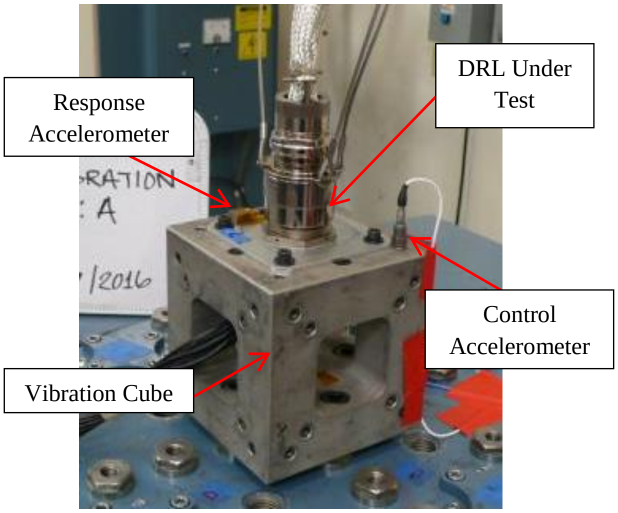


*Figure 7 Vibration Test Configuration*

During the ramp up to full vibration levels, at approximately -3dB, all five connectors electrically and mechanically separated, thus failing the vibration test.

### Vibration Root Cause Analysis

After complete disassembly of the connector and evaluation of the test set up, it was determined that there was no critical hardware failure (i.e. broken springs, broken components, etc.), and that the normal abort vibration case had taken the connector beyond its designed capabilities. During vibration, the mass of the connector components, in-line with the load path for connector separation, were being accelerated to a point that when the mechanical stops, held down by a latching spring, were impacted, the force generated exceeded that of the latching spring force. Overly simplifying this phenomenon meant that we were dealing with the force equation:

$$F = M \times A \quad (1)$$

To remove the premature separation failure mode, two variables could be adjusted: mass and latching force. Acceleration is dictated by the vibration profile.

A design change to increase the latching force of the connector was briefly evaluated, but ultimately was not pursued due to requirement constraints of the overall envelope of the connector and to the allowable force available in the system for functional separation. For those reasons, the only available design path was to reduce the mass of the critical components that are in the separation load path of the connector as shown in Fig. 7.

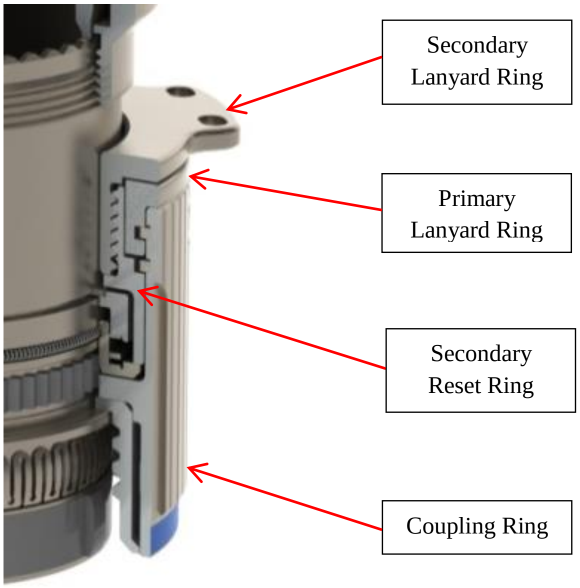


*Figure 8 Critical Component Load Path*

In order to confirm the design direction of removing weight from the critical components, one of the original development connectors was evaluated under a sine vibration sweep to anticipate resonance and what potential impact reducing weight would cause. To accomplish this, an accelerometer was mounted to the secondary lanyard ring to measure vibration response. The test control was located on the vibration cube as shown in Fig. 8. After testing the original design, a lower weight configuration was tested by removing the secondary lanyard ring and secondary reset ring. This effectively simulated a 20% reduction of mass in the critical components.

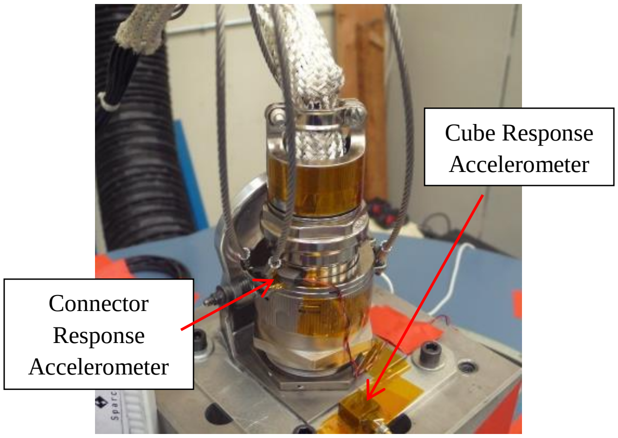
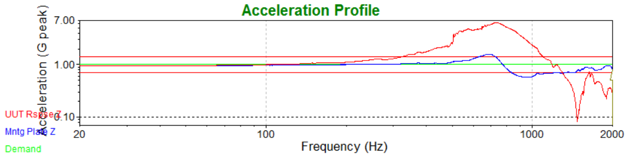


*Figure 9 Sine Sweep Test Configuration*

With a one g acceleration sweep, the original design showed a resonance at approximately 750 Hz with a magnitude of approximately 7 times that of the input. Under the same sine sweep conditions, the simulated light weight mass model still showed a resonance at approximately 750 Hz, but the magnitude of the resonance was only about 4 times that of the input. Fig. 9 shows the comparison between the original design and the simulated light weight mass model. At key frequencies, the resonance exhibited by the critical components was significantly reduced in the light weight mass model than that of the original design.

Original Design Response (Red)



Simulated Light Weigh Design Response (Red)

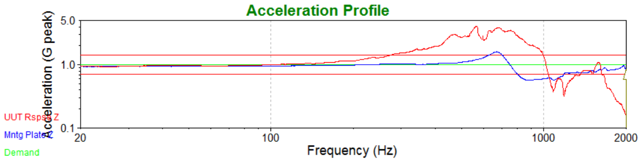


*Figure 10 Sine Sweep Results*

## CONNECTOR REDESIGN

To achieve a light weight connector design, three of the four critical components underwent significant redesign. The coupling ring was reduced in height by approximately 1/8” (3.175mm). The secondary lanyard ring was modified to have 3 full threads engaged to the secondary reset ring, instead of 6. The metal stops of the threaded interface between the secondary lanyard ring and secondary reset ring was also switched from bottoming on the bottom of the secondary lanyard ring to the top of the secondary lanyard ring. The secondary reset ring was effectively cut in half. The portion of the ring that originally interfaced with the latching components to reset the connector after separation was replaced with a snap ring. The secondary reset ring interfaces with the other components in the connector were also optimized for weight reduction. After all of these design changes, shown in Fig. 10, the total weight reduction achieved in the critical separation components was 28%.

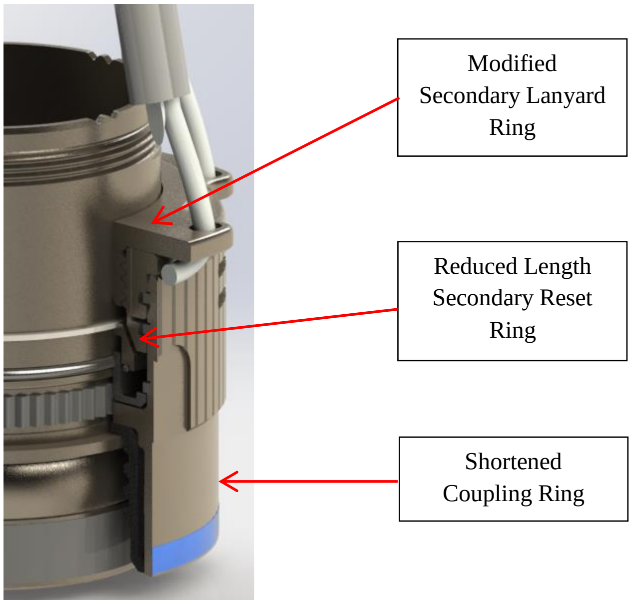


*Figure 11 Light Weight Design Modifications*

Achieving the weight reduction meant that the redesigned connector would have reduced acceleration resonance at 750 Hz frequency range. Effectively, the mass and acceleration of the connector had been significantly reduced. By maintaining the same latching force as was previously provided in the original connector design, high confidence was realized in meeting the connector requirements. This was validated by retesting five, newly prototyped, light weight, DRL connectors through the vibration environment. The redesign not only stayed electrically and mechanically connected through the duration of the test, but was able to attain a three times test duration without any degradation to the core functions of the connector. Overall Grms margin was not able to be tested due to shaker table capabilities.

### Shock Testing

The test setup for Shock Response Spectrum (SRS) shock testing included a suspended beam and a mechanical impactor to generate the shock profile. A representative test setup is shown in Fig. 11. Response accelerometers were placed directly onto the connector mounting plate. The connector was monitored for electrical discontinuities greater than 1 μsec throughout testing.

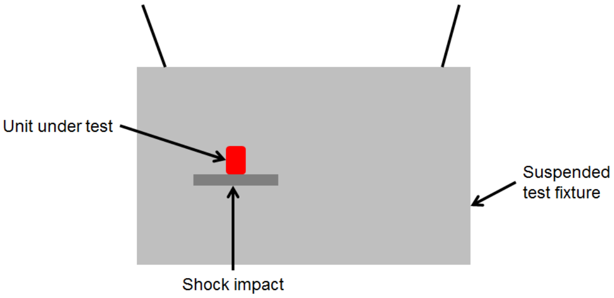


*Figure 12 Suspended SRS Shock Set Up*

The first attempt at performing the shock testing resulted in fairly nominal test conditions, as demonstrated by Fig. 12; however, the DRL exhibited both electrical and mechanical separation during the shock event through the axis of the connector. This failure mode was the same as what was witnessed during vibration testing.

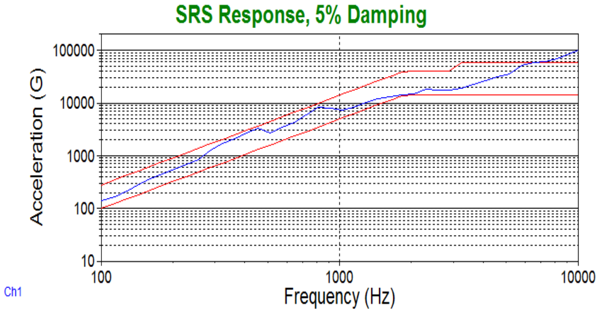


*Figure 13 Suspended SRS Shock Test Profile*

After evaluation of the test set up, the root cause of failure was deemed to be due to over-testing. Video evidence of the tests showed the entire test setup displacing in the direction of the impulse nearly one full inch. The additional velocity generated in the connector, as a result of the displacement, added significant impact loads against the latching mechanism via the components in-line with the functional separation load path. In normal flight conditions, the rigidity of the connector mounting structures do not allow for large displacements during shock environments. To better simulate flight environments, a new test stand was developed that was more representative of a resonance beam. Fig. 14 illustrates the modified test setup.

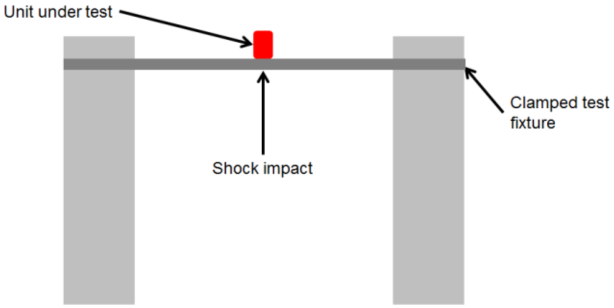


*Figure 14 Resonant Beam SRS Shock Set Up*

This setup was validated to meet the SRS shock profiles without introducing significant displacements (Fig. 14). There were peaks outside of allowable test tolerances at 1100 Hz, but with the connector passing at these levels, the test fixture was validated to be similar to flight conditions. Performing a retest of the DRL connector demonstrated the DRL was capable of meeting the SRS shock environments required for human-rated space flight with an additional margin of +3db above qualification requirements.

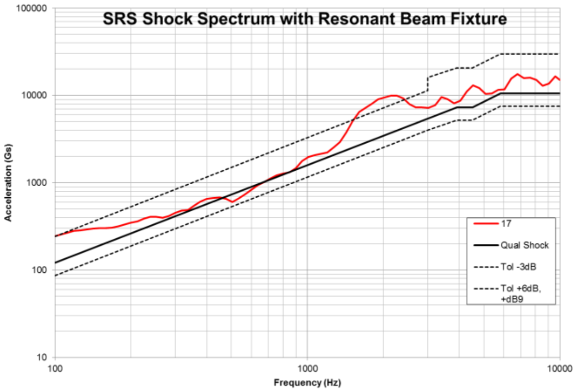


*Figure 15 Resonance Beam SRS Shock Profile*

## LESSONS LEARNED

Three significant lessons were learned from the development testing of the DRL connector systems:

1. Analytical models of the connector system under both vibration and shock environments were pursued as early risk mitigation plans. Both sets of finite element modeling and LS-Dyna predictions proved to not accurately simulate actual conditions. The first component that was extremely difficult to simulate was the latching spring force of the connector. Attempting to accurately model the characteristics of a canted coil latching spring proved futile and it was less of a cost and schedule impact to just perform actual testing. The other difficulty of modeling the connector system is anticipating the interactions of non-rigid bodies. The LS-Dyna analysis came close to accurately representing this, but ultimately could not predict the actual interactions of non-coupled components within the connector.
2. Elegant solutions can be acquired in the face of extreme requirements. The general approach to most of our test failures, especially during mechanical environments, is to beef up the structures or springs to ensure that it passes. In this particular case, removing mass provided a connector that met all requirements, as well as providing the added bonus of reduced weight for weight critical launch vehicles.
3. Test stand proofing is incredibly important in verifying new products or requirements. As it is difficult to directly mount accelerometers onto a small, circular connector, it was incredibly important to fully understand what the acceleration input into the connector was. In addition to ensuring the right profiles were being tested to, it was important to evaluate the characteristics of the test setup that are not represented in the recorded acceleration levels. This includes fixture stiffness and rigidity. The initial SRS shock testing showed all acceleration levels within the allowable test tolerances and yet it still over tested the parts due to the high displacement that was present. Fixture evaluations should be done using mass models; otherwise, one may expunge multiple units just trying to achieve a good test setup.

## CONCLUSION

Utilizing the light weight design, the DRL connector out performs the maximum predicted environments of the most extreme systems of human-rated space flight vehicles; providing critical electrical signal while mated and low release forces when separation must occur. It fits within a smaller envelope than the M38999/31 Type 4 allowing a plug in replacement to single lanyard connectors. This connector also meets the requirements of fault tolerance for human rated spaceflight, a condition not met by standard lanyard connectors.

## REFERENCES

1. Office of Safety and Mission Assurance (2012). *Human-Rating Requirements for Space Systems,* NASA, USA, 28, 33.
2. Laughlin, P. (2015). *US Patent 9,481,461.* Thousand Oaks, CA.
3. DLA Land and Maritime (2017). *Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, or Breech Coupling), Environment Resistant with Crimp Removable Contacts or Hermetically Sealled with Fixed, Solderable Contacts, General Specification for,* Columbus, OH.