Development Testing and Subsequent Failure Investigation of a Spring Strut Mechanism

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Abstract

Commodities are transferred between the Multi-Purpose Crew Vehicle (MPCV) crew module (CM) and service module (SM) via an external umbilical that is driven apart with spring-loaded struts after the structural connection is severed. The spring struts must operate correctly for the modules to separate safely. There was no vibration testing of strut development units scoped in the MPCV Program Plan; therefore, any design problems discovered as a result of vibration testing would not have been found until the component qualification. The NASA Engineering and Safety Center (NESC) and Lockheed Martin (LM) performed random vibration testing on a single spring strut development unit to assess its ability to withstand qualification level random vibration environments. Failure of the strut while exposed to random vibration resulted in a follow-on failure investigation, design changes, and additional development tests. This paper focuses on the results of the failure investigations including identified lessons learned and best practices to aid in future design iterations of the spring strut and to help other mechanism developers avoid similar pitfalls.

Executive Summary

Functional and random vibration tests were performed on three separate occasions during the development of the CM-SM umbilical spring strut. Initial testing of the Lockheed Martin (LM) designed hardware was performed in partnership with the NASA Engineering and Safety Center (NESC). After a pre-vibration functional test, anomalies were observed in the first two random vibration test orientations that involved loosening and tightening of one of the strut rod ends. The final test configuration, with transverse loads applied by a dual-shaker configuration to both rod ends (shown in Figure 1), resulted in a rotation of one rod end, the forward lug, relative to its adjoining element, the secondary piston. Due to the rotation, the tooling holes in the secondary piston, nominally in the neutral bending axis, were subjected to maximum bending resulting in fatigue failure. Given the nature of the failure, a post-vibration functional test was able to be conducted and helped assess deployment force margin changes due to observed wear as shown in Figure 2.

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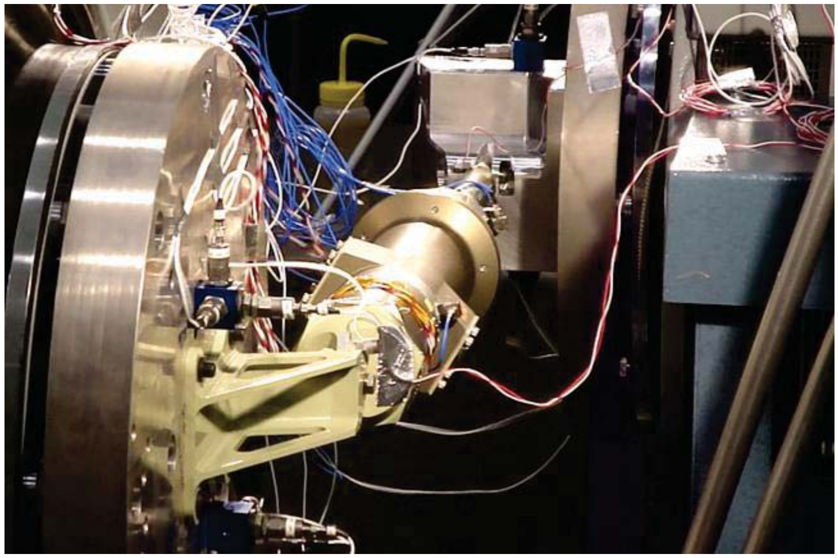

Figure 1. Y-axis Random Vibration Test Setup

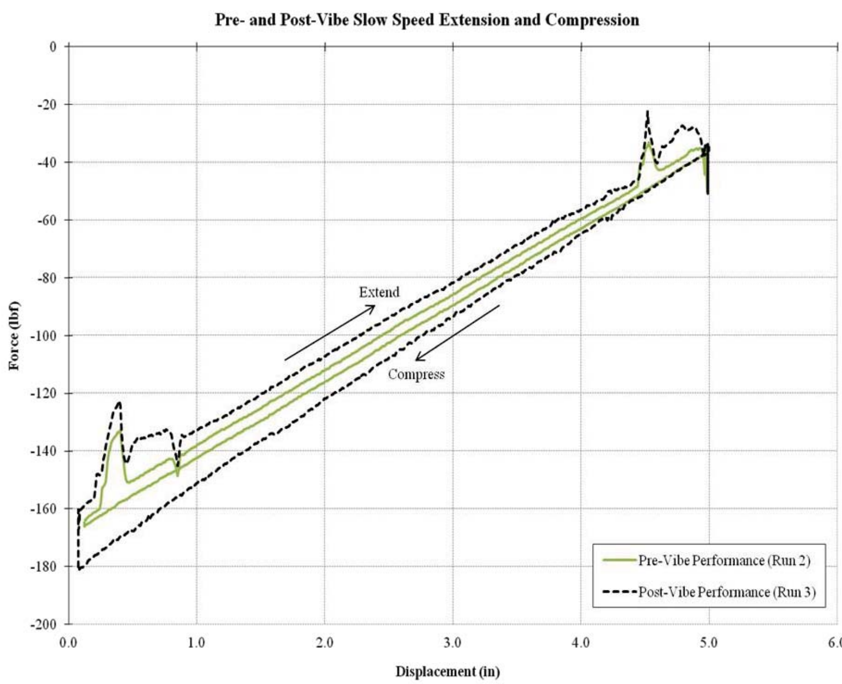

Figure 2. Force vs. Displacement Plot for Low-Speed Extension

A joint NESC and LM root cause investigation was performed immediately following the failure of the secondary piston. LM addressed the proximate cause of inadequate joint torque resistive capability at the forward lug-to-secondary piston threaded interface and minimized schedule impacts by maximizing the reuse of the hardware used in the initial development test in an additional vibration test. The additional development tests were conducted by LM with design changes implemented whereupon additional failures were observed related to accumulated fatigue, which was subsequently addressed.

The NESC meanwhile continued the root cause investigation specifically looking to address why the secondary piston rotated and identified a most probable failure scenario from a combination of significant contributors including off-nominal contact constraints (as illustrated through observed wear on the forward lug shown in Figure 3), sensitivities introduced by the spring strut retention method, and C.G. offset from the spring strut centerline. Evidence supporting this assessment was collected from inspection data, analyses, videography, literature research, and vendor documentation.

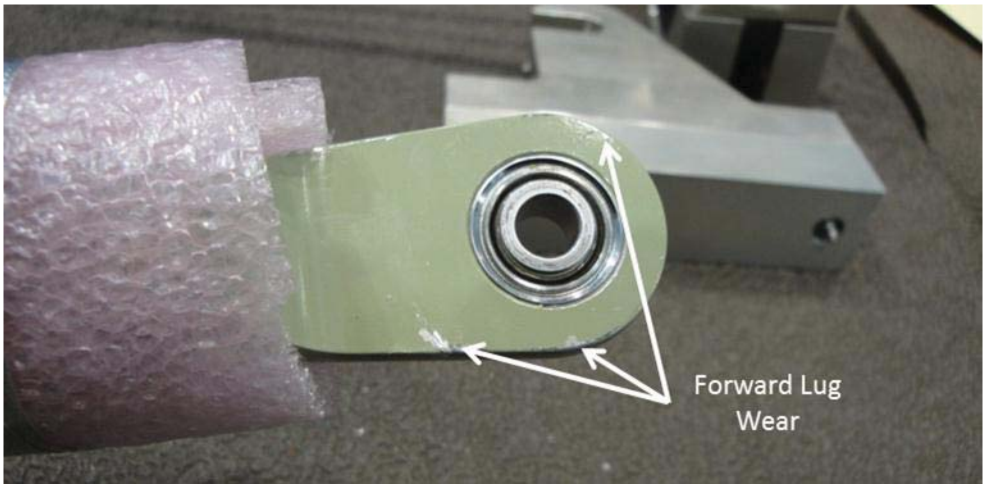

Figure 3. Forward Lug Wear Post-Vibration Testing

The strut, with correct actions employed, has since successfully completed qualification and acceptance vibration testing with no failures or anomalies and is slated to fly on the Exploration Flight Test-1 (EFT-1) in September, 2014.

Results from this unpublished assessment identify key lessons learned and best practices for in-line spring struts and mechanisms in general. These key takeaways focus on design as well as process concerns in areas of design, analysis, test, and workmanship. The valued added by the development test program will help satisfy the future needs of the MPCV through increased confidence in the mechanism’s reliability and ability to meet future programmatic constraints.