

44th AEROSPACE MECHANISMS SYMPOSIUM

ORION - Crew Module Side Hatch - Proof Pressure Test Anomaly Investigation

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Summary

The Orion Multi-Purpose Crew Vehicle program was performing a proof pressure test on an engineering development unit (EDU) of the Orion Crew Module Side Hatch (CMSH) assembly. The purpose of the proof test was to demonstrate structural capability, with margin, at 1.5 times the maximum design pressure, before integrating the CMSH to the Orion Crew Module structural test article for subsequent pressure testing. The pressure test was performed at lower pressures of 3 psig, 10 psig and 15.75 psig with no apparent abnormal behavior or leaking. During pressurization to proof pressure of 23.32 psig, a loud ‘pop’ was heard at ~21.3 psig. Upon review into the test cell, it was noted that the hatch had prematurely separated from the proof test fixture, thus immediately ending the test. The proof pressure test was expected to be a simple verification but has since evolved into a significant joint failure investigation from both Lockheed Martin and NASA.

Background

The Orion CMSH draws a significant amount of heritage from the Apollo Command Module Side Hatch. They share a similar trapezoidal shape, perimeter mechanical latches and twin double four-bar hinges.



Figure 1: Apollo Command Module Side Hatch – View Looking Out

Structure

Although the Orion CSMH shares the same trapezoidal structural shape as Apollo, the Orion CSMH is larger in size and a flat metallic structure whereas the Apollo CSMH was a curved composite structure. The design driver for Orion's departure of a curved shape was due to the severe Orion Crew Module cabin leak requirements. The gasket chosen at the time to meet the severe requirements was a Gask-0® seal, which in turn required a uniform sealing surface with tight tolerances that a flat surface was deemed simpler and cheaper to manufacture. As the Orion program evolved, cabin leak requirements relaxed such that the seal was later changed to a hollow silicone seal. That change allowed a latch loads reduction which then trickled down into additional mechanical hardware seeing loads relief. However, the structure was unable to be updated for optimization to the seal change due to engineering, material and manufacturing long lead times.

Mechanisms

The Orion CSMH shares a similar latching system as the Apollo CSMH. Orion's latches are larger in size, increase in quantity from 15 to 17 total, utilize fixed length linkages and employ higher precision rigging features on each latch. The Orion CSMH utilizes a series of 17 four-bar linkage latches, linked together thru a series of linkages and bell cranks and driven from a single ratchet-style gearbox. Rigging of the latches is performed at each latch base through an adjustable latch base mount that provides minute latch positional control to adjust latch location and latch preload. The Apollo CSMH rigging was performed by adjusting the length of the linkages between latches through the rotation clocking of a single rod-end bearing. Adjustments were limited to ½ thread pitch.

Each latch is designed as an over-center mechanism which, when driven past its toggle point, cause the latch to drive further over-center toward its individual hard stop. In the design of Apollo and Orion's CSMH, an internal pressure would apply an outward acting load on the CSMH. This would in turn load up on the rollers on each latch and, as long as the latches are rigged at a point beyond the toggle point, would force the latches towards their respective hard stops. All latches are driven by a single gearbox. The gearbox is designed to drive the latches open and closed and incorporates a latch restraint mechanism. The latch restraint, when engaged, locks out any induced latch movement that would drive the latches to the unlatched position.

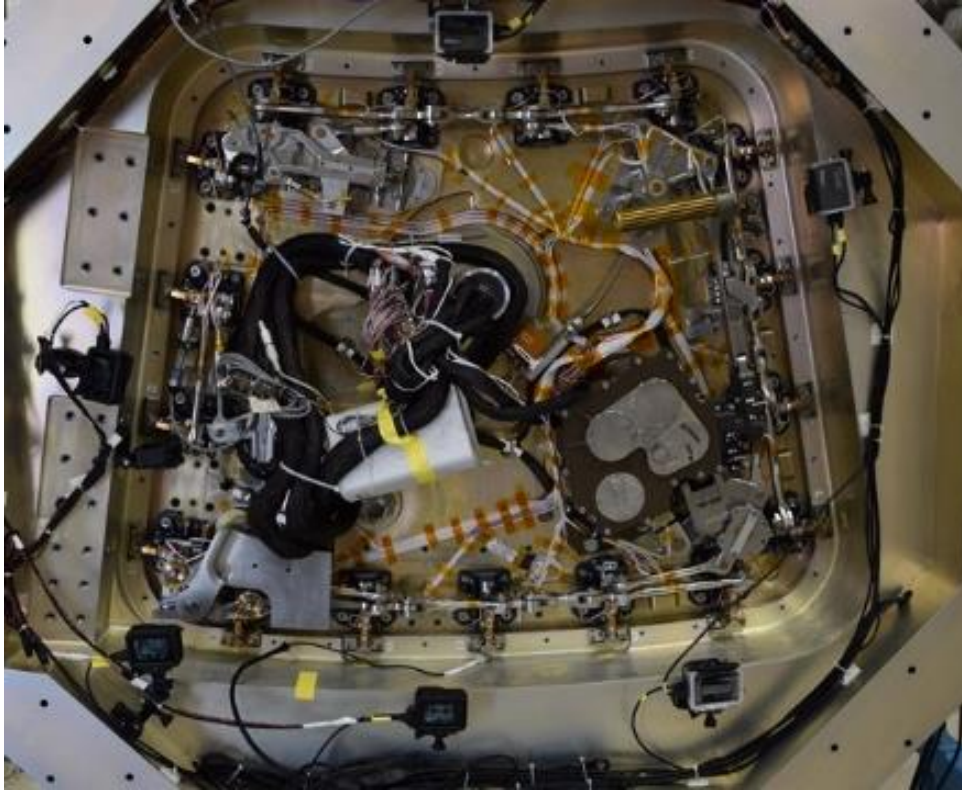


Figure 2: Orion Crew Module Side Hatch – View Looking Out

Testing

The purpose of the EDU was to perform risk reduction testing in support of NASA's Exploration Mission-1. Due to this test article being an EDU and experiencing an unexpected failure, the decision was made to perform additional testing to understand the cause of the anomaly and any influences or sensitivities to variables that were part of the anomaly. A subsequent series of eight (8) tests were performed in varying configurations, with a substantial increase in instrumentation, to study effects of the following:

- Latch restraint engagement vs. disengagement
- Latch rigging (latch distance from hard stop)
- Varying pressure to study non-linear effects
- Initial latch preload setting

In all of the tests where the gearbox latch restraint was disengaged, similar latch behavior occurred where the individual latches moved toward the toggle point. This result ruled out rigging and latch preload as a driving variable to the proof pressure test anomaly. In all of the tests where the gearbox latch restraint was engaged, individual latches moved toward their respective hard stops (away from their respective toggle point).

Analysis

The analysis performed up to the time of the test anomaly was not adequate to accurately model the complex interaction of the CMSH structure, mechanism and test fixture flexibility. A considerable effort

was initiated as a result of the test anomaly to understand the influences of the pressure load on the mechanism such that the hatch would instantaneously release.

The following simple diagram depicts how the CSMH structure deforming from an internal pressure load caused movement of the latches:

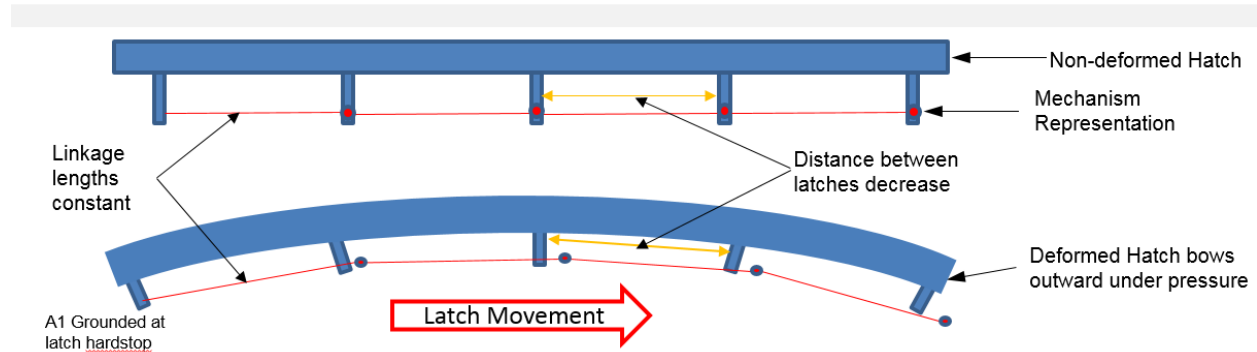


Figure 3: Diagram of Latch Motion with Internal Pressure Load Applied

Several approaches were made to address the analysis complexity: Finite Element Model (FEM) using MSC.NASTRAN and flexible body assessments use MSC.ADAMS. The MSC.ADAMS model used Computer Aided Design (CAD) models of the Orion CSMH, to generate a complete 17 latch kinematic assembly. Flexibility was added to key members that reacted high loads through the use of 1-D springs where stiffness's were analytically derived from the FEM. Latches were modeled using a bushing element at the roller contact region. Stiffness's for latches were derived through separate testing. Finally, the structure was modeled using FEM derived enforced displacements at each latch location. The FEM structural displacements has not been correlated to test data. However, using the this model setup and displacement inputs, the MSC.ADAMS model did indicate latch movement indicative of the latch movement that resulted in the proof pressure test anomaly as well as the instrumentation in the subsequent testing. The take-away was the indication of latch movement away from the hard stops when an internal pressure load was applied. Quantification of the latch movement is still being improved upon through increased modeling complexity and additional testing to correlate analysis predictions. One single major improvement to the model will be the incorporation of a fully flexible hatch structure and elimination of the enforced displacements with the dependence on a separate analysis for input.

Results

Ultimately the proof pressure test failure of the Orion CSMH was due to the following factors:

1. Excessive structural deflection
2. Gearbox latch restraint not engaged
3. Latch train motion not indicative of true over-center mechanism

The excessive CSMH structural deflections, although well understood on their own, were not well understood as a system. The structural deflections led to undesirable latch train movement. The hatch structure was well within its structural margins but the stiffness of the hatch was insufficient to prevent inducing mechanism movement in the CSMH latch drivetrain.

The gearbox latch restraint not being engaged was an unplanned event, though it's results led to realizing an unknown potential failure. This will in turn lead to a more robust design. The CMSH latch assembly is designed to be fault tolerant. In order to test each leg of the fault tolerance, they must be tested individually for full insight. This lack of restraint engagement gave us that insight. Testing with it engaged would have only masked the potential problem.

The insufficient hatch structural stiffness led to undesirable motion that was large enough to move all 17 latches toward their respective toggle points, with some going past their toggle points. The latch design is an over-center mechanism that did not behave as a true over-center mechanism where when an external load is applied to the mechanism, it would continue toward a safe position. In this case, the latch mechanisms were moving in the wrong direction for safe operation of the CMSH.

The test results and supporting analysis show how important it is to test every possible configuration to verify that the fault tolerance in a mechanism is working as intended. It also shows the importance of fully understanding the differences in how heritage flight hardware is used in a new environment.

The lessons learned during the investigation were as follows:

1. When using a heritage design, validate any assumptions made that change from a known successful hardware configuration. These changes will have an impact on hardware performance.
2. Often over-center mechanisms are considered fool-proof under static loading conditions. This anomaly provides an example of how mounting stiffness can defeat the over-center nature of a latch.
3. When testing, instrument the article so that in the unfortunate event of a test failure, the effort can "fail smart". This test was assumed to be a simple check and the original instrumentation did not provide nearly enough insight to be able to understand what happened.
4. Make sure critical configurations are verifiable. The latch restraint that did not fully engage could not be seen without difficult borescope inspections.
5. A kinematic model with structural flexibility is needed to fully verify adequate over-center linkage performance.