*Structural Integrity Series: Part 3*
*by G.E. Sanford and J.S. Welsh*

# EELV SECONDARY PAYLOAD ADAPTER (ESPA) STATIC QUALIFICATION TESTS, PART 3 OF 4

This is the third of four installments that details the process of flight qualifying the EELV Secondary Payload Adapter (ESPA). Developed by team members from the Air Force Research Lab/Space Vehicles Directorate (AFRL/VS), DoD Space Test Program (STP), TRW, and CSA Engineering, this adapter will take advantage of the primary payload's unused volume and mass margins. Included in this installment is a thorough description of the test objectives. Previous installments have detailed the determination of load factors, test hardware, and instrumentation.

## ESPA TEST OBJECTIVES

As detailed throughout this series of papers, an iterative process between FEA models and experimental validation is required to complete not only this, but almost any other structural qualification test. It would be exceedingly difficult to design the experimental qualification tests without the results generated from the previously run FEA models, but yet, the FEA predictions are not validated until after the successful completion of the qualification tests. Because of this delicate balance between numerical and experimental methods, with ultimate validation coming only from the experimental qualification test results, numerous safeguards were employed to ensure the validity of the experimental data generated during the qualification tests. These safeguards will be described in following sections.

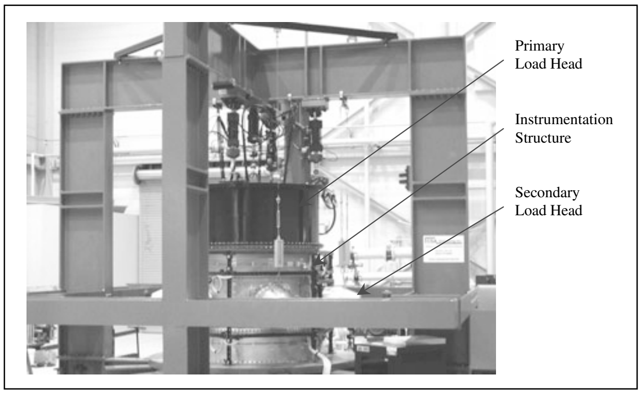


**Fig. 1: Photograph of the ESPA test article integrated into the reaction structure**

The specific objectives set for the qualification test of the ESPA were as follows. The structural integrity of the ESPA must not be compromised while subjected to any of the qualification loads (125% of the anticipated flight loads). Another objective of the test was to collect sufficient stiffness and strain data to correlate the finite element models to actual experimental data. These models will be used extensively for mission-specific strength, dynamic, and guidance control simulations.

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While the stiffness of the ESPA could have been measured during the multi-directional loading scenarios, it is generally much easier to avoid this unnecessary complexity. For this reason, many simple unidirectional load conditions were applied to the ESPA prior to the qualification loading. Based on the acquired load and deflection data acquired during these tests, the stiffness of the ESPA was accurately determined.

### Reaction Structure

Typically, a static load test consists of placing the test article into a large reaction structure capable of reacting loads applied to the test article by a series of hydraulic actuators. The reaction structure specifically fabricated for the ESPA qualification tests is shown in Fig. 1. Ideally, the reaction structure would be infinitely rigid compared to the test article such that it did not deflect during the application of the qualification loads. Since this scenario is not obtainable, and quantifying the exact deformation of the reaction structure would require additional analysis and experimental instrumentation, it is critical that the test article and instrumentation be rigidly secured to the same physical location. This prevents any distortion of the reaction structure from altering the experimental data. This was achieved in the current test by bolting the ESPA test article and the instrumentation structure to the same base plate, as shown in Fig. 1.

Also shown in Fig. 1 are six bolted aluminum adapters, or load heads, that were used to apply the correct loading into the ESPA secondary payload interfaces. All loads were applied directly to these load heads, which in turn transfer the loads into the ESPA structure. Load heads bolted to each of the six secondary interface flanges were designed to simulate actual flight conditions. To achieve the appropriate load transfer, the stiffness of each load head had to be iteratively analyzed to match the estimated flight conditions. This analysis, coupled with tight machining tolerances on the mating surfaces of the load heads ensures the ESPA will witness not only the correct loads, but also realistic load peaking. Likewise, aluminum adapters were designed to bolt to the upper and lower primary surfaces of the ESPA, as shown in Figure 1 and previous installments. Load applied to the primary load head was transferred into the upper aluminum adapter, which was reacted by the lower aluminum adapter. Similarly for the secondary load heads, these adapters transfer the applied qualification loads into ESPA as the predicted flight conditions.

## Loading and Load Control

As previously discussed, hydraulic actuators were used to apply the qualification loads into the ESPA. For the qualification load conditions, 17 actuators were simultaneously controlled to the desired loads. Actuator capacities range from 22 to 267 kN (5 to 60 kip) based on a maximum hydraulic pressure of 20.7 MPa (3,000 psi). Pressure supplied to each actuator was regulated by an MTS Systems Corporation Model G761-3560 5-port, 3.8 Lpm (1 gpm) servovalves. As shown in Fig. 2, six servovalves were mounted to each of three distribution manifolds that uniformly supplied pressure to each valve.

Control of the servo-hydraulic loop was performed using a 20-channel MTS Systems Corporation Aero90 LT digital control system. Control of the hydraulic equipment was accomplished through individual channel PDIF (proportional, differential, integral and feed forward) parameters that were operator-adjusted to tune the control loop and achieve optimum system performance on a channel-by-channel basis. This control loop continuously compares the load cell signal (feedback) to the desired load (command) for each actuator. The difference between the command and feedback was defined as the error. If found to be excessive, the error of each load channel was input to the PDIF parameters which resulted in an adjustment to the servovalve output current. The servovalve current controls the hydraulic flow into and out of each hydraulic actuator, which in turn, changes the applied load until the error is reduced to acceptable values.

Each load cell, manufactured by Interface Inc.,[1] was calibrated by inputting the full-scale calibration value provided by the manufacturer and verified by a quality control engineer prior to performing each test. Each load cell contains a dual-bridge configuration that was utilized by the MTS control system for hardware safety. The load controller continuously conditions and samples the signals from both bridges, controlling to the A-bridge signal while monitoring the B-bridge. For the ESPA qualification tests user-defined inner and outer AB compare limits, set to 1.0 and 3.0%, respectively, in the Aero 90 control software defined the maximum allowable percent deviation between the two signals from each load cell. Exceeding the inner AB compare limit caused the load controller to place the test in a holding configuration, while exceeding the outer AB compare limit caused the test to abort by removing pressure to the hydraulic actuators. Both bridges of the load cell were conditioned with separate conditioner cards to prevent a single uniform error into both bridges, a condition that would make the comparative function ineffective.

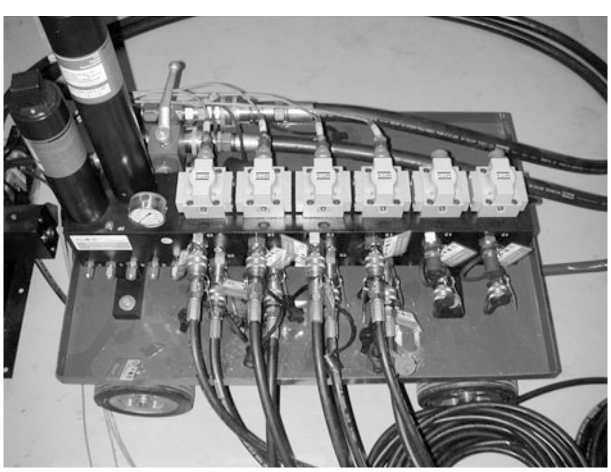

**Fig. 2: Photograph of one hydraulic distribution manifold equipped with servovalves**

In addition to the inner and outer AB compare, several other limits were set by the operator within the MTS software prior to each qualification test. The first line of defense against a potential load control anomaly was the inner and outer Multiple Input/Output Processor (MIOP) limits. The MIOPs are used in the MTS control system to process, monitor, and control the performance of each load control channel. For the ESPA qualification tests, the inner MIOP limit error of 3% was set to place the system in a hold status, while the outer error limit of 4% was set to abort the test.

Independent of the MIOP error limits, error detector limits were used to set an inner and outer error band around the commanded load for each control channel. The inner error limit, set to 4% of full-scale load, was used to detect slowly developing problems common to mechanical systems. Examples of such problems are sticky actuators, sticky servovalves, hydraulic fluid leakage, or actuator linkage problems. Outer error limits, set to 5% of full-scale load, were used to detect sudden problems in the test setup. As with the other errors, the inner limit is set to hold the test, while activating the outer limit will trigger a system abort.

A generic conditioner limit was the last line of defense against overloads. Set to 7% error of the full-scale load for each channel during the present tests, these conditioner limits were programmed to trigger a system abort when reached.[2] The overarching function of each of these independent error systems was to prevent an overload of the test article, a situation that could easily ruin the test article.

Additional system features were used to protect the test article and to ensure the proper loads were applied during the qualification tests. MTS has implemented what they term dynamic and static null pacing to help assure that loads are applied with minimal error, while allowing for unavoidable nuances during a large-scale structural test. Static null pacing is used to set a maximum error band at a given command point. During ESPA testing, this maximum error was set to 0.3% of the full-scale load. In this example, the controller and data acquisition would not record a data record until all of the loads are within 0.3% of the targeted values. If the system could not achieve this balance within three seconds, a hold command was automatically triggered. Under a hold condition, all control channels were set to remain at the current command point while the operator can adjust the PDIF as necessary. The dynamic null pace feature, set to 3.0% for the present testing, was used to ensure that errors during transitions (e.g., increasing load to decreasing load) were minimized and phase or unbalanced loads did not occur.[2]

In the following final installment, the data acquisition system and test procedure will be presented. The test procedure details precisely how the qualification tests were performed to meet the test objectives.

## References

1. Interface, Inc., Scottsdale, AZ, 2002.

2. MTS Systems Corporation, *Aero90 Operator Training Manual*, MTS Systems Corporation, 1996. ■