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ESPA Grande Qualification

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ABSTRACT

ESPA is established launch infrastructure for small satellites on Atlas V, Falcon 9, and Delta IV. Auxiliary payloads[*] (APLs) mount to ESPA on Ø15-inch[†] ports subject to limits on spacecraft mass and center of gravity (CG). ESPA Grande has increased payload capacity compared to the original ESPA due to larger diameter (Ø24-inch) ports and having fasteners every 10° compared to 15° spacing on ESPA.

The small satellite standard Ø15-inch port referred to as ESPA class,[‡] which has become a standard interface for small satellites, was redefined in 2016 with a delta qualification (static load) test. New ESPA APL limits, including introduction of an alternate version of the interface, referred to as ESPA Heavy (with Ø5/16" instead of Ø1/4" fasteners), are the following:

1. ESPA class: 220 kg at 51 cm (485 lb at 20 in), an increase of 21% compared to heritage ESPA class,
2. ESPA Heavy class: 322 kg at 51 cm (710 lb at 20 in), a mass increase of 77%.

These increased payload capabilities for ESPA were documented in a paper at the 2017 Small Satellite Conference.[1]

In 2018, ESPA Grande, with its more capable Ø24-inch ports, was tested for the first time despite having flight heritage based on analysis and similarity to the ESPA Ø15-inch port. Prior to testing, the advertised capability of the Ø24-inch port was 318 kg at 51 cm (700 lb at 20 in).

This paper documents the results of ESPA Grande qualification testing, and it describes the use of the ESPA Mass Acceleration Curve (MAC) which was implemented for this test program. The ESPA MAC provides design load factors for the range of APL mass available with the new, tested capabilities for both ESPA and ESPA Grande.

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[*] The nomenclature used in this paper for satellites mounting to ESPA, i.e., Auxiliary Payloads (APLs) and Primary Payloads (PPLs), is dated and is being replaced in the community with terminology reflecting multi-manifest missions and co-manifested missions that can no longer be divided into distinct categories referred to as Auxiliary and Primary. However, for continuity with references to previously published ESPA documentation, APL and PPL designations are utilized in this paper.
[†] The symbol "Ø" preceding a dimension indicates the diameter of a circle.
[‡] "Heritage ESPA class" APL capability was established by test in 2002 as 181 kg with CG at 51 cm (400 lb at 20 in).

OVERVIEW

ESPA is the EELV Secondary Payload Adapter, where EELV stands for Evolved Expendable Launch Vehicle. The original EELVs were the Atlas V and Delta IV vehicles by United Launch Alliance (ULA); Falcon 9 by SpaceX was certified as an EELV in 2015. ESPA is a ring structure that provides launch capability on EELVs for small satellites via Ø15-inch ports. ESPA Grande is a more capable version of ESPA with Ø24-inch ports.

ESPA Grande qualification testing was performed at the Space Vehicles Directorate of the Air Force Research Lab (AFRL/RV) on Kirtland Air Force Base (KAFB) in May 2018. Two versions of the Ø24-inch interface were tested. One port had the original ESPA Grande interface with 36 equally spaced Ø1/4-inch fasteners; this port configuration is referred to as the Grande Standard interface. A second port configuration, the Grande Heavy interface, had 36 equally spaced Ø5/16-inch fasteners. The ESPA test article, shown in Figure 1, weighs 464 lbs; the nomenclature ESPA 4-24-42 designates the number of ports (4), the port diameter in inches (24) and the ring height in inches (42). It should be noted the Ø24-inch port can be used on an ESPA Grande as short as 32 inches but the larger height is commonly used to accommodate larger auxiliary payloads (APLs).

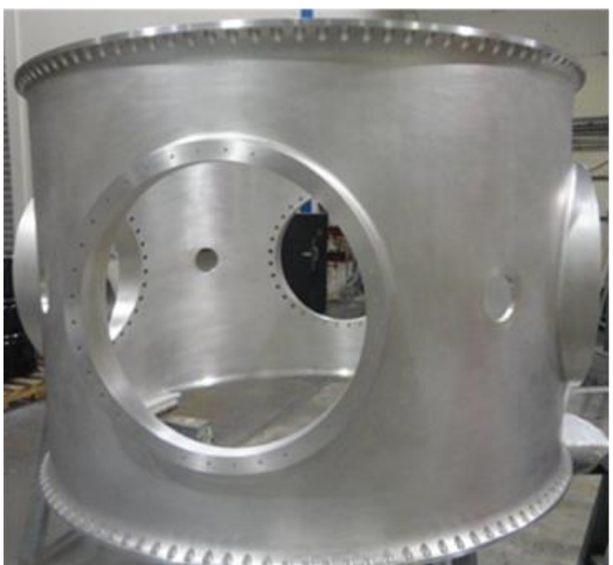


Figure 1: ESPA 4-24-42 test article

The goal of the test was to simulate the heaviest APL possible. Ultimately, analysis predicted healthy margins in the ESPA structure at the maximum loading achievable within the capabilities of the test facility. Nevertheless, the testing demonstrated APL capability for the 24-inch port to be increased by 120%, for both Grande Standard and Grande Heavy interfaces, compared to previously advertised capacity for the ESPA Grande port.

ESPA MASS ACCELERATION CURVE (MAC)

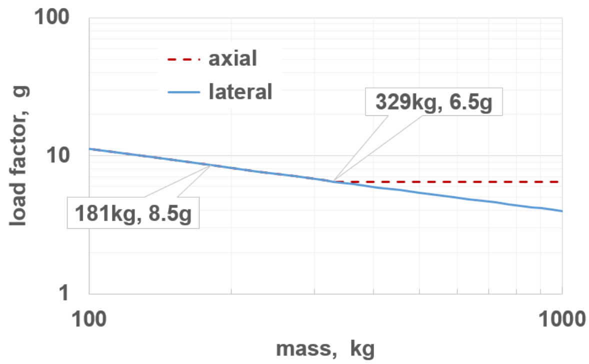
The ESPA Mass Acceleration Curve (MAC) was implemented for the ESPA Grande test to specify load factors enveloping the launch environment for the APLs. Rationale for using the MAC approach is as follows. This test of ESPA Grande, and the recent Delta Qualification of the original ESPA, both demonstrate much more capability than the original ESPA APL limit of 181 kg at 51 cm (400 lb at 20 inches) established in 2002 with qualification testing.[2] The 2002 ESPA test utilized a combination of axial and lateral load factors (10g in two directions simultaneously) based on guidance from EELV manufacturers Boeing and Lockheed Martin; these load factors were taken from a MAC for design and test of launch vehicle secondary structure. Soon after the test, as the EELV designs matured, ESPA design load factors for APL CG at 51 cm (20 inches) were set to 8.5g in two directions simultaneously, corresponding to a vector sum of 12g applied to the ESPA port.[3] Design guidelines for all ESPA APLs since the first ESPA mission in 2007 have adhered to these load factors, but it no longer makes sense from an engineering perspective, considering that the standard ESPA port is now qualified for over 75% more mass than the original ESPA mass of 181 kg at 51 cm. The 2018 ESPA Grande test demonstrated capability above 450 kg at 51 cm (even using the 8.5g/8.5g load factors), so the time is right to refine the load factors for ESPA APLs.

The ESPA MAC is derived from a mass acceleration curve originally developed at the NASA Jet Propulsion Laboratory (JPL) in the 1980s and commonly used in the aerospace community since that time.[4] The JPL MAC was scaled to intersect 8.5g for the ESPA mass and center-of-gravity (CG) combination of 181 kg at 51 cm to maintain a link to the original load factors. And the axial-direction load factor in the ESPA MAC is never permitted to be less than the maximum axial load factor specified for EELV primary payloads (PPLs), i.e., 6.5g, per the EELV Standard Interface Specification.[5] The ESPA MAC is tabulated in Table 1 and shown graphically in Figure 2. It should be reiterated that use of the mass acceleration curve is standard in the aerospace industry.

Table 1: ESPA Mass Acceleration Curve

APL mass		acceleration, g		
kg	lb	axial	lateral	vector sum
91	200	11.7	11.7	16.5
136	300	9.7	9.7	13.7
181	400	8.5	8.5	12.0 *
227	500	7.7	7.7	10.9
272	600	7.1	7.1	10.0
329	725	6.5	6.5	9.2
363	800	6.5	6.2	9.0
454	1000	6.5	5.6	8.6
544	1200	6.5	5.2	8.3
635	1400	6.5	4.8	8.1
726	1600	6.5	4.6	7.9
816	1800	6.5	4.3	7.8
907	2000	6.5	4.2	7.7

heritage ESPA class *



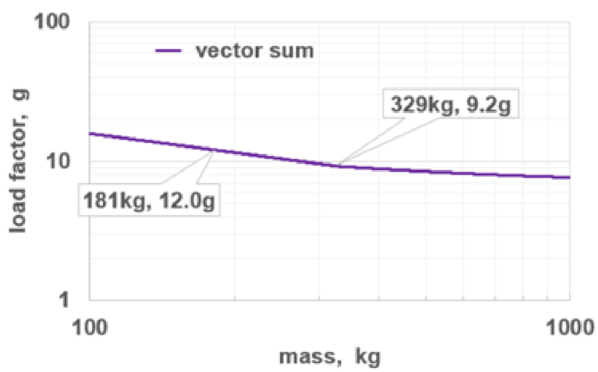


Figure 2: ESPA Mass Acceleration Curve

ESPA HEAVY AND GRANDE HEAVY INTERFACES

Both ESPA and ESPA Grande ports can be modified to utilize Ø5/16-inch fasteners instead of traditional Ø1/4-inch fasteners. The ESPA Grande with Ø5/16-inch port fasteners has flight heritage on the ORBCOMM Generation-2 Falcon 9 missions.[6] The larger fasteners require new versions of existing ESPA separation systems.

The ESPA Heavy capability established in 2016 for the standard ESPA (Ø15-inch port) slightly exceeds the previously advertised capacity of the Ø24-inch ESPA Grande port (318 kg at 51 cm [700 lb at 20 in]). However, because of the higher circumferential fastener density for the Ø24-inch port, there is not a capacity increase for the Grande Heavy interface; the Grande Standard and Grande Heavy interfaces have both been tested to the new capability limits for ESPA Grande.

TEST APPROACH

The test objectives were to assess the maximum mass and CG combinations for two ESPA Grande APL configurations:

1. Grande Standard APL port with Ø1/4-inch fasteners,
2. Grande Heavy APL port with Ø5/16-inch fasteners.

Qualification test load factors representing a primary payload (PPL) were taken from worst-case flight conditions from the EELV Standard Interface Specification (SIS), and APL load factors were based on mass using the ESPA MAC. These load profiles were enveloped by six load cases, and a seventh load case was added that neglected PPL loading and simply maximized the cantilevered loading on the ESPA test ports. The first six load cases complied with the axial/lateral load ratios in the SIS; the seventh load case ignored the axial/lateral load ratio and took the APL actuators to their maximum capacity—to produce the highest achievable moment into the ESPA structure.

Pre-test analysis was performed using a finite element model of the test stack to

- determine maximum APL masses that could be simulated during the test,
- calculate margins on structure and fasteners,
- set the actuator loads to achieve qualification loading, and
- determine strain gage locations.

Unlike the ESPA delta qualification test in 2016, it was not feasible to size a large PPL to be used with any combination of forces simulating Grande APLs. This is because the ESPA Grande with APLs utilizes a significant fraction of the launch vehicle capability, therefore necessitating a different strategy than was used for the previous test. When ESPA is a mission element in an integrated payload stack (IPS), the IPS as a whole must satisfy the loading scenarios in the EELV Standard Interface Specification (SIS). The strategy for this test program was to make sure the reactions at the Standard Interface Plane (SIP),[§] due to all imposed loads, meet but do not exceed the requirements in the SIS; this was to guard against over-testing the major bolted interfaces and possibly limiting the loads that could be imposed on the ESPA ports. Loading of the primary load head, for each load case, was computed as that required to bring the interface loading at the SIP to the limit specified in the SIS after APL masses with associated loads are identified.

It should be noted that ESPA testing and analysis since 2002 has consistently shown that loading of the primary interface has a secondary effect on strength margins in the ESPA structure, compared to loads imparted by the cantilevered APLs. Testing has demonstrated no issues with carrying a PPL (or a stack of co-manifested APLs) up to 7,711 kg (17,000 lb) on the primary ESPA interface. Therefore the inability to replicate a large PPL in this test along with substantial ESPA Grande APLs was not considered to be an issue.

TEST OPERATIONS

The test operations were similar to the ESPA Delta Qualification test that was performed in September 2016; details for the 2016 test are described in Reference 1. Strain gages were installed at key locations on the ESPA structure, including the high-stress regions adjacent to the ports. Dual-bridge load cells were used in lieu of actuator hydraulic pressure readings, to monitor actuator loads applied to the test ports. Instrumentation and load cell channels were recorded continuously during test operations, and key strain channels were compared to analytical predictions in real time. All test cases were performed with a series of increasing loads, and all loads were applied simultaneously. Each load case had hold points that allowed sufficient time to review data.

POST-TEST REVIEW

All success criteria for the test were achieved:

1. Verification that all loads were applied at the qualification level, i.e., 125% of Maximum Predicted Environment (MPE).
2. The ESPA structure did not exhibit detrimental elastic deformation, permanent set, or failure under flight acceptance level (110% of MPE) loads.
3. The ESPA exhibited no catastrophic failure at or below the qualification level.
4. Critical load and strain data were recorded.

TEST RESULTS

Tested capability of the ESPA Grande Ø24-inch port is summarized in Table 2. Test equipment limitations did not allow for testing to the full capabilities of the ESPA Grande structure, but flight-like load cases demonstrated the new capacity of the Ø24-inch port to be 700 kg at 51 cm (1543 lb at 20 inches), representing mass-CG combinations 120% greater than the previous limits of 318 kg at 51 cm (700 lb at 20 in). This increased capability was achieved with both Grande Standard and Grande Heavy interfaces—the new ESPA Grande Heavy interface doesn't necessarily provide more capability, but can provide higher margins for risk-averse mission designers. In addition, APLs on ESPA Grande inside a 4-meter fairing will effectively be volume constrained rather than mass constrained. If a mission designer prefers to use the heritage ESPA load factors for ESPA Grande, the new tested capability, i.e., 465 kg at 51 cm (1026 lb at 20 inches), still represents an increase of 47%.

Table 2: ESPA Grande new and heritage capability

	mass		
	kg	lb	**% increase**
Heritage ESPA Grande	**318**	700	**--**
ESPA Grande (redefined)	**700**	1543	**120%**
ESPA Grande Heavy	**700**	1543	**120%**
Grande/Grande Heavy using 8.5g/8.5g	**465**	1026	**47%**

All masses have CG at 51 cm (20 inches) from port

If the ESPA MAC is retroactively applied to the 2016 ESPA Delta Qualification program, capability for the standard Ø15-inch-port ESPA increases to 257 kg at 51 cm (567 lb at 20 in) and the ESPA Heavy interface increases to 450 kg at 51 cm (991 lb at 20 in).

Table 3: ESPA compared to heritage capability

	mass		
	kg	lb	**% increase**
Heritage ESPA Class	**181**	400	**--**
Standard ESPA (redefined)	**220**	485	**21%**
ESPA Heavy	**322**	710	**78%**
Standard ESPA using MAC	**257**	567	**42%**
ESPA Heavy using MAC	**450**	991	**148%**

All masses have CG at 51 cm (20 inches) from port

[§] The EELV Standard Interface Plane (SIP) is the location of the interface between the Integrated Payload Stack (IPS) and the Launch Vehicle. The IPS can be a single space vehicle or multiple space vehicles integrated together with ESPA and/or other adapters.

CONCLUSION

This paper reviews the 2018 ESPA Grande Qualification test program that was performed at the Space Vehicles Directorate of the Air Force Research Laboratory at Kirtland Air Force Base, New Mexico. The test program introduced the ESPA Mass Acceleration Curve to define load factors encompassing the range of auxiliary payload mass available with the new tested capability. Increased ESPA Grande capability has been validated and new payload limits for the ESPA Ø24-inch port are documented, augmenting the 2016 testing of the standard ESPA. Future documentation will define ESPA and ESPA Grande capabilities as mass-CG moments instead of unique mass-CG configurations, e.g., 700 kg at 51 cm; this is more appropriate to reflect actual capabilities and will enable new APL configurations without unnecessary and potentially incorrect limitations.

References

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