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EELV Secondary Payload Adapter (ESPA)

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Abstract. Despite growing worldwide interest in small satellites, launch costs continue to hinder the full exploitation of small satellite technology. In the United States, the Department of Defense (DoD), NASA, other government agencies, commercial companies, and many universities use small satellites to perform space experiments, demonstrate new technology, and test operational prototype hardware. In addition, the DoD continues to study the role of small satellites in fulfilling operational mission requirements. However, US government agencies are restricted to the use of US launch vehicles, which eliminates many affordable launch opportunities. Additionally, many small satellite users are faced with shrinking budgets, which limits the scope of what can be considered an "affordable" launch opportunity. In order to increase the number of space experiments that can be flown with a small, fixed budget, the Space Test Program (STP) has teamed with the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VSD) to develop a low-cost solution for the small satellite launch problem. Our solution, which will be implemented on Evolved Expendable Launch Vehicle-Medium (EELV-M) boosters, is called the EELV Secondary Payload Adapter (ESPA). ESPA can potentially shrink the cost of launching a 180kg (or smaller) satellite to under $500,000, less than 5% of the cost of a dedicated launch vehicle.

ESPA Motivation

STP is one of many organizations using small satellites to accomplish their mission. However, small satellite launch costs are currently very high. For example, the least expensive expendable launch vehicle available to US government agencies is the Orbital/Suborbital Program (OSP, or "Minotaur") vehicle (a converted Minuteman II ICBM). Using a dual-payload adapter, the cost to launch a pair of small satellites on OSP is about $14M, or $7M per spacecraft. Other small launch vehicles are similarly expensive; Pegasus costs about $18M and both Taurus and Athena I/Athena II cost more than $20M. Arianespace offers inexpensive secondary payload flights on Ariane 4 and Ariane 5 boosters using an adapter called Ariane Structure for Auxiliary Payloads (ASAP) as shown in Figure 1. Unfortunately, foreign launch systems are not currently available to DoD or other US government customers (unless the White House grants a foreign launch waiver).

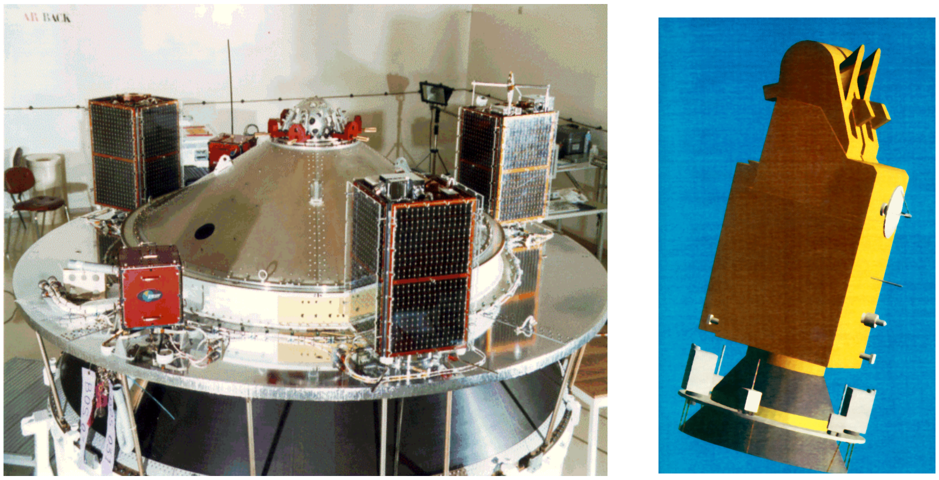


Figure 1. Secondary Payloads on Ariane 4 Launch Vehicle

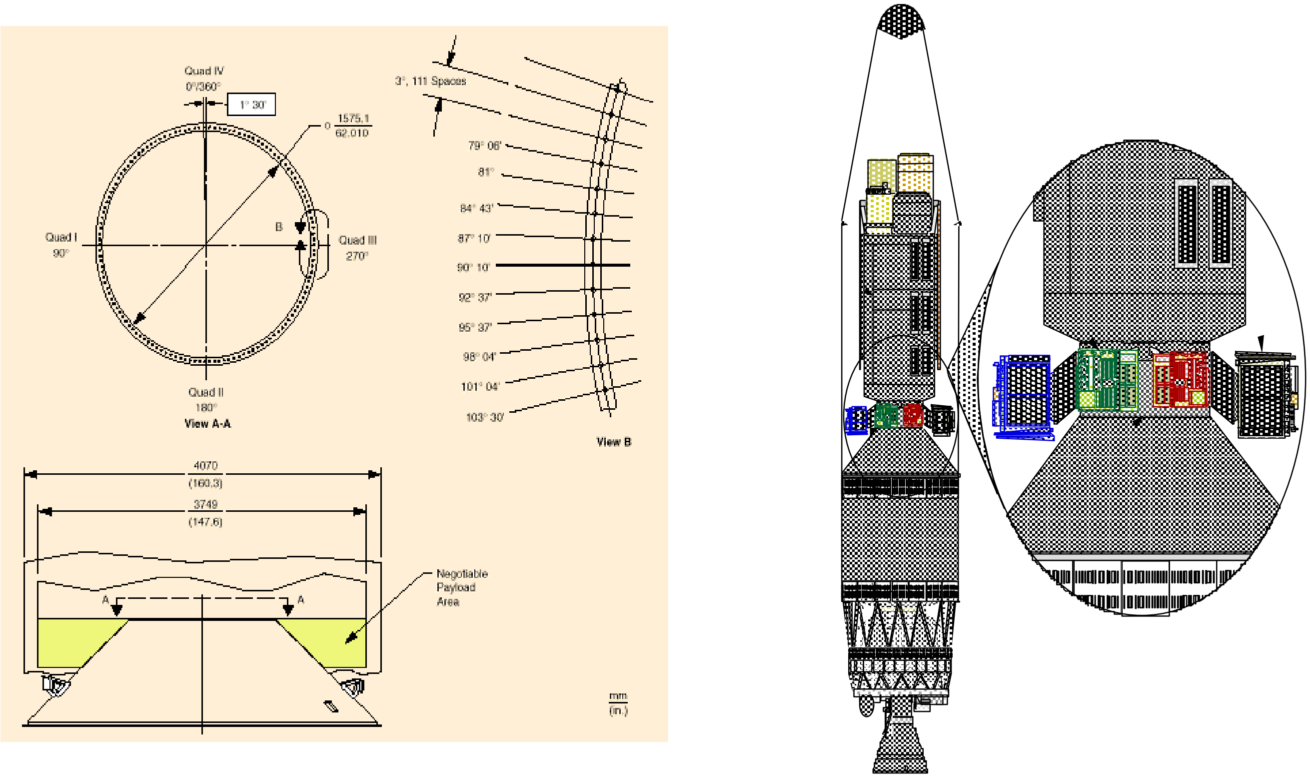
Beginning in Fiscal Year 2002 (FY02), all launches of large DoD payloads will be performed by the EELV family of boosters developed by Lockheed-Martin (with their Atlas 5) and Boeing (with their Delta IV). The EELV program office at Los Angeles AFB, California, recently awarded contracts for 28 EELV launches through FY06. All but two of these 28 launches will be the so-called "EELV-Medium" boosters. Both the Atlas 5 (Medium) and Delta IV (Medium) are very capable boosters. On at least 15 of the 26 manifested flights for these vehicles (58%), there is performance margin of at least 2,000 lbs. Currently, there is no capability for carrying secondary payloads on EELV. ESPA is designed to use large projected payload margins on DoD EELV-Medium launches to orbit up to six small satellites plus a large primary payload on a single launch.

ESPA Design

The Space Test Program (STP; office symbol SMC/TEL) has teamed with the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VSD) at Kirtland AFB to produce ESPA. ESPA consists of a 250-pound (estimated empty mass), 26-inch tall cylinder with a primary spacecraft isolation system (described below) and accommodations for six secondary payloads.

The secondary payloads are mounted at equal intervals around the cylinder. This configuration allows the secondary payloads to be released before the primary payload if necessary, a capability not offered with ASAP. As shown in Figure 2, ESPA is mounted to the EELV standard interface plane (SIP). The SIP, a 62.01-inch bolt circle, is the mechanical interface defined for all military EELV-Medium payloads. (All primary payloaders must provide an adapter cone to attach their satellite to the SIP). The primary payload adapter cone is mounted to the top of ESPA. To alleviate primary payload mechanical interface concerns, the top of ESPA will replicate the SIP.

The design limit for secondary satellite mass is currently 400 pounds (about 180kg). However, secondary payloads on ESPA will likely be limited more by usable volume rather than by weight. The precise total usable volume for each secondary payload is currently being defined, and will obviously vary with payload fairing diameter. Most DoD EELV-M launches are expected to use 4-meter diameter fairings (3-meter and 5-meter fairings are also available); with the 4-meter fairing, usable secondary payload volume is probably limited to a cube of 30-inches on each side. The ESPA secondary payload standard interface (mechanical and electrical) is also still being defined. However, ESPA will be able to accommodate up to a 16 ¾-inch V-band such as that used in the Shuttle Hitchhiker Ejection Launch System (SHELS). Rather than define one particular mechanical interface for ESPA that all customers must use, an option for a "blank mounting plate" and user-provided interface may be incorporated.



From Delta IV Payload Planner's Guide, September, 1998

Figure 2. EELV Standard Interface Plane and ESPA (Delta IV Shown).

The EELV program office has initiated special studies with Boeing and Lockheed-Martin to study the many technical and programmatic issues associated with ESPA. Among these issues are timelines for adding ESPA and secondary payloads to a given EELV launch and loading requirements for ESPA. It is assumed ESPA can be loaded with any number of satellites so long as mass balance is maintained. Figure 3 shows ESPA top and side views with a notional load of two large spacecraft and four small spacecraft.

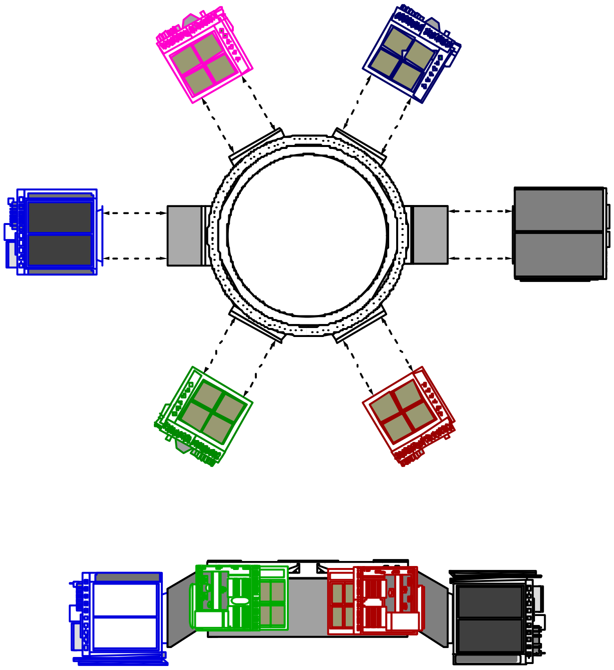


Figure 3. ESPA Top View (Top) and Side View (Bottom) with Notional Satellite Load.

Incorporating ESPA will obviously impact the primary payload. ESPA will raise the primary payload by 26 inches. This raises the payload center of gravity and reduces the usable volume inside the payload fairing. However, designing primary payload adapters (adapters that connect the primary spacecraft to the SIP; as stated above, these adapters must be provided by each primary payload) with ESPA use in mind would minimize these effects. Incorporating ESPA will actually have positive impact on the primary payload as well. ESPA will incorporate a primary spacecraft isolation system. The purpose is to minimize the dynamic interaction between the primary and secondary payloads and to reduce the dynamic response of the primary payload. Vibration isolation systems will also be optional for the secondary payloads to reduce dynamic loads. Finally, low-shock/non-pyrotechnic separation systems will be used for the secondary payloads. Low-shock separation systems will mitigate concerns associated with secondary payload separation prior to primary payload separation (on occasions when that option must be utilized) and non-pyrotechnic systems offer improved launch vehicle safety.

Vibration Isolation

During the past decade, billions of dollars have been lost due to satellite malfunctions, resulting in total or partial mission failure, which can be directly attributed to launch vibration loads. AFRL and CSA Engineering, Incorporated, of Mountain View, California, have developed, designed, tested, and successfully flown the world's first whole-spacecraft launch vibration isolation system. This system was successfully flown on 10 February 1998 on a Taurus launch vehicle for the Naval Research Laboratory's Geosat Follow-On (GFO) spacecraft. The success of the GFO mission was repeated on 3 October 1998 when AFRL flew a second whole-spacecraft isolation system with the National Reconnaissance Office's Space Technology Experiment (STEX) satellite on a Taurus LV. The whole-spacecraft isolation systems that were developed and built for GFO and STEX are low-risk, passive devices that provide isolation in the axial (launch) direction. For both the GFO and STEX missions, the whole-spacecraft isolation system performed extremely well, reducing the structural-borne vibrations at the worst loading conditions by at least a factor of five. Overall, the system reduced vibration levels for the other load cases by more than a factor of 3. In order to meet schedule and the stringent requirements for the GFO and STEX missions, the whole-spacecraft isolation system was designed, fabricated, and tested in less than 4 months. This accomplishment proved not only the technical performance of the isolation technology, but also the ease-of-use and flexibility required for routine use in operational systems.

By reducing structure-borne vibrations for spacecraft, whole-spacecraft launch isolation directly impacts the overall cost of a spacecraft's design, testing, and operation. With lower loads, spacecraft components such as solar arrays and other flexible structures can be made lighter and use less expensive materials, resulting in both mass and production-cost savings. This extra mass margin can be used to incorporate additional equipment into the spacecraft that will enhance mission performance. Alternatively, the reduced weight will allow some spacecraft to be flown on smaller, less expensive launch vehicles. This technology will also enable the launching of more fragile spacecraft, such as advanced optical systems, and will enable the use of commercial off-the-shelf components. The potential savings using this technology could be several million dollars per launch and reach into billions of dollars over the next decade and beyond. Ball Aerospace and the Air Force's small launch vehicle office (SMC/TEB) estimated that whole-spacecraft isolation technology saved the GFO and STEX programs 6-12 months in schedule and $8-10M in launch delay and redesign costs. Analytical results show a 90% reduction in dynamic loads. The flight data, shown in Figure 4, concurs with analytical predictions and shows an overall 50% g RMS reduction seen from all loading conditions. The dark color is the response below the isolation system; the light color is the response above the isolation system (and therefore experienced by the spacecraft).

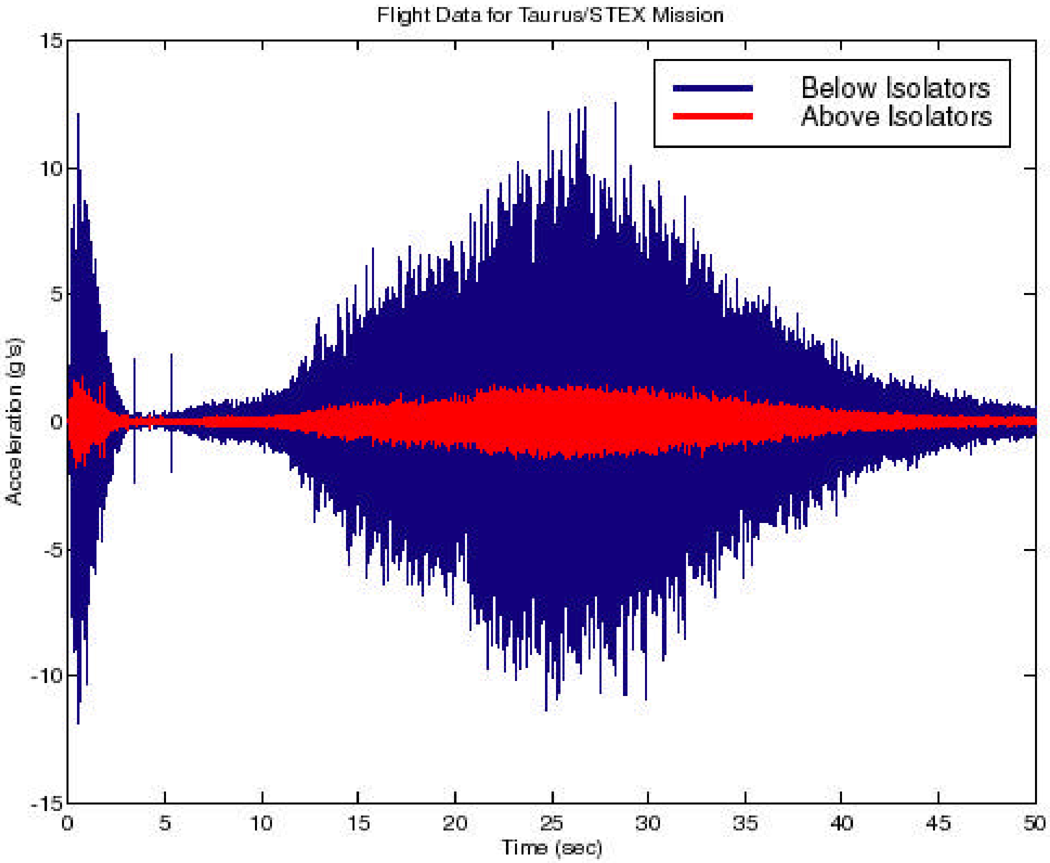


Figure 4: Flight Data for STEX Spacecraft.

The primary payload on ESPA will have a tunable vibration isolation system that should provide at least a factor of two reduction in vibration loads. Tunable vibration isolation systems will be optional for each secondary payload. A tunable system offers great flexibility, allowing the use of the same isolation hardware for many different payloads and on different launch vehicles. Depending on particular spacecraft needs, the vibration isolation system may be axial, lateral, or combined axial/lateral.

CSA Engineering performed a study investigating the feasibility of a whole-spacecraft isolation system for a primary satellite and six small secondary payloads. All payloads were mounted to the LV with an ESPA. The primary satellite mass was 4,635 kg. Of the six small secondary payloads, four had a mass of 94 kg and two had a mass of 160 kg. The isolation systems were designed to provide passive axial/lateral isolation. Lockheed-Martin and Boeing provided launch vehicle models, loads for flight events, and other information required to perform the feasibility study.

For each of the six small secondary payloads, eight critical locations representing spacecraft components were selected to provide information in three axes. According to the study, the isolation systems reduced the dynamic acceleration by at least a factor of two for components with significant baseline accelerations, and by a factor of 4 to 5 for several components with especially high baseline acceleration levels.

For the primary spacecraft, 25 response locations representing critical components (3 axes each) were selected. Two loading events were studied for the primary payload; the same event used for the secondary payloads and one additional event. The results of vibration isolation for the primary satellite were similar to those for the secondary payloads. The isolation system reduced the dynamic acceleration on most primary payload components by a factor of 2 to 4 and reduction factors as high as 6 to 7 were observed for several selected components.

Low Shock Separation Systems

The preferred separation systems for secondary payloads on ESPA will be low shock and non-pyrotechnic. A low-shock/non-pyrotechnic system will increase the likelihood of ESPA being flown on a mission by addressing issues associated with the integration of a separation system. A non-pyrotechnic/low-shock separation system will decrease safety concerns associated with typical pyrotechnic systems and will eliminate redesign of shock sensitive components. AFRL is developing several of these separation systems that could potentially be used for ESPA. One separation system, called the Low Force Nut (LFN) and shown in Figure 5, is based on actuation and damping properties of shape memory alloys to provide low shock, synchronized deployment of spacecraft. The LFN was developed by Lockheed-Martin Astronautics, Littleton, CO. The LFN offers “in situ” reset capability that allows the device tested to be the one that is flown and eliminates pyrotechnic safety and handling concerns. Shock output for the LFN is less than 500 g’s while maintaining release times less than or equal to 50 milliseconds.

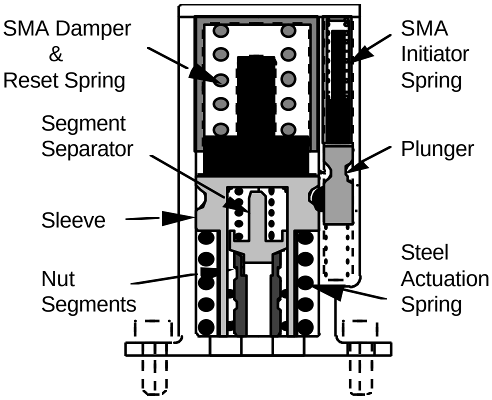


Figure 5. Lockheed-Martin Low Force Nut.

The LFN is currently in production at Starsys Research Corporation (SRC), Boulder, CO. The performance of the LFN was successfully demonstrated in May 1999 as an experiment on an AFRL satellite called MIGHTYSAT I. The experiment consisted of support electronics suitable for obtaining acceleration and separation times for the LFN.

Another potential low shock/non-pyrotechnic separation system for ESPA is SRC’s QWKNUT. The QWKNUT, shown in Figure 6, was also designed to provide low shock, synchronized deployment of a spacecraft and provides “in situ” reset capability (less than 1 minute). The QWKNUT has a shock output less than 500 g's, a release time less than or equal to 30 milliseconds, a total mass of ~450 g, and may be preloaded to 3,000 lbf. The QWKNUT fast release times are made possible by redundant shape memory alloy triggers, which respond to a standard pyrotechnic firing pulse. The QWKNUT was qualified in May 1999 to release the United States Air Force Academy's FalconSat 1 spacecraft on the first OSP/Minotaur launch vehicle. This launch is scheduled for September 1999. Several successful ground separation tests were performed on the FalconSat 1 spacecraft to demonstrate the QWKNUT's release, preload, shock, and reset capabilities.

Figure 6. Starsys Research QWKNUT for Spacecraft Separation.

Still another potential separation system AFRL is investigating for ESPA is a non-explosive Marmon clamp (V-band) release mechanism that is being developed by NEA Electronics, Chatsworth, CA. This V-band release mechanism, shown in Figure 7, is designed to replace explosive bolt and pyrotechnic separation nuts in separating cylindrical structures. Favorable features of this device for ESPA are it's low-shock release, non-explosive nature, pyro-pulse compatibility, electrical and mechanical redundancy, and reset capability.

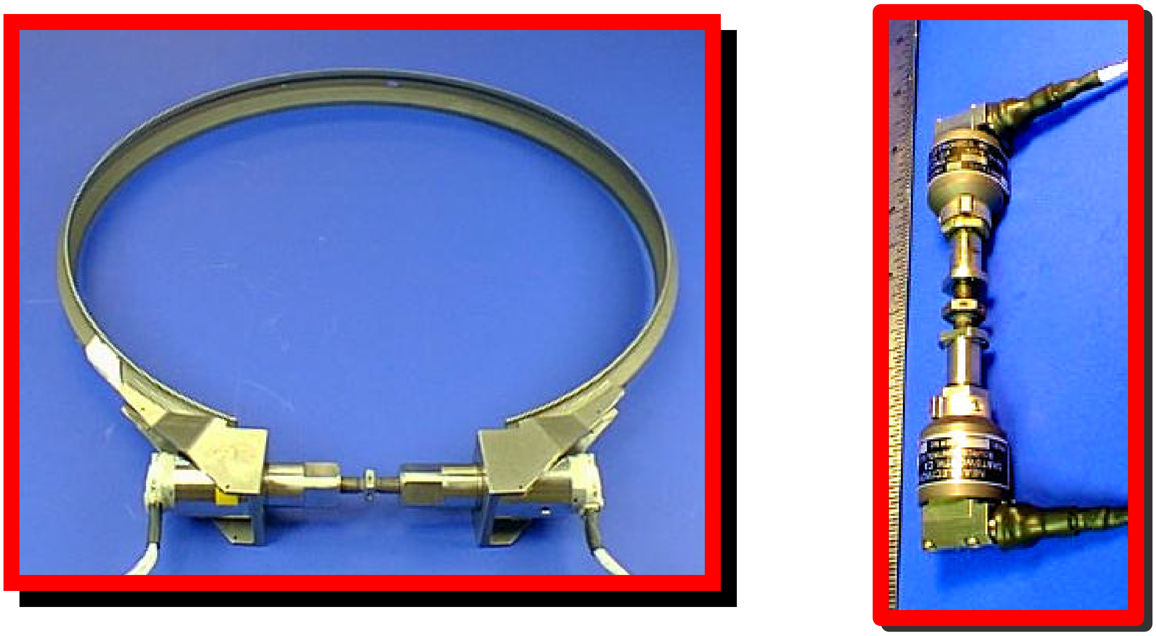


Figure 7. NEA Low-shock/Non-explosive V-Band Release Device.

The ESPA Program

STP and AFRL/VSD are working together to design ESPA and build two ESPA units. The first unit will be used for EELV qualification testing and the second will be a flight model. Preliminary Design Review is scheduled for September 1999, and Critical Design Review is scheduled for August 2000. Both ESPA units will be finished in FY02, and STP hopes to demonstrate ESPA on a DoD EELV-M launch in FY03 (only one DoD EELV mission is scheduled in FY02).

Since the demonstration mission is planned with STP needs in mind, STP is trying to manifest the first ESPA on a launch going to an orbit useful for many Space Experiment Review Board (SERB) payloads. The FY03 EELV-M missions with orbits useful for SERB payloads include the Global Positioning System (GPS), Defense Meteorological Satellite Program (DMSP), and Space-Based Radar (SBR or Discoverer II). The GPS and DMSP launches definitely have suitable weight margin for ESPA, and SBR is under review. Currently, STP is planning to pay ESPA hardware and mission integration costs for the first flight. However, it should be noted STP is unlikely to fill all six secondary payload slots. We currently project one to four ESPA slots filled by SERB payloads. STP hopes to fill any remaining slots with non-STP payloads, particularly for organizations that can pay their portion of the flight integration costs. Priorities for filling any open slots on the demonstration mission are as follows: 1) DoD Payloads; 2) Other US Government Payloads; 3) University, commercial, and foreign payloads. Due to EELV processing timelines, the ESPA payload manifest should be decided two years prior to the launch date. STP will manage the secondary payload manifest for the first ESPA mission, so interested payloaders should contact STP for information regarding the demonstration launch. STP and AFRL may provide low-shock separation systems for payloads on the first ESPA mission as part of the overall system demonstration, but later missions will likely require each payloader to provide their own qualified (preferably low-shock/non-pyrotechnic) separation system.

After the demonstration mission, STP hopes to "commercialize" ESPA. The goal is to authorize commercial use of the ESPA design in return for integration and mission management services for DoD. Presently, it is unclear what organization will take responsibility for ESPA.

The cost goal for ESPA, assuming a fully loaded ring, is less than $0.5M per satellite. The recurring cost for the ESPA units is estimated at $600,000 plus $50,000 for each secondary payload isolation system (if needed). The EELV integration costs for ESPA are estimated at $1M, although a more refined figure should come from the special studies currently underway with Boeing and Lockheed-Martin. Assuming no EELV launch cost-sharing with the primary payload (a reasonable assumption for DoD launches), the total ESPA mission cost could be as low as $1.9M for six small satellites, or about $320,000 per satellite. Thus, by using ESPA, the cost to launch a single small satellite drops from $7-10M to about $0.3-0.5M.

Conclusion

We expect ESPA to have a tremendous impact on future military and commercial spacecraft programs by providing a fast and inexpensive way of launching small payloads. ESPA provides a cost-effective means for launching up to six small satellites, plus a large primary payload, on a single EELV-Medium booster. ESPA causes minimal impact to the primary payload and provides the primary payload with an improved flight environment through the use of a passive whole-spacecraft vibration isolation system. For improved safety and ease of integration, ESPA will incorporate low-shock/non-pyrotechnic secondary payload separation systems. Most importantly, ESPA can provide access to space for small satellites for less than 5% of the cost of a dedicated launch vehicle.