

# Multiple Payload Adapters; Opening the Doors to Space

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**Abstract**—In order to increase the number of satellites that can be flown on a small, fixed budget, low-cost Multiple Payload Adapters (MPAs) are needed to take advantage of excess payload capability on launch systems. This paper will discuss the development of several MPAs at the Air Force Research Laboratory-Space Vehicles Directorate (AFRL/VS) in support of current and future Air Force and DOD requirements. The adapters are being designed using state-of-the-art manufacturing processes, launch vibration isolation, and low-shock separation technology that can accommodate multiple satellite configurations. The MPAs can deploy multiple satellites, in a large range of sizes (15 kg to 1000 kg), depending on the design configuration. The MPAs are being developed to support the Minotaur, the Evolved Expendable Launch Vehicle (EELV), as well as the Space Shuttle. The successful development of these adapters will greatly reduce the cost of launching satellites into orbit by allowing for the efficient use of currently unused payload margins. These MPA concepts maximize the opportunity for low-budget satellites to be manifested for launch, and are being proposed to fly as early as 2003.

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## 1. INTRODUCTION

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, thus eliminating many affordable launch opportunities. Additionally, many small satellite users are faced with shrinking budgets that limits the availability of "affordable" launch opportunities. Because of these factors, numerous satellites and their significant payloads are shelved as they wait for space lift. Many of these are eventually mothballed as their launch window passes, wasting millions of research and development dollars. In order to increase the number of spacecraft that can be flown with a small, fixed budget, the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VS) is developing low-cost solutions for the small satellite launch problem.

The benefits of using this untapped lifting capacity are twofold. First, it becomes possible to dramatically increase the amount of experiments conducted in space. This additional research can then provide many tangible benefits. Foremost among

these, many small satellites serve as technology demonstrators for future large DOD satellites. By demonstrating this technology on a small satellite, it can effectively reduce the risks and costs inherent to these massive Air Force and military programs. The second benefit of tapping this previously unused lifting capacity is that it can work to dramatically reduce launch costs. With these MPAs, we will be able to place multiple payloads on a single launch vehicle rather than spreading them out over several launches. By utilizing our space lifters in a more efficient manner, and creating an opportunity for several programs to share launch costs, MPAs will save the Air Force millions of dollars in spacelift costs.

These statements have led some to refute our claims as overly optimistic. When determining the path of these adaptors, we ran into the age-old "chicken versus the egg" argument; do we design the adaptor to accommodate current satellites, or do we design the adaptor and expect satellites to conform? It is our belief that once this capability has been demonstrated, many teams will design their satellites to specifically meet these accommodations. This belief is in part based on the fact that many satellite program offices have expressed a willingness to incorporate these adaptors into their design, given a significant increase in the probability of a timely launch. Each of these payload adaptors incorporates "standard" mechanical and electrical interfaces in order to facilitate this design process. We understand that this is a dramatic shift in paradigm, but if we can use these adaptors to provide an increased probability of reaching orbit, satellite designers will jump at the prospect. As an example, *all* EELV payloads are required to accommodate a single, set interface. Why should the smaller and cheaper secondaries not be held to the same standard, if it would ensure them a greater probability of getting to space?

The AFRL/VS has been working with several commercial companies to develop innovative technologies that can provide solutions to these space lift shortfalls. In order to establish flight heritage for the following systems, the AFRL has arranged several flight demonstrations to facilitate the transition of these technologies to the commercial industry. A discussion of these projects is included.

## 2. EELV SECONDARY PAYLOAD ADAPTER (ESPA)

In 1995, the Air Force's Space Test Program (STP), managed under the Space and Missile Test and Evaluation Directorate of the Space and Missile Center (SMC/TE, now SMC/Det 12) identified large unused payload margins on the majority of DOD's Evolved Expendable Launch Vehicle (EELV) manifests. In some cases this unused lifting capacity approached 3628 kg (8000lb). As a result of these findings, the STP advocated utilizing this excess margin for the deployment of secondary payloads. The STP has teamed with the AFRL/VS to develop a low-cost solution that will exploit this opportunity.

The EELV Secondary Payload Adapter (ESPA) is designed to deploy six radially mounted, 181kg (400 lb) secondary payloads and a 6800 kg (15,000 lb) primary. The ESPA is targeted for an EELV flight in FY06. Figures 1 through 3 illustrate the ESPA concept.

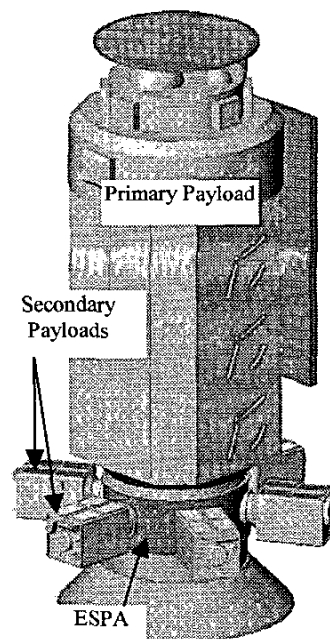


Figure 1. ESPA on the Launch Vehicle Stack

The ESPA is essentially an adapter ring that will be installed between the EELV final stage and the primary payload. The ESPA cylinder incorporates the 157.7 cm (62.01 in) EELV Standard Interface Plane, on both the fore and aft plane, allowing it to mount onto Lockheed Martin's Atlas V and Boeing's Delta IV launch vehicles, as well as payloads that are

specifically designed to deploy from the EELV. In addition, the ESPA features six standardized 38 cm (15 in) secondary payload mounting locations.

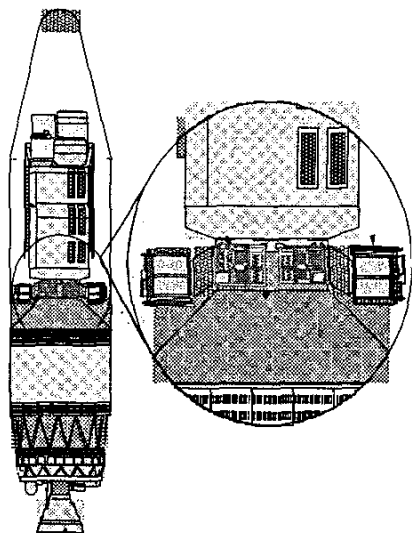


Figure 2. EELV Adapter Concept

When integrated under the primary payload, and incorporating the optional primary payload isolation system, the ESPA raises the primary 76 cm (30 in). This change in height, when unaccounted for, can result in dramatically increased loading on the primary payload, as well as altered vibrational modes in the entire launch vehicle. In order to accommodate this change in height, and to reduce its effects on the primary and the launch vehicle, the ESPA structure is designed to be stiff in all directions. This approach minimizes the effect the change in height has on the rocking frequency of the primary payload. The high stiffness and the utilization of the EELV Standard Interface Plane make the ESPA nearly transparent to the primary payload, as well as the rest of the launch vehicle.

The entire ESPA cylinder, including Primary and Secondary Payload Mounting Flanges, is machined from a single billet of 7075 Aluminum. This results in dramatically reduced labor associated with bolting the flanges to the ESPA cylinder. It also greatly reduces the risk, uncertainty, part count, and lead-time associated with the bolted or bonded joints. This design approach has reduced the cost of fabricating the ESPA structure from nearly \$300K to about \$75K when compared to a comparable design utilizing composite materials. Additionally, the use of an integrally machined aluminum structure also precludes the necessity for acceptance testing of the

structure. This results in an additional cost savings of over \$150K. Furthermore, designing the ESPA structure such that it can be integrally machined from a single aluminum billet reduces the recurring costs by nearly \$450K and saves nearly six months in lead-time, compared to a similar design utilizing composite materials.

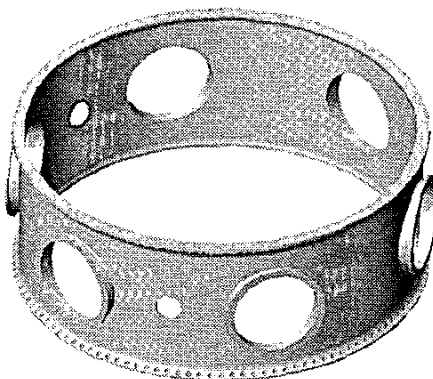


Figure 3. EELV Secondary Payload Adapter (ESPA)

Another innovative technology that ESPA will use for its payloads is whole-spacecraft isolation. During the past decade, billions of dollars have been lost due to satellite malfunctions, resulting in total or partial mission failure. Many of these failures can be directly attributed to launch vibration loads. AFRL/VS will reduce these launch vibration loads on the satellites via two mechanisms; Soft-Ride and shock rings.

Soft-Ride, developed by AFRL and CSA Engineering, Incorporated, of Mountain View, CA is the world's first successful whole-spacecraft isolation system. It has been successfully demonstrated on two different launch vehicles and a multitude of payloads. Soft-Ride has flown on Taurus three times, and on Minotaur twice. Soft-Ride is a low-risk passive device that can be tailored for the needs of a particular launch. This tailoring involves both the frequency response of the isolation system, as well as the direction of damping (axial, lateral, or both).

Figure 4 shows data from Soft-Ride's second flight, which was on a Taurus launch vehicle. As is demonstrated by the graph, Soft-Ride was able to achieve an overall 50% RMS reduction, seen from all loading conditions, while reducing the structural vibrations at the worst loading conditions by at least a factor of five.

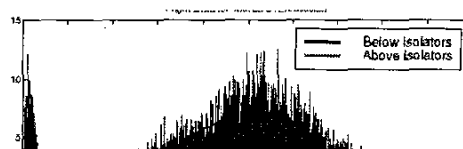


Figure 4: Flight Data from SoftRide's 2<sup>nd</sup> Flight.

Soft-Ride is optimized for frequencies below 100 hertz and can be used for vibration isolation on the primary payload. The other whole-spacecraft isolation system, shock rings, will be utilized for the secondary payloads. Shock rings are optimized for frequencies above 150 hertz (frequencies between 100 and 150 hertz have historically not been problem areas). The secondary payloads, due to their horizontal mounting, will require the additional stiffness of the shock rings, as opposed to the play of the Soft-Ride. Much like the Soft-Ride, shock rings can be tailored to more effectively isolate specific frequency ranges.

In addition to whole-spacecraft isolation, the ESPA will incorporate low shock separation systems to further decrease adverse loading on the payloads. Impulse-like loads from pyrotechnic separation systems are another major cause of irreparable satellite damage and mission failure. By employing non-pyrotechnic separation systems, it is possible to reduce these shock loads on the spacecraft by over an order of magnitude. The separation systems for the ESPA will be designed to provide an interface between the launch vehicle and payload and will meet structural and safety requirements while having minimal impact on the payload with regard to shock, tip-off, deployed mass, and surface area coverage.

The ESPA will undergo quasi-static testing in the first quarter of FY02, on the AFRL/VS's Crusher test stand (Figure 5). The three objectives of this testing are verify ESPA stiffness, verify ESPA strength margins, and validate modeling procedures. The computer-controlled test stand is capable of commanding 20 servo-hydraulic actuators and reading 256 channels of analog data. The AFRL/VS has recently received the ESPA and is currently preparing for these tests.

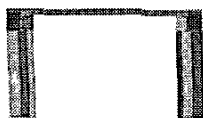


Figure 5. Crusher Test Stand at AFRL/VS

### 3. UNIVERSITY NANOSAT PROGRAM

A promising way to perform missions from space is to use clusters of microsatellites that operate cooperatively to perform the function of a larger, single satellite. The University Nanosat program is a collaborative effort between the AFRL, AFOSR, DARPA, STP, and NASA/GSFC to explore this shift in paradigm. This program consists of nine nanosatellites (nanosats) designed and built by eight universities, which are baselined to deploy from the Space Shuttle via the Shuttle Hitchhiker Experiment Launch System (SHELS) in two separate flights.

The first flight consists of three satellites designed and built by Stanford University and Santa Clara University. A schematic is shown in Figure 6. The second flight consists of six satellites designed and built by Utah State University, the University of Washington, Virginia Tech, Arizona State University, the University of Colorado at Boulder, and New Mexico State University. A schematic of this configuration is shown in Figure 7.

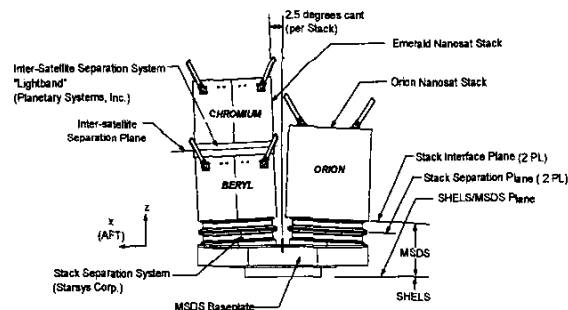


Figure 6: Nanosat-1 General Arrangement

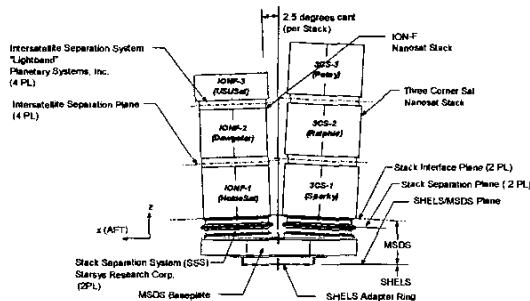


Figure 7: Nanosat-2 General Arrangement

The AFRL/VS is tasked with developing the integrating structure and two of the three separation systems needed for the deployment of these satellites.

The integrating structure consists of an aluminum platform with two mounting locations, each of which can support a stack of one or more nanosatellites. The integrating structure also attaches to the SHEL/S, and the whole system is installed in the Shuttle Orbiter Payload Bay. The integrating structure is designed such that each stack of nanosatellites is canted 2.5° from the Z-direction, giving the stacks a total divergence of 5° (as illustrated in Figures 6 and 7). This divergence provides a relative separation velocity between the two stacks when they are launched simultaneously from the integrating structure.

The two separation systems being developed by the AFRL are the Stack Separation System, provided by Starsys Research Corporation, and the InterSatellite/*Lightband* Separation System, furnished by Planetary Systems Corporation. Both systems will employ non-pyrotechnic, low-shock separation techniques. Low-shock separation is absolutely necessary in this program because of the close proximity of the satellites, as well as the potential to experience multiple device firings. Some satellites on the Nanosat-2 mission will experience the shock from four distinct separation events. Therefore, we must utilize low-shock separation systems in order to mitigate the amount of damage that these events will cause to the satellites. Figure 8 shows the integrating structure and the Stack Separation System. Figure 9 shows the *Lightband* Separation System.

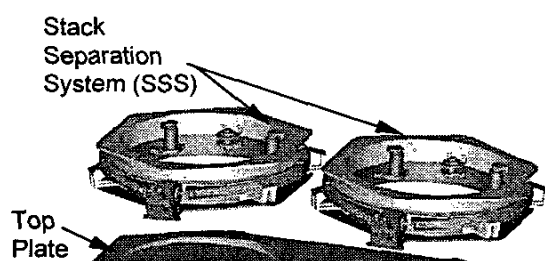


Figure 8: Integrating Structure and Stack Separation System

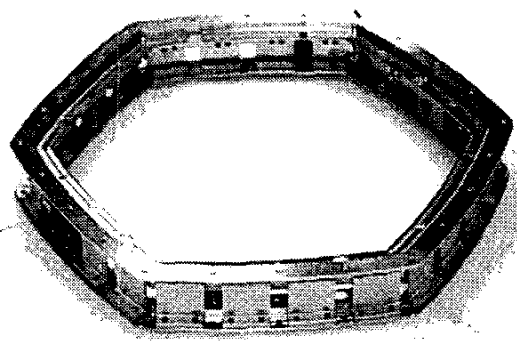


Figure 9: InterSatellite/*Lightband* Separation System

The nanosatellites deploy and are placed in their proper orbit through the following three separation events. First, the entire Nanosat system (to include the integrating structure and two stacks of satellites) separates from the SHEL/S, via a separation system developed by NASA/GSFC. Several days later, each stack of satellites is simultaneously deployed from the integrating structure via the Stack Separation Systems. This latency period allows the Shuttle Orbiter ample time to return to earth; thus avoiding any potential recontact hazards. After the stacks deploy, the *Lightband* systems separate the individual satellites, at a time determined by the Universities who developed the satellites.

#### 4. MINOTAUR MULTIPLE PAYLOAD ADAPTER

The "Minotaur Multiple Payload Adapter" program with Applied Aerospace Structures Corporation (AASC), Stockton, CA will design, fabricate, test, and flight qualify a fully re-configurable MPA. The MPA as shown in Figure 10 will be designed to accommodate 2 to 10 small spacecraft for the Minotaur launch vehicle. This is a jointly funded

effort between the AFRL/VS and the SMC/TEB (now SMC/Det. 12).

The overriding goal of this program is to design a generic, flight-qualified, reconfigurable MPA for various mission scenarios and rapidly changing flight manifests. By utilizing a "building blocks" approach and post-assembly inserts and routing, AASC will be able to quickly piece together a custom-made MPA for practically any mission scenario. In addition, AASC will be able to rapidly reconfigure the MPA if there occurs a sudden, last minute change in launch manifest.

The Minotaur MPA will incorporate the use of innovative joining techniques, low-shock, non-pyrotechnic separation systems, and whole-spacecraft isolation. The separation systems and isolation are of the same variety as the ones considered for use on ESPA. The MPA is targeted for a Minotaur launch in early FY03.

As illustrated in Figure 9, there are two configurations for the MPA. It is anticipated that using these two configurations will greatly enhance the capability of the MPA to carry a wide variety of payloads with a negligible influence on the total cost of the program. Both configurations will utilize the same structural members and jointing techniques. The top configuration is our basic "triad" (a fourth vertical could be added to produce a "quad" arrangement). Of particular interest in this design is the fact that the verticals connect to form a torque box in the middle of the structure, and the angle between any two walls is variable, in order to succinctly meet the needs of a particular payload package. In this way we have more flexibility in maneuvering payloads, thereby optimizing the CG and mass characteristics of the MPA, as a whole. The bottom picture illustrates the "cantilevered" baseline. Our initial analysis showed the "triad," and its adjunct the "quad," to be optimized for larger numbers of small satellites. However, they fell short in accommodating two larger satellites. In order to retain the ability to launch two satellites, the "cantilevered" option has been carried forward. Again, the inclusion of both designs has not added significantly to the total cost of the program because both families of configurations use the same basic building blocks and design methodology.

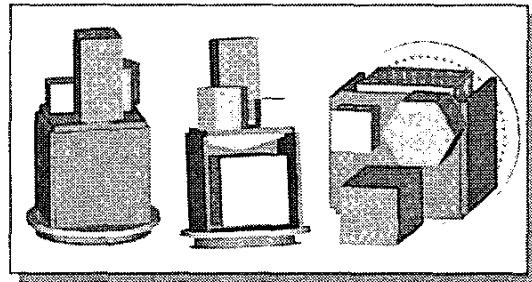
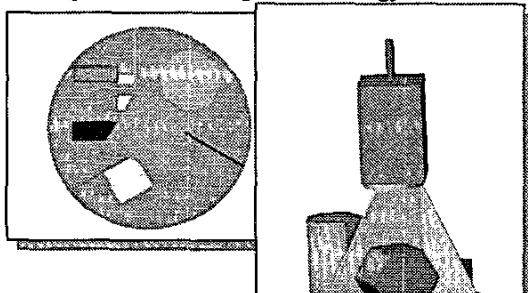


Figure 10: Multiple Payload Adapter Concepts for Minotaur

This MPA, much like ESPA, will undergo flight qualification testing in the Crusher test facility at the AFRL/VS (Figure 5). Like ESPA, the three objectives of this testing are to verify stiffness, verify strength margins, and validate modeling procedures. It is anticipated that this testing will occur in the third to fourth quarter of FY02.

## 5. SUMMARY

We expect the MPA technologies that the AFRL and their team members are developing to have a tremendous impact on future military and commercial spacecraft programs by providing a fast and inexpensive way of launching multiple small payloads. The MPA technology allows the use of excess launch capacity that is currently being wasted. For example, an EELV lifting a single large DOD satellite may have several thousand kilograms of excess capacity. The ESPA MPA can take advantage of this excess capacity, saving \$15M to \$45M in launch costs. The MPAs are being designed to have minimal impact to the primary payload and provide improved flight environments through the use innovative state-of-the-practice component systems such as vibration isolation and low-shock non-pyrotechnic separation.

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#### **BIOGRAPHIES:**

**1Lt. Brandon Arritt** is a research engineer with the Air Force Research Laboratory's Space Vehicles Directorate. His work focuses on developing next generation launch vehicle structures that will greatly enhance the United State's access to space. After receiving his B.S. in Mechanical Engineering at the US Air Force Academy, Lt. Arritt developed components for NASA's NGST while earning his M.S. in Mechanical Engineering at the George Washington University.

**Eugene Fosness** is the Transition Lead for the Spacecraft Component Branch of the Space Vehicle Technologies Division at the U.S. Air Force Phillips Laboratory at Kirtland Air Force Base. Gene Fosness received a B.S. in Civil Engineering from North Dakota State University in 1981 and his M.S. in Civil Engineering from the University of New Mexico in 1991. He is currently employed as a Research Structural Engineer in the Space Vehicles Directorate at the U.S. Air Force Research Laboratory

**Peter Wegner** is a research engineer for the Air Force Research Laboratory's Space Vehicles Directorate. His research focuses on the design, fabrication, and testing of innovative structures for spacecraft and launch vehicle applications. He has a B.S. in Aerospace Engineering from the University of Arizona, a M.S. in Aerospace Engineering from Stanford University, and a Ph.D. in Mechanical Engineering from the University of Wyoming.

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**Mr. Steven Buckley** is a TRW systems engineer supporting the Air Force Research Laboratory's Space Vehicles Directorate. He is involved in developing new technologies that are directly

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