Utilizing Excess Capacity of Current Launch Vehicles to Lift Secondary Payloads

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Abstract—Spacelift is a precious commodity that should never be wasted. Taking advantage of excess capacity on space launch vehicles is crucial to orbiting as many satellites as possible and is sometimes also the only path to orbit for many small and low-priority payloads. There have been many attempts to utilize this excess capacity over the years. Recent successes include the EELV Secondary Payload Adapter (ESPA) and the manifesting of small secondary payloads on Minotaur and Falcon I launch vehicles. In most cases, the process of adding secondary payloads to an existing launch mission is problematic due to a variety of reasons including politics, funding, compatible requirements, and availability of crucial tools such as multi payload adapters. This paper will examine the factors that impact the development of multiple manifest launch missions. In particular it will identify the various types of secondary payloads that have been flown, outline the history of adapter development for smaller payloads, and identify the critical elements necessary to successfully manifest multiple satellites on one launch vehicle. Finally, this paper will outline a successful process to put small secondary payloads on all Minotaur launch vehicles and identify a growth path that others can follow to take advantage of excess launch capacity most efficiently.12

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Introduction

Utilizing the excess capacity on current space launch vehicles has been the goal of many in the small satellite community. Most launch vehicles fly with excess capacity, some fly with hundreds or thousands of kilograms in excess capacity. Taking advantage of this excess capacity would, in theory, provide achievable access to space for many small and lower priority satellites that otherwise could not secure spacelift. The reality is that utilizing this excess capacity can be very difficult. The reasons for this difficulty are rooted in added technical complexity of the launch mission, reluctance of the managers for the prime satellite payload or of the launch managers to accept the added effort and risk of carrying a secondary payload, incompatibility of orbit/mission requirements, and the lack of “return on the investment” to the primary and launch managers of carrying secondary satellites. There are several organizations in the small space community that are developing processes to actively plan and execute multi-payload missions. For example, small Research and Development (R&D) satellites are routinely manifested on Minotaur I space-launch missions. This activity was enabled by choosing a format for the secondary payloads that standardized the interface with the launch vehicle, the development of a small and easily to integrate secondary payload format, and most importantly, by a group of visionary leaders in the launch and satellite community that recognized the opportunity and took on the extra effort to make it work.

The Opportunity

Many space-launch missions do not have a significant level of excess capacity. In an ideal world, satellite managers would buy “just enough” launch vehicle to deliver their precious cargo to the intended orbit. This ideal is realized often in the small launch vehicle community (the Minotaurs, Raptors, Pegasus, Taurus, and Falcon small launch vehicles) when payload mass and orbit requirements sometimes closely match the lift capacity of the launch vehicle. This ideal spacecraft/lift capacity balance is rarely achieved by proper planning. The incentive that drives this phenomenon is the dramatic differences between the cost of lift of a small launch vehicle (around $25M) and larger vehicles (over $65M) causing satellite managers to buy less launch vehicle than they really need. This results in missions with no excess capacity where even the mass of payload separation system fasteners becomes problematic. The techniques to deal with a mission were too much payload is “shoehorned” into too little launch vehicle are interesting but are the subject of another paper.

This paper’s focus is how to take advantage of those missions where the primary payload is significantly lower than the capacity of the launch vehicle to the intended orbit. Many small launch vehicle missions fit in this category.

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2 IEEEAC paper # 1191, Version 1, Updated December 16, 2007
Larger launch vehicles usually fly with excess capacity, sometimes thousands of kilograms of excess capacity. Utilizing this excess lift capacity is very attractive for the small satellite community because it represents “hitching a ride” on an existing launch opportunity without the need to identify and fund the full cost of a ride to orbit. The small payload community sees secondary payload spacelift as the only affordable way to deliver their payloads to orbit. They would prefer to be the primary payload with control of the spacelift mission but must settle for the limited control associated with the role of a secondary payload due to fiscal constraints. On the other hand, the primary payload and launch managers rightfully see the burden of manifesting secondary payloads on their mission as added risk and complexity that takes some of the focus of the integration and launch team off of the primary mission and aims it at the secondary satellites. Dealing with these dichotomies is essential to being able to utilize the excess capacity on current launches.

Overcoming the obstacles that hinder executing multi-payload missions will result in new lift opportunities for many satellites that can not afford to fund their own launch opportunities. It will also maximize the capacity of this country to fly satellites by treating each launch as a “pipeline to orbit” where excess capacity is not wasted instead of a ride for a single payload where excess capacity is tolerated.

**Obstacles To Achieving Multiple Payload Launches**

The major obstacles to achieving efficient and routine multi-payload missions involve the lack of efficient secondary payload accommodations on all launch vehicles, inadequate manifesting processes that matches the physical needs and mission requirements of primary and secondary payloads into an integrated satellite launch mission, and limited management and leadership techniques that create an integrated mission team that is focused on the successful flight of all of the payloads.

Adequate tools that enable multi-payload missions need to be developed. The most important of these tools are adapters for each launch vehicle that can accommodate secondary payloads efficiently with minimal impact to primary payload mission. These secondary payload accommodations should be removable to allow maximum performance missions where a single primary payload requires the full capacity of the launch vehicle. On the other hand, the “standard” configuration for any launch vehicle should be with secondary payload accommodations installed and filled to capacity with selected secondary payloads. This ensures that no spacelift is wasted. Several payload adapters have been developed and flown. For example, the Ariane Ariane Structure for Auxiliary Payloads (ASAP) has enabled several multi-payload missions, Orbital has flown several Pegasus and Taurus missions with secondary payloads using their Dual Payload Attach Fitting (DPAF) configuration, and the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VS) has developed several multi-payload adapters for the Minotaur and EELV vehicles. For example, the EELV Secondary Payload Adapter (ESPA), built by CSA Engineering, Mountain View, California, recently carried four small R&D satellites and the large Orbital Express satellite on an Atlas 5 medium-capacity launch vehicle.

The technical problems of developing secondary payload accommodations are easy to solve. The more difficult problem is how to manage multiple-payload missions from feasibility studies through separation of all payloads on orbit. The key to the successful management of a multi-payload mission is to achieve a “total mission” focus from all participants in the process. The launch provider needs to look at all the satellites as an “integrated payload stack” and focus on the successful delivery of that stack to orbit vice delivery of the primary payload to orbit and then the separation of the secondary payloads. The primary satellite team needs to embrace the mission of the secondary payloads and make achieving those missions their goal too. The secondary payload teams need to recognize their place in the overall mission architecture and strive to minimize integration activities aimed solely at their payload and minimize launch and on orbit impacts to the primary payload.

**Enabling Tools**

Multi-payload missions require several “tools” in order to be executable. These tools fall into several categories. The
main physical tools are the payload adaptors and payload dispensers. A payload adapter is a structure that can "adapt" satellites of several diverse configurations into an Integrated Payload Stack (IPS). In contrast, payload dispensers carry several payloads of the same configuration. Both of the structures require enabling tools to be useful. The Air Force Research Laboratory Space Vehicles Directorate has been developing several Multi-Payload Adapters (MPAs) over the last decade. These include the EELV Secondary Payload Adapter (ESPA). This adapter is designed for the Delta IV and Atlas 5 launch vehicles. It recently flew on an Atlas 5 mission where it flew the Orbital Express primary payload and four small R&D satellites. Multi-Payload Adapters (MPAs) for the smaller Minotaur class launch vehicles have also been developed. The inaugural mission of the Minotaur I flew an innovative isogrid MPA built by One Stop Satellite Solutions (OSSS). The MPA carried four small satellites and then separated and accomplished a free-flying satellite mission of its own. An innovative isogrid ring has been built by Design Net and is slated to fly on an upcoming Falcon I flight. These adapters provide the necessary structure to carry various payloads as an IPS.

Structure is critical but other innovations are required to effectively fly multi-payload missions. These innovations enable the operational use of MPAs. The first enabler is standardized mechanical interfaces. Several standard mechanical interfaces have been developed over the years. An obvious one of value to smaller research and development satellites is the 15 inch, 24 hole bolt circle as used on the ESPA. This interface is used for R&D satellites up to about 200 kilograms. Another interface that is often used for small satellites is the 38.8 inch, 60 bolt hole interface. This interface is used on the Pegasus, Minotaur I, Raptor 1, and Raptor 2 launch vehicles. It is useful for satellite payloads up to 400 kilograms. A larger interface that is currently used is the 62.01 inch, 121 bolt hole interface used on the Delta IV and the Minotaur IV launch vehicles. This interface is adequate for larger payloads up to 1000 kilograms.

Standardized electrical interfaces also help enable multi-payload missions. Unfortunately, standardized payload electrical interfaces have not been accepted by the satellite community. Typically, satellite payloads build custom interfaces that conform to the payload accommodations that are provided by the chosen launch vehicle. Much work needs to be done to develop standard electrical interfaces and have them be universally accepted by the satellite community. In the mean time, non-standard electrical interfaces can be made to work with some additional effort.

Another enabling tool has nothing to do with hardware and may be the most important enabler of multi-payload missions. This enabling tool involves a mission management process that ensures that a reasonable process is used to manifest the IPS, integrate and test the individual payloads and integrated stack, and manage all integration tasks with the launch vehicle. This process starts with the manifesting process. The manifesting process is critical to the success of any multi-payload mission. The manifesting process ensures that the various satellites can be successfully integrated into an IPS. This involves careful planning in several critical areas. The first is that the manifested individual free flyers have compatible mission requirements. The second is that the manifested free flyers can be physically integrated, using an MPA, into an integrated stack that can be flown. Critical factors such as integrated stack mass and balance, integrated stack dynamic envelop, and the crucial deployment scheme  on orbit are need viable solutions to execute a multi-payload mission.

Once the mission payloads have been manifested, it is necessary to create and integrated payload team. This task must be successfully accomplished or the mission will be almost impossible to execute. The key is to get several diverse payload teams to operate as a mission team. Unfortunately, many payload teams are totally focused on their individual satellite payload. This is totally understandable given the long process required to design, build and test satellites. It is important to realize that a single-minded focus on a single payload will not work for multi-payload missions. Each payload team must develop a mission focus. This focus encompasses the individual payloads, the process to take those individual payloads and create an IPS, the integration of the suite on the launch vehicle, and finally the launch of that IPS as a mission team. For multi-payload missions there is no "my mission" or "your mission". There is only "our mission".

A MODEL FOR THE FUTURE

Fortunately several multi-payload missions have been executed that have pioneered the process and serve as a model for future missions. The inaugural mission of the Minotaur I flew and IPS that looked like a single payload to Orbital Sciences Corporation. The complex IPS was composed of four student built satellites, a DoD experimental optical balloon, and an innovative payload isolation system. This multi-payload mission was complicated by the fact that most of the payloads were from the academic community and were not ready to fly when they were manifested. In addition, the mission suite was manifested late in the launch vehicle integration process leaving only 14 months to finish the payloads and integrate them on the MPA. Despite these challenges, the mission team was successfully convened and was able to work through all technical issues and obstacles. The mission team took an attitude that the total mission was important and the any other payload problem was their problem. A poignent example of this approach occurred when the team was integrating all the payloads on the MPA. One of the payloads came in six pounds heavier than planned. This additional mass would invalidate all the trajectory analysis done by Orbital. Normally this would force the mission manager to fly the mass model (Every manifested payload built a mass model that represented the final flight configuration of their payload. In the event that the
delivered satellite did not match the planned and analyzed configuration, the mission manager could save the mission by flying ballast in the form of the mass model in place of the heavy payload to preserve critical IPS mass. CSA Engineering stepped in and changed the material on a support ring on the isolation system from steel to aluminum. This saved enough mass on the IPS to allow the payload to fly despite missing their mass bogy. This is an excellent example of how a mission team needs to operate. When one payload had a problem that they could not solve, another stepped in and fixed it. All payloads flew and the IPS development was successfully completed and all payloads were delivered to orbit.

Another innovative program uses the Poly Picosat Orbital Deployer (P-POD) to fly small picosat payloads. These payloads may be as small as a 1000 cubic centimeters and mass about one kilogram. P-PODs are best described as multi payload dispensers as they fly standardized satellites of a common configuration. The Space Development and Test Wing, Kirtland, AFB, New Mexico, routinely flies P-PODs on Minotaur I launch vehicles. The P-POD is small enough and uses a standard mechanical and electrical interface to make integrating the P-PODs on the Minotaur I fourth stage very easy. Two P-PODs can be carried on each mission. NASA Ames Research Center took advantage of the P-POD capability on a Minotaur by flying the GeneSat payload on the TacSat-2 launch in 2006. NASA/ARC took advantage of the fact that a P-POD can carry three individual 10 centimeter cube satellites or carry one payload that is 10 cm X 10 cm X 30 cm. This capability opens up the utility of the P-POD for the R&D community. P-PODs represent the simplest types of multi-payload missions. The P-POD is very easy to integrate and can be flown at a very low cost. In addition, NASA/ARC has pioneered a method to get real value out of the P-POD system for the R&D community. These secondary payloads fly on Minotaur missions with minimum integration effort and with no significant impact on the primary payload. The ease of integration is a result of standardized mechanical and electrical interfaces. The P-PODs are carried as scab-on payloads on the fourth stage rocket body. The P-PODs remain attached to the fourth stage after separation of the primary payload and are separated into orbit only after completion of the Collision/Clearance Avoidance Maneuver (C/CAM). This ensures the secondary payloads have not impact on the primary payload on orbit. While the P-POD integration on a Minotaur simplifies the multi-payload launch mission, it does illustrate the salient points necessary for success. The Air Force Research Laboratory and NASA are collaborating in applying the lessons of flying P-PODs on a Minotaur I to nanosat class payloads. Specifically we are working to standardize mechanical and electrical interfaces and develop integration schemes with current launch vehicles that minimize the impact to the primary payload spacetlift mission.

Figure 3: the JAWSAT Populated MPA

Figure 4: The P-POD

Figure 5: The P-POD Integrated on a Minotaur

**SUMMARY/CONCLUSIONS**

Spacelift is a precious commodity that should never be wasted. Carrying secondary payloads is one way to ensure that launch vehicles fly full. While some missions do not support secondary payload carriage, many do. Several things need to happen to make multi-payload missions happen. The first is to build adapters for all launch vehicles that facilitate carrying secondary payloads with minimal impact on the primary payload spacetlift mission. Supporting
efforts to standardize mechanical and electrical interfaces will facilitate multi-payload missions as well. In addition, secondary payloads should be designed that minimize the integration requirements with the launch vehicle and operations planning can be accomplished that facilitate operating several space vehicles in relatively close proximity on orbit. The small space community is actively developing the tools needed to facilitate multi-payload missions. Several items need further work. Most importantly, the launch and primary payload communities need to embrace the goal of filling each spacelift mission to full capacity. This takes effort and planning on their parts. The secondary payload community needs to strive to design "minimal impact" satellites that minimize the impact of carrying secondary payloads on the launch provider and the primary payload. Finally, we all need to dig in and make it happen.

REFERENCES

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BIOGRAPHY

Mr. Steven Buckley (Launch Vehicle Technology Lead) is an Air Force systems engineer supporting the Air Force Research Laboratory’s Space Vehicles Directorate. He is involved in developing new technologies that are directly applicable to Air Force space related research and development. These projects include whole spacecraft isolation, multi-payload adapters, responsive small satellites and launch vehicles such as the Minotaur, Raptor, and Falcon SLVs. He is retired from the U.S. Air Force with 25 years of military service. While on active duty he was responsible for providing space lift for the launch of 16 R&D satellites using three different launch vehicles. He has supported over 53 launches including air-to-air missiles, surface-to-air missiles, developmental rockets and satellite launch missions. He received his B.S. in Aerospace Engineering from the University of Florida in 1983. He received an M.S. in Aerospace Engineering from the University of Dayton in 1992.