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Responsive Space Launch with the Scorpius Family of Low-Cost, Expendable Launch Vehicles

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**DOD ACCESS TO SPACE FOR SMALL SATELLITES:
CURRENT OPTIONS AND DIRECTION**

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ABSTRACT

This paper will outline the current technical and programmatic avenues for Department of Defense (DoD) small satellites to gain access to space. While DoD small satellites currently reside in the research and development arena, there are several efforts underway to increase access to space. These efforts are intended to reduce time to space and cost for research and development programs, but also in anticipation of future operational small satellites. This paper will discuss the DoD Space Test Program (STP) process, which is the primary method by which most DoD small satellites gain access to space. The Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) program will be discussed, with current plans outlined. Finally, recent Air Force Space Command (AFSPC) policy on secondary satellite access to space will be provided, with a brief synopsis of the current implementation. In conclusion, an assessment of the future of DoD small satellite access to space will be offered.

BACKGROUND

The DoD Space Test Program is charged with providing spaceflight for the DoD research and development community. It is a voluntary program that has been in existence since 1965. Over 430 DoD experiments have been flown on 165 missions. As a point of reference, over the last 10 years, the Space Test Program has launched 17 free-flying small satellites. Utilizing expendable launch vehicles, the Space Shuttle, the International Space Station, sounding rockets, and other methods, the Space Test Program has produced an impressive 91% success rate. In an effort to reinforce the Space Test Program as the DoD single access point to space for research and development efforts, the Deputy Secretary of Defense re-validated the program on 8 Jul 2002. The discriminator between the Space Test Program and the national laboratories is the focus that the Space Test Program places on mitigating risk to the experiment. The Space Test Program procures off-the-shelf hardware as much as possible and applies a disciplined systems engineering approach to maximize the potential for the experiment to succeed.

The entry point to the Space Test Program is the DoD Space Experiments

Review Board. This board is comprised of representatives from all services, DoD agencies, the Office of the Secretary of Defense, and NASA. The board meets annually to prioritize experiments, with the primary criteria being military relevance. Typically, 35-45 experiments are reviewed.

After experiment validation and prioritization by the Space Experiments Review Board, the Space Test Program Office at Kirtland Air Force Base in Albuquerque, New Mexico then procures the services requested by each experimenter consistent with priority, opportunity, and available funding. Services can include launch vehicle procurement and integration, satellite procurement and integration, and on-orbit operations. The Space Test Program includes an operating location at the Johnson Space Center in Houston, Texas. The Houston office also acts as the single DoD access to the NASA human spaceflight program.

Due to funding constraints, only approximately 20% of the annual Space Experiments Review Board prioritized list is manifested for spaceflight. The primary cost drivers are satellite procurement and launch vehicle procurement.

This paper will initially discuss the general requirement for small satellites, and the benefits of reducing the cost of access to space. There will then be a discussion of the four current methods of small satellite access to space; converted Inter-Continental Ballistic Missiles (ICBMs), commercial small launch vehicles, the Space Shuttle, and as secondaries on medium class launch vehicles.

For the purposes of this paper, small satellites are categorized as any satellite whose launch mass is less than 500kg. Additionally, the term "secondary" is defined as any satellite that does not drive the primary mission requirements (for example, orbit). Also, it should be noted

that national policy prohibits US Government organizations from procuring foreign launch vehicles; therefore they are not considered as an option in this paper.

REQUIREMENT

The current government function for small satellites is research and development, including both NASA and DoD. The national security focus traditionally has relied heavily on a vibrant technological base, which requires a robust research and development infrastructure. In the DoD, consistent funding for research and development projects is often topline driven. In other words, instead of determining what technologies to pursue, estimating that cost, and then funding to that estimate, the DoD establishes topline funding goals as a percentage of the DoD budget. It is up to the DoD services and agencies to budget the funding allowance. The technologists then work within these budgets.

Small satellites are often less capable than larger satellites in terms of redundancy, mission life, and performance. Small satellites are therefore less expensive. However, small satellites can be very capable spacecraft, and thanks to improvements in miniaturization and processing power, they are becoming even more so. As most program managers view the cost of the spacecraft and cost of the launch vehicle (and on-orbit operations) as inherent components of mission cost, it is obvious then that reduced launch costs directly reduce mission costs. Per the DoD practice of budgeting a topline amount for research and development, a reduction in mission cost will directly increase the amount of missions that are able to be executed by the DoD research and development community.

Due to the unique characteristics of small satellites (lower cost satellite/launch),

there is the eventuality that small satellites will be called upon to perform operational national security missions. Mission areas currently under consideration are; space control applications, distributed sparse aperture applications, and rapid “gap-filler” communication and imaging applications.

It is important to note that, although a reduction in the cost of space access may be the predominant goal, there is additionally a clear need to have a reasonable reliability/success rate. Whether for research and development or for operational missions, any launch capability must be effective, since the resources expended are too great to allow a low success rate. Additionally, the time from conceptual planning to launch must be made shorter. For research and development payloads, technology transformation time delays directly impact the fielding of advanced concepts. There must be a quicker path from concept to demonstration/test to results to the field. Also, potential operational missions are focused on quick response capabilities.

Therefore, there is a clear need for the DoD to apply resources to the small satellite community. Lower cost access to space will directly result in greater technological development opportunities. And, although solidly in the research and development niche, small satellites will one day perform operational applications.

CONVERTED ICBMS

Perhaps the most intriguing and innovative idea for small satellite access to space is the converted ICBM. Hundreds of deactivated, surplus ICBMs are currently in storage. These boosters are maintained by the government and are often used as targets for missile defense tests. These government boosters are available through a contract with Orbital Sciences Corporation for space

launch. The Space and Missile Systems Center Detachment 12 manages this contract. Each launch must be approved by the Secretary of Defense and must comply with national ICBM treaties. Thus, this option is only available to US government organizations.

The current operational launch vehicle based on a converted ICBM is the Minotaur. The Minotaur is a combination of the Minuteman II ICBM and the Orbital Sciences Corporation Pegasus small launch vehicle. By utilizing surplus ICBM motors, the total launch vehicle procurement cost is reduced. The Minotaur has flown twice, and is capable of lifting 385kg to a 500km, sun-synchronous orbit.

The Peacekeeper vehicle (based on the Peacekeeper ICBM) is currently being designed, and has yet to fly. The contract that converts the Peacekeeper ICBM to an orbital launch vehicle was awarded to Orbital Sciences Corporation in early 2003. This vehicle is projected to be operational by 2006. The anticipated capability of the Peacekeeper launch vehicle is 1120kg to a 500km, sun-synchronous orbit. Due to the increase in capability over the Minotaur, several concepts for multiple payload adapters are under development. Both vehicles, by using existing boosters, can be called to service in as little as 18 months.

Based on current known costs, the approximate cost to the orbits referenced earlier is ~\$50,000/kg for the Minotaur, and ~\$18,000/kg for the Peacekeeper. Note that these costs are flyaway costs, which includes the cost of the range resources, payload processing, integration, and mission assurance.

COMMERCIAL SMALL LAUNCH VEHICLES

The current commercial fleet of small launch vehicles is comprised of the Orbital Sciences' Pegasus XL and Taurus (a Taurus XL version is in development). The Lockheed Martin Athena launch vehicle is believed to be unavailable at this time. The Pegasus has flown 32 times, with 18 consecutive successful launches since 1996. The Pegasus XL has the capability to place a 255kg satellite into a 500km, sun-synchronous orbit. The Taurus has flown five times, with the sixth launch failing in 2002. The Taurus is capable of placing 950kg to a 500km, sun-synchronous orbit.

Based on current known costs, the approximate cost to the orbits referenced earlier is ~\$70,000/kg for the Pegasus XL, and ~\$37,000/kg for the Taurus. Note that these costs are flyaway costs.

Based on the goal of reducing the cost of access to space and the renewed national emphasis on operationally responsive launch, several efforts are underway commercially and within the government to create new small launch vehicles. Regardless of who leads the effort, the government appears to be very interested in participating with the commercial community in developing the capability. The most mature government program is called the Responsive Access, Small Cargo, Affordable Launch, or RASCAL. The Defense Advanced Research Projects Agency (DARPA) manages RASCAL. RASCAL is a concept that utilizes a high performance aircraft as a reusable first stage, and a low-cost expendable upper stage. The estimated performance of RASCAL is 75kg to a 500km, sun-synchronous orbit. The program is targeting a 2006 launch and is designed to be in the \$10,000/kg range. Two of the most promising new commercial efforts are launch vehicles from Microcosm

Incorporated and Space Exploration Technologies. Both of these companies are developing liquid-fueled small expendable launch vehicles. The specific information about each vehicle is proprietary, but it is believed that these efforts are targeting the <\$25,000/kg range. The projected first flights are believed to be in the 2004/2005 time frame.

Additionally, there has been a recent national emphasis on responsive space launch. Typically this requirement has been linked to small launch vehicles. Both the National Aerospace Initiative and DoD leadership have recently outlined the requirement to develop a launch system that could handle 250-450kg satellites and launch in days rather than months. The initiative would target the \$3-4M per launch range (\$10,000 to 17,000/kg) and launch in 2007.

SPACE SHUTTLE

The Space Shuttle is a very capable method for providing access to space for small satellites. Ejecting small satellites from the cargo bay is a very robust capability, yet this option is limited by both the Space Shuttle orbits and the human spaceflight safety process. The Space Shuttle orbit is ~300km at mid-inclinations. However, Space Shuttle orbits are dominated by the requirement to service the International Space Station. Therefore, the current exclusive orbit for the Space Shuttle is 390km at 51.6degrees. This orbit is undesirable for most free-flying satellites, as the low altitude often results in a very limited on-orbit lifetime. Additionally, the requirements to comply with human spaceflight safety requirements demands a level of effort that so burdens small satellites that it can adversely impact their mission (additional hardware can add mass, cost, and design challenges; operational constraints

can drive inefficient on-orbit operations; removal of desired materials can complicate design/fabrication, etc...).

There are several efforts underway to create a small satellite propulsion system (either integrated to the host satellite or as a “throw-away” module) that will help address the low altitude issue. Additionally, there are efforts underway to “containerize” small satellites. This effort may alleviate some safety requirements on the satellite, as the satellite is completely contained in the human spaceflight rated container. Current plans call for both of these efforts to be available by 2005.

SECONDARIES

The final method currently used to gain access to space is flying as a secondary satellite on a medium class launch vehicle. Generally, this method can be the least costly; although the cost of adapters, analysis, complying with the host prime spacecraft requirements, and sharing of launch costs can vary widely. Additionally, the secondary spacecraft is only a candidate if there is a prime mission going to an appropriate orbit for the secondary. Thus, secondary satellites opportunities cannot satisfy all small satellites.

The current medium launch vehicle secondary opportunities are with the heritage launch vehicles (vice the Evolved Expendable Launch Vehicles), including the Titan II/IV, Delta II, and Atlas II vehicles. Since each of these vehicles came from radically different development environments, there is no reasonable secondary capability common to all vehicles. Additionally, today, each secondary opportunity is treated as a unique, one-of-a-kind event. This results in the need for custom mounting adapters, custom integration, longer lead times, and generally more expensive efforts. There are no

accurate cost to orbit figures, and this option is considered not to be a reliable method of consistent, cost efficient access to space for small satellites.

However, since the DoD is committed to the Evolved Expendable Launch Vehicle (EELV) fleet as the preferred (required) medium launch vehicle, then the focus of future secondary opportunities is on the EELV. There are several hardware solutions in work to address secondaries on both the Lockheed Martin Atlas V and Boeing Delta IV, including some proprietary efforts underway that will not be discussed here. The government led efforts underway include a NASA requirement under solicitation and the DoD EELV Secondary Payload Adapter (ESPA).

The ESPA is a joint Air Force Research Laboratory and the Space Test Program development designed to accommodate secondary satellites on both EELV-Medium vehicles. The design allows for up to six small 181kg satellites with a volume of 61cm x 61cm x 97cm each, to be accommodated on one launch vehicle in addition to the prime satellite. The basic philosophy underlying the development of ESPA is to minimize the impact of the secondaries on the prime payload. This is accomplished by strictly limiting the secondary satellite mass/volume and by only raising the prime satellite by 61cm from its standard position. ESPA is intended to be developed, qualified and proven by the government, then transitioned to industry for further development and/or usage. This transition effort is underway. The first flight of ESPA is on the STP-1 mission in 2006.

POLICY

There are currently two policies of interest to the DoD small satellite

community. These policies address roles, responsibilities, and timing.

First, a single lead for small satellites within the DoD has not been officially recognized. Although this function has been performed de facto by the Space Test Program, formal direction is non-existent. This situation results in a disconnected/confused relationship between organizations. Additionally, it creates resource allocation issues. On 18 June 2002, the Air Force Space Command Director of Operations issued an interim policy letter¹ that declared STP as the "...front door for all agencies requesting launch services for piggyback payloads and secondary satellites on (combatant command) COCOM missions." The policy addresses both secondaries on expendable launch vehicles and piggybacks on host satellites. The focus in this paper is on the secondary process. This policy purposely excluded EELVs and is applied solely to heritage launch vehicles. However, it is acknowledged that this policy forms the basis for future EELV secondary policy.

The secondary satellite component of the policy places the Space Test Program as the secondary launch opportunity coordinator, with both the launch vehicle program office and the prime satellite office as approval organizations. Additionally, the policy calls out an extensive AFSPC headquarters coordination flow.

Given that there is a secondary policy, and there is the basis for an EELV secondary policy, there is also some direction regarding the timing of any secondaries on EELV. Per various responses to inquiries from NASA, there will be no secondaries on an EELV prior to the STP EELV launch in 2006. Currently, efforts are underway to define the EELV secondary process, capabilities, and to

establish missions, as long as the flight requirement is after 2006.

CONCLUSIONS

First, small satellites have a bright future in both the research and development community and ultimately in the operational environment. A decrease in the access to space cost is directly related to the future viability of small satellites. This decrease in cost must be accompanied by high reliability, and per recent initiatives should be much quicker to execute.

There are several viable methods to achieve access to space, and some exciting new capabilities on the horizon. Converted ICBMs offer great capability at a reduced cost for government users. Both the Minotaur and Peacekeeper space launch vehicles offer incredible value, but ultimately, they are limited to the amount of boosters in storage and are not available to the entire industry.

The commercial small launch vehicle industry is currently dominated by Orbital Sciences Corporation. New government and commercial small launch vehicles are under development that, if successful, will offer a significant reduction in cost. These efforts come on the heels of previous initiatives, however, and the burden to produce results is high.

The Space Shuttle continues to offer tremendous opportunities to small satellites at a reasonable cost. The significant hurdles include human spaceflight rating and the low altitude. Both of these issues are receiving attention and improvements will only make this opportunity better. The effects of the Columbia tragedy and any impacts to small satellite opportunities have yet to be defined at the writing of this paper.

The secondary satellite concept is at a crossroads. The mission unique philosophy of the heritage launch programs

¹ Interim Policy on Secondary/Piggyback Payload Approval Process, dated 18 Jun 2002

appears to be giving way to a more common, standardized process. Given the success of efforts currently underway, this method of gaining access to space for small satellites appears to be very promising.

National policy clearly supports a robust small satellite access to space capability. Both the EELV secondary satellite policy and the low-cost, operationally responsive space launch focus indicate that the highest levels of DoD are committed to supporting small satellite launch options.

In conclusion, there are several discrete methods of spaceflight for small satellites. While one can argue that the current state of affairs (specifically the “high” cost), is inadequate, there should be optimism that the opportunity for reasonable access to space options for small satellites is on the rise.