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Small Payload Launch Opportunities and Challenges

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ABSTRACT

Small payload launch opportunities have been difficult to arrange within the United States, driving many small payload owners to foreign launch services as their best option. This is in spite of the fact that each year in the United States thousands of pounds of excess capacity to orbit goes unused. There are several reasons for this that this paper will address, along with a review of potential options for improving the situation. In addition to these secondary rideshare opportunities, there are several emerging small launch vehicle offerings that will be capable of providing dedicated space access for small payloads; these U.S. systems and their associated development status will also be discussed herein.

Even if the U.S. small payload launch opportunities could be made completely accessible, there would still likely be more small payloads seeking a launch than the available capacity could satisfy. Various categories of small payloads will be postulated and the issues and options for acquiring secondary launch opportunities will be discussed. Safety, integration, and mission assurance implications and options will be discussed in the context of establishing criteria and guidelines acceptable to the launch services providers, launch service acquirers, and prime satellite owners.

The third topic of this paper is the operational implications of a proliferation of small satellites on space track capabilities and space debris in general. The perception of these concerns could impact the ability to acquire a launch opportunity, where any damage due to collisions have liability implications for the launching state and the ability to keep an accurate track of small objects in space complicates this matter.

This paper will draw upon the significant insight and ongoing engagement of the launch community by the authors. In addition, the three described topics will be further addressed through the findings and recommendations produced by working sessions at the 2015 Small Payload Rideshare Symposium held in June. This paper is intended to frame these three important topics and stimulate an informed discussion among the small payload rideshare community and the various government agencies responsible for space policy, launch services, and on-orbit support operations leading to an increase in viable opportunities.

INTRODUCTION

This paper summarizes the authors' perceptions of the small satellite launch status, issues, concerns, and opportunities based on the presentations, panels, and side discussions at the 2015 Small Payload Rideshare Symposium. The paper attempts to frame and characterize the major issues for continued discussion and eventual resolution or mitigation.

The goal of achieving routine, affordable access to space for small satellites involves more issues than just finding a launch opportunity. It is predicated on the assumption that the small satellite performs a useful function and provides meaningful data to a recognized set of users; it assumes that the small satellite provider has completed all the necessary licensing and approval processes; part of these processes involves addressing the requirement to dispose of the satellite after its useful lifetime.

In the case of those small satellites that have no stabilization or propulsion capabilities, it assumes that the satellite will be placed in an acceptably low orbit that will ensure that it decays naturally within the currently defined 25-year period. It assumes that, over this lifetime, adequate consideration has been given to the marginal increases in tracking and cataloging efforts that permit the development of collision warnings and that the additional risks to other operational satellites has been determined to be acceptable.

Heretofore, most of these issues received very little attention beyond the relatively small group of people directly involved in these activities. However, recently there have been a number of proposals and initiatives to launch large constellations of small satellites, which could affect these issues dramatically. These proposed constellations could be divided into two groups, with each group having its own set of issues and factors.

The first group includes proposals by commercial companies to deploy several thousand small satellites providing Internet services; it is assumed that this class of satellite would be in the higher end of the small satellite range and would likely have both stabilization and maneuver capabilities. The second set consists of constellations of hundreds of CubeSats that might not have maneuver capabilities.

This dramatic proliferation of small satellites has already begun to attraction much more attention from a wider spectrum of government and commercial organizations. This increased attention could have a significant effect on the ability to secure routine, affordable launch services for the entire small satellite community.

2015 SMALL PAYLOAD RIDESHARE SYMPOSIUM

The Small Payload Rideshare Association's (SPRSA) 17th annual Small Payload Rideshare Symposium was hosted by John Hopkins University, Applied Physics Laboratory on the 9-11th of June this year [1]. The purpose of these symposia is to provide a forum for government, industry, and academia to discuss the issues related to providing routine, affordable access to space for small payloads. This year's program was divided into topical sessions and attempted to explore some of these issues.

The first question addressed was, "What would be required to routinely access the excess capacity available on large launch vehicles?"

Each of the large U.S. launch vehicle families (Atlas V, Delta IV, and Falcon 9) is capable of carrying secondary payloads ranging from CubeSats at the smallest end of the spectrum through satellites larger than EELV Secondary Payload Adapter (ESPA) class (~200 kg). While excess launch capacity is available on many of these launches, relatively few of these missions carry secondary payloads. This session attempted to drive out the key reasons for this and explore the steps that would be necessary to better capitalize on these launch opportunities.

Since small satellites can either reach orbit as a secondary satellite on one of these larger launch vehicles or on a small, dedicated launch vehicle, a separate panel at the Symposium reviewed the status of some new small launch vehicles projected to enter the market in the near term. While this paper will only summarize the providers represented at the Symposium there are other small launch vehicles that currently exist or are in development.

The second question addressed was, "If this excess capacity could be routinely accessed, how should this capability be optimized or best used?"

The purpose of this question was to explore the value of small satellites and the system trades between satellite size and mission capability; if an optimum size could be found that would maximize the mission capabilities of the small satellite that fell within a range that could more easily be accommodated on most large launch services, the likelihood of negotiating routine flight opportunities would be increased.

The third question addressed was, "If this capacity was routinely and efficiently used for small satellites, what would be the implications for space traffic management and space debris?"

This question has implications for U.S. treaty obligations, international liabilities, space tracking, object cataloging, and potential collision warning, risk evaluations performed by operational satellite users, and satellite regulation, approval and licensing.

The Symposium sought to identify and frame the issues discussed in these sessions as a step towards broader discussions and eventual resolutions or mitigations. A summary of these sessions will be presented in this paper in the order listed above.

SMALL LAUNCH VEHICLE OPPORTUNITIES

The most straightforward method for a small satellite to reach orbit is through the use of its own launch vehicle. The advantage of this approach is that the small satellite operator controls the launch schedule and selects the best orbit possible within the capabilities of the small launch vehicle selected; the disadvantage is usually the cost of the launch service.

The use of small, dedicated launch vehicles within the United States has changed over time with the progression from all launch systems and services being under government control to the emergence of commercial launch systems and services being available as an adjunct to the government systems. With the advent of commercial launch services under the Commercial Space Launch Act, a number of small satellite launchers emerged in the 1990s. Some of these were purely commercial developments, while other developments were either funded by the government or benefited from some form of government support.

Some succeeded in becoming operational, while others disappeared from the marketplace after an initial failure. In 2000, the Air Force began flying Minotaur, a decommissioned ballistic missile converted to a small space launch vehicle, for government missions.

Over the years the costs of these small launch vehicles increased steadily (some by as much as almost a factor of ten) for a variety of reasons. While the reasons for the cost increases may have varied from system to system, the results have been the same; the costs of these dedicated small systems have moved beyond what many small satellite operators can afford, relegating the use of these systems to a diminishing number of government customers.

However, today there is a re-emergence of small launch vehicles being developed with a goal to provide launch services in the 2-15 million dollar range. Private companies are developing some of these, while others are government-sponsored developments with hopes of eventual commercial spinoffs. Several of these systems were discussed at the Rideshare Symposium and are briefly reviewed here.

Rocket Labs of New Zealand, founded in 2007, is developing their Electron launch vehicle capable of placing 100 kg into a 500 km sun synchronous orbit. Their plan is to launch once a week with a launch cost of $4.9 million. Their Rutherford oxygen/hydrocarbon engine has been test fired over 300 times over the last two years the first stage of Electron is powered by nine of these engines. Launching from New Zealand, they can reach inclinations ranging from 45° to sun synchronous.

Firefly Space Systems of Austin Texas was formed in January of 2014 and plans to test fire their engine this summer. They are planning the first launch of their Firefly vehicle in 2017 and expect it to be capable of placing 400 kg in low earth orbit.

Interorbital Systems, founded in 1996 and operating from Mojave, California, has been developing their NEPTUNE orbital system based on their Common Propulsion Module (CPM) which can be used as a stand-alone sounding rocket. By clustering these CPMs as basic building blocks, they plan to provide a series of scalable orbital systems. Their NEPTUNE 5 consists of five clustered CPMs and a kick stage.

The Boeing Phantom Works Airborne Launch Assist Space Access (ALASA) project, sponsored by the Defense Advanced Research Projects Agency (DARPA) consists of a two-stage rocket launched from an unmodified F-15E. Plans are for 12 launches, 3 with engineering payloads and 9 demonstration missions. The goal is to deliver approximately 43 kg to 185 km at 45° inclination for less than $1 million. The first launch and all 11 subsequent flights are scheduled for 2016.

Super Strypi, while not part of the Symposium program, was discussed in light of its pending maiden launch. Super Strypi is a government developed small launch vehicle managed by the Operationally Responsive Space Office in Albuquerque. It is scheduled for its maiden launch as part of the ORS-4 mission from the Navy's Pacific Missile Range Facility on Kauai in October of this year.

These new systems will be demonstrated over the next few years as they complete their initial launches. Even if they are not all successful, for the first time in years there are a number of new options that offer the promise of reduced costs for the dedicated launch of small payloads. This sector of the community appears energized and will hopefully provide new operational capabilities in the near future.

SECONDARY PAYLOADS AND EXCESS LAUNCH CAPACITY

Excess capacity or excess performance is usually seen as margin above and beyond that held by the launch services provider and the prime spacecraft. This excess capacity could be used to carry additional small payloads. Excess capacity is usually available in some amount on both foreign and domestic launch services providers in their support of both government and commercial spacecraft.

There are three basic models for excess margin. In the government model the Government customers hold all performance margins as part of their mission assurance options and actively control all vehicle integration activities. In the first commercial model commercial customers would consider all launch vehicle performance capability as theirs and would view excess capacity as a commodity they could sell to offset their launch costs. In the second commercial model, the launch services provider would retain control of all excess capacity beyond that necessary to ensure the success of the prime mission.

The first commercial model has not resulted in many secondary missions on U.S. commercial launches for a variety of reasons; sometimes the commercial owners' view of the value of the excess capacity has not matched the price the secondary users were willing to pay. Other factors, such as mission success considerations, inadequate funds to merit the perceived increase in complexity, and the difficulty in matching their injection parameters with those of available secondary satellites, have also limited the ability to conclude agreements.

The majority of the U.S. manifest is dedicated to launching government payloads and the government customers have traditionally adopted the government model described earlier assuming the excess capacity was theirs rather than the launch services providers. Some government acquirers include contract terms requiring that all excess margins be allocated to them. The majority of the launch services providers have not resisted this approach and have supported their customers preferences.

This perspective is based on buying the entire launch vehicle's capability rather than simply buying a launch service; the rationale is that they:

- have paid for the entire vehicle,
- are responsible for mission success,
- and that secondary payloads represent a potentially marginal threat to mission success.

Considering the value and importance of these national security and civil missions, this is a difficult position to argue against.

Nevertheless, this approach has basically placed excess capacity on these missions beyond the reach of the general small satellite community. While the government agencies occasionally use the excess capacity for their own secondary satellites, this has been more the exception than the rule.

There are several reasons for the limited number of government secondary missions; one reason is simply limited funding; others reasons include the difficulty of aligning flight opportunities and mission parameters with the mission requirements of the secondary payloads. Orbital heights and inclinations required by the secondary payloads may limit the number of prime mission that could support them. Another factor is schedule incompatibilities; secondary payloads must meet the schedules imposed by the prime missions. Any failure to meet these key milestone dates can result in the loss of the flight opportunity.

In addition to finding prime mission partners willing to accept secondary payloads, the secondary payload owners face the additional difficulty of negotiating acceptable launch opportunities: launch schedules are fixed by the primary spacecraft and its requisite injection parameters, which may not be suitable for all small satellite missions.

The advantages of launch opportunities as a secondary payload on a large prime mission are lower costs and often greater performance to a wider range of orbits; under the best of circumstances, the secondary payloads would only be required to pay the additive or integration costs and not a pro rata share of the prime launch vehicle cost. The disadvantages are no control over launch schedule and limited control over deployment parameters.

All these issues combine to create a difficult situation. Small satellite builders are reluctant to build completed spacecraft without a relatively certain assurance of a launch; once a launch opportunity presents itself, the small satellite builder may have limited time to complete his work and meet the required mission schedules.

One of the more notable examples of recent successful secondary flights is the Atlas V Aft Bulkhead Carrier (ABC); the National Reconnaissance Office (NRO) sponsored the first flights of the ABC designed by ULA and has flown it three times on their missions. This Atlas-unique secondary adapter is capable of carrying 85 kg; while it can accommodate a single small satellite, it has recently been used to mount a collection of P-PODs for dispensing 28U of CubeSats.

When a government agency has a requirement for a secondary launch on a specific mission, it could be included in their Request for Proposal when they initially seek a launch provider; if they have no need for the excess capacity, there should be a process by which it could be offered up for responsible use, if there is no impact to the primary payload or compromise the security of the mission. The potential small satellites that could benefit from these opportunities could come from other agencies within the national security, civil, and commercial sectors and be built by government, industry, and academia.

It is highly probable that the best match for a civil secondary payload might be on a national security mission; an academic small satellite, designed to demonstrate a new technology or capability without a government sponsor, might only be able to meet its orbital requirements by flying on a commercial mission. To achieve the most effective and efficient use of excess capacity across all the U.S. space sectors, a process would be required that allowed for maximum access to all U.S. launches independent of the acquirer or prime mission owner.

This is a challenging goal and could only be achieved through the cooperation of all the U.S. space sectors.

Mission success/mission assurance concerns are real and government agencies should always have the right to review the integration of secondary payloads on their launch vehicles. The most the small payload community should expect is a balanced position that recognizes valid mission assurance concerns while offering up as much excess capacity as could be prudently made available.

Key issues to routinely accessing excess capacity on these classes of missions include:

- Who should manage the excess capacity?
- Who should identify appropriate secondary payload candidates?
- Who should select, plan, and integrate these secondary missions?

The individual government agencies responsible for either the prime spacecraft or the launch service may not be inclined to spend their limited appropriated funds for these purpose; they could more easily justify spending appropriated funds for mission assurance reviews to ensure that the inclusion of a secondary on their prime mission would not pose an increased risk to their mission success.

This leaves the launch services provider as a viable candidate to fill this role. Currently, it is not clear that the secondary satellite market is robust enough to make this a self-sustaining commercial business; many the secondary missions fall more in the category of a public good than a true market. Often, these secondary satellites are technology or capability demonstrators that could ultimately lead to new missions and new programs. These marginal investments in future developments may prove to be the best approach to securing support and funding for new programs in limited budget environments.

If the launch services providers could justify satisfying this secondary demand in the near term, there is the possibility that it could develop into a viable market in the longer term.

For the near term, the U.S. launch manifest will continue to be dominated by government missions. Without some change, the excess capacity on these missions will likely remain largely unavailable for secondary rideshares other than a few CubeSats and select government small satellites. Other U.S. small secondary satellites will most probably continue to seek launch opportunities with foreign providers.

Government and industry are at a crossroads as to how to actively manage the question of excess launch capacity. The government agencies are, and should be, conservative in ensuring a high probability of mission success and low risk in providing launch services for the nation's most valuable and critical space missions. Excess performance margin, of itself, can be a component of assuring mission success by simply providing additional margin to mitigate unforeseen circumstances.

But how much margin is really needed? At what point does additional margin begin to be more of a waste of capability than a useful hedge against uncertainty? Government and industry should work together to clearly understand the answers to these trades. As the government begins to acquire launch services more competitively, it will be even more important that the proposals and contracts are clearly written and specify what capacity is required and who would be best positioned to manage any excess capacity while assuring mission success.

If the government agencies, working among themselves and with commercial companies and academia, can develop acceptable and efficient ways of maximizing the use of excess launch capacity for high value secondary missions, the U.S. could capitalize on this currently untapped asset.

OPTIMIZING AVAILABLE EXCESS LAUNCH CAPACITY

Once a solution has been found as to how to provide efficient access to this available capacity, the next task would be to establish an appropriate level of performance capability that could be made routinely available. Setting this value too high would limit the number of flight opportunities and setting it too low would waste available performance. It should be an amount available on the majority of all prime mission launches; it should be an acceptable amount to the prime spacecraft operators who pay for the prime launch service, the launch services acquirers who are responsible for launch mission assurance, and the launch services providers whose market share in a competitive environment depends on sustained mission success.

A key enabler for the CubeSat community was the standard P-POD dispenser. The small satellite community needs a similar standard. Assuming that the excess capacity on U.S. launch vehicles could somehow be made available, what size payload capability would be optimum? Seeking too large a capacity would limit the number of times it would be flown; settling for too small a capability would limit the value of the flight opportunity.

Clearly, an EELV Secondary Payload Adapter (ESPA) ring defines the high end of the small satellite adapters and is so capable that it will likely be flown infrequently since few missions would have this much excess capacity available; however, it has de facto established a "standard" spacecraft size, i.e. an ESPA-class payload of a given volume and 200 kg weight.

P-PODs, in any quantity, would still be limited to deploying CubeSats and would not be of use to other small satellites.

For the purposes of this discussion, the reference to a standard size secondary adapter should be viewed as a description of a capability rather than a point hardware design. Once a "standard" size and weight has been chosen, there may be a need for several secondary adapters that would accommodate this standard, each able to interface with a variety of launch vehicles.

All spacecraft components can be divided into two general categories – bus services and mission equipment. As spacecraft get smaller the bus services begin to account for a higher percentage of the available weight and volume. At some point, as is the case with CubeSats, some bus services, such as stabilization and propulsion, may be dropped altogether.

Several studies have been done to attempt to define that "sweet spot" where maximum mission capability is achieved at minimum weight and volume. The tentative conclusion seems to be that a useful size would be a standard secondary adapter capable of carrying about 90-100 kg or half an ESPA class payload.

These adapters should be able to accommodate a single small satellite or serve as a mount for a collection of P-PODs. This approach would provide both standardization from an integration perspective and flexibility in payload selection and operations; this flexibility would offer the small satellite community the best chance for routine secondary launch opportunities. The Atlas V Aft Bulkhead Carrier (ABC) is an example of just such an adapter – capable of mounting an 85 kg small satellite or a collection of P-PODs uniquely to the Centaur stage. This type of flexibility in the range of payload accommodations is an excellent model for maximizing efficient use of excess capacity.

Ideally, two standard adapters in this size range could be made available on essentially every flight with adequate margins. With each capable of carrying about 90 kg, the total secondary capability routinely available would be around 180 kg; this seems like a realistic goal for a routine secondary accommodations that could be available on most U.S. large launch vehicles. This approach would seem to offer the best compromise between the maximum weight likely to be available and acceptable on most U.S. prime launches and a capability to provide flexible launch opportunities for a variety of highly capable and useful small satellites.

Routine flight opportunities with limited available weight appear to be more valuable than aperiodic opportunities with large available weight. Routine flight opportunities would allow small satellites to drop out of the flight queue and others in waiting to move into their space. To achieve this degree of flexibility, the standards and requirements would have to be comprehensive enough the permit early certification and flight approval. Essentially, the queue of small satellites waiting for launch would have to be transparent to the launch vehicle and the prime missions.

While this would not be possible in all cases, it should be a goal as the community continues to define the best terms and conditions for improving the safety and acceptability of small secondary satellites as a class.

If secondary payloads are to be affordably and easily integrated onto large launch vehicles, the interfaces need to be minimal. If more than one small satellite is involved, sequencers could be used rather than individual interface commands from the launch vehicle; designs for these types of secondary sequencers already exist.

Typically, secondary payloads are not deployed until after the deployment of the primary spacecraft to reduce risks to the prime mission. A general set of conditions that if met by the secondary spacecraft, would facilitate acceptance by both the prime spacecraft and the launch service acquirer and provider.

SMALL SATELLITES & SPACE DEBRIS

Space debris is defined as any man-made object in space that is not serving a useful purpose. These are typically dead satellites, rocket bodies, parts or pieces from deployments, explosions, or collisions. The space surveillance system attempts to track all objects in space, and for those that can be tracked consistently enough to establish an orbit, enter them into a catalog. The smaller the object, the more difficult it is to track and, unfortunately, the majority of the potentially lethal space debris is currently beyond our ability to effectively track.

Just as air traffic control works to avoid collisions among aircraft, space traffic control would have the objective to avoid collisions among space objects. Spacecraft are less maneuverable than aircraft and the implications of movement are more pronounced. Spacecraft flight paths are fixed by Kepler's laws and the results of a propulsive maneuver are limited, while consuming a finite propellant resource. Some satellites don't have a capability to maneuver while they are active, much less after their useful lifetimes.

CubeSats, as an example, typically have short lifetimes and no maneuver or disposal capability. Space debris mitigation guidelines specify that objects will either reenter within 25 years after the end of the mission, or will be moved sufficiently far from useful orbits that they will not pose a risk of collision. CubeSats have usually met the 25 year decay rule by flying in low orbits, roughly under 600 km. Satellites under this altitude generally decay naturally within 25 years.

But this limits the launch options to those missions that could provide secondary deployments to this insertion threshold, where many LEO constellations—notably for communications—prefer higher altitudes to increase ground coverage and user access.

There are drag enhancement options and small de-orbit propulsion options available for consideration by small satellite operators. They represent an additional complexity and expense that can create a conflict between responsible environmental behavior and sound economic business cases. Most drag enhancement devices actually increase the object's cross section and marginally increase the short-term collision risk, while seeking to meet disposal guidelines that are intended to decrease the long-term risks.

One of the key observations pointed out in the debris session at the Rideshare Symposium was that potential collisions scale with quantity more than size. Potential collision calculations assume a volume around each object that is typically much greater than its actual size – usually kilometers. Therefore the estimates are not as sensitive to the actual spacecraft size – one tenth of a cubic meter or ten cubic meters – as they are to the number of possible objects that could be involved in a collision. Other spacecraft seeking to avoid a collision react to this larger conjunction area. This has significant implications for large CubeSat constellations with no maneuver capabilities.

The regulatory environment for commercial space is currently not straightforward. The Department of Transportation's Federal Aviation Authority (DoT/FAA) has authority for licensing commercial launch sites, launches, and re-entry. The Federal Communication Commission (FCC) and the International Telecommunications Union (ITU) regulate radio frequencies. The National Oceanic and Atmospheric Administration (NOAA) regulates remote earth sensing.

The efforts of these U.S. agencies are conducted through a lengthy process of rulemaking that must include a cost-benefit analysis. The result is a complicated process for obtaining licenses to launch and operate a system from the commercial operator's perspective, and difficulty in enforcing debris mitigation compliance from the government's perspective.

There are growing concerns from the operators of existing space systems about the potential operational impact of new, large constellations of small satellites, which could provide a stimulus for revised or increased regulations. The industry as a whole can expect continued debate and a growing call for regulation, active space traffic management, or both.

The U.S. is a signatory to international treaties that hold the launching state liable for damages incurred from objects it places in space. To date, there have been so few collisions that case law has not been developed. The international perception is that the U.S. seems to be lagging behind the international community in their concern for the growing amount of space debris and its potential for damage.

There is a clear environmental concern that should, and likely will be, recognized as the number of nations operating spacecraft increases and the implications of collisions, damage, and the subsequent creation of additional debris becomes more apparent. All objects in space represent a potential threat to all other objects in space.

Tracking the total number of objects in space will become more challenging and expensive as the number of objects increases. Tracking and cataloging is necessary to know which objects are which, who is responsible for them, and whether or not they can maneuver.

The ability to maneuver has both a positive and a negative aspect. Maneuver allows for options to avoid collisions and de-orbit; maneuver also complicates tracking since, after a maneuvering, a cataloged object will not appear as expected and will require some time to correlate data and re-establish a cataloged track. Satellite users currently do not necessarily publish or otherwise notify anyone of their maneuvers before execution or in near real time after the fact.

After a spacecraft has maneuvered and before a new track has been established, there is a period of time when all collision encounter analyses are invalid; a given maneuver may actually have placed the satellite into a potential collision encounter that was not recognized. The ability of the tracking systems and operators to communicate potential threats to operators may not be adequate to allow for considered maneuver options. Our space surveillance networks have the responsibility to track, catalog, and provide warning for potential dangers. Commercial space operators may soon account for a much larger portion of the objects that must be tracked.

Their interest timely tracking and warning information has led to the creation of commercial space track services specifically tailored to these needs.

The ability to efficiently track and catalogue all objects in space is a critical requirement whose importance will only increase with the projected growth in the number of satellites in orbit and the amount of space debris. Furthermore, without a cohesive plan inclusive of the commercial and government markets, the ability to ensure a safe orbit for all satellites will decrease over the next decade as thousands of small satellites, including CubeSats, enter orbit.

If the government is to provide these services to an increasing number of users, the costs to provide the information will likely increase. The options for funding this activity will need to be addressed and could range from pure government funding all the way to taxes on commercial operators to offset the government's costs.

Space operators are expending more resources evaluating the potential encounters and possible collisions between their active satellites and other space objects. This is necessary to determine whether or not there is sufficient risk to warrant a risk avoidance maneuver. Typically, these types of maneuvers may only be rarely implemented, but the resources to reach the determination are not trivial and are likely to become even more costly and difficult as the number of objects increase.

These analyses to evaluate the need or benefits of maneuvering a spacecraft take time and money even if decision is to do nothing. All maneuvers have implications for operations, satellite resource management, and ultimately satellite lifetime considerations. Every new space system has a potential impact on other satellite operators, but this is often not considered in system design. Large-scale constellations of small satellites may have a significant impact on other satellites operations.

The need for some type of space traffic management will only increase with time; the growing number of objects in space represents a significant environmental problem with international implications and consequences. The need for a risk/benefit analysis may soon become an integral part of the decision to deploy any satellite; this could be a concern for the deployment of constellations involving numerous small satellites, especially if they have no provision for maneuver or de-orbit.

Small satellite operators can be seen as responsible members of the international space community by voluntary and overt compliance with space debris mitigation guidelines and best practices.

SUMMARY

Small satellites can provide significant mission capabilities; some of these capabilities may be of value to only a small user community while others may offer significant public good.

Space is a finite shared resource and all objects placed in space have potentially profound implications for all other objects. In this environment, the value of the individual small satellite and the usefulness of the mission data it provides will likely become a more critical part of any risk/benefit analysis.

How should the value of a satellite or a space-based capability be evaluated and judged? Who should make the judgment? Since the launching state is ultimately responsible for damages, should each launching state make the determination as to whether the benefits of a specific satellite or capability outweigh the risks? Is the ability to place an object in orbit sufficient justification for permitting it?

All U.S. sectors are involved with satellites – national security, civil, and commercial. No single government agency is responsible for behavior of all three sectors. The increasing number of small satellites and the plans to launch hundreds, if not thousands, of small satellites in the future are outpacing the government's formulation of policy and the creation of regulations to ensure safe orbital operations for all space users. This is **a** national issue with international ramifications that will undoubtedly receive increased attention in the near term.

OBSERVATIONS

The availability of small, dedicated launch services seems to be increasing. While these new systems have not yet launched, there are enough initiatives underway to justify the optimism that some of these new systems will mature into an affordable and operational capability in the near future.

Secondary payload launches from large launch services deploying prime payloads are more problematic. Foreign and some limited commercial launches appear to offer an impressive increase in secondary payload launch opportunities; foreign launch services will likely remain and attractive and viable option for many U.S. secondary payload missions.

Secondary payloads on government missions still represent a significant challenge. The government prime spacecraft owners and the government launch services acquirers typically have little problem flying government sponsored secondary spacecraft; flying secondary payloads that do not directly support specific agency mission areas are more problematic.

The only established processes for accessing secondary flight opportunities on these government missions primarily address government small satellites. Current practices limit the launch services providers from making excess capacity available to general users.

The launch services providers have few incentives and no clear business case to provide secondary payload services, even if their government customers were to allow it.

Space traffic management and the management of space debris are attracting increased attention at the international level. These issues will only become more important as the number of satellites increase.

In this environment, the value of the individual satellites and the data they provide will become a critical aspect of obtaining launch and operational approvals and licenses.

The ability to maneuver out of harm's way and to dispose of satellites at the end of their lifetime may become a non-negotiable requirement.

RECOMMENDATIONS

Government, industry, and academia need work together to develop acceptable and efficient ways of accessing and maximizing the use of excess launch capacity for high value secondary missions if the U.S. is to capitalize on this unexploited asset.

The small satellite community should develop a classification for various small satellite categories and the needs and conditions pertinent to each; this could help facilitate the discussions about the value of utilizing the excess launch capacity and the terms, conditions, and processes necessary to make it efficient.

The small satellite community needs to develop a standard set of requirements that, when met, would ensure minimal-to-no risks to prime mission success.

The community needs to define a standard secondary size and interfaces that would facilitate routine secondary flight opportunities; this should be a limited practical size that could be flown frequently. Currently this appears to be about 90 kg (half ESPA size), which would match the "sweet spot" identified for maximizing mission capabilities in small satellites. This would provide for a spectrum of secondary launch standards – CubeSats/P-PODs, half ESPA size, and ESPA size. For secondary spacecraft lager than ESPA size, there would still be the option of internal payload carriers where ESPA rings or an A-Deck ring could be stacked to provide for mounting the larger payloads inside these adapters.

As the issues of space debris, space tracking capabilities and responsibilities, and international space traffic management are sorted out at the governmental levels, the small spacecraft community should actively consider their contributions to these problems and voluntarily adopt an environmentally responsible approach in their plans and operations.

REFERENCES

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