Access to Space for Technology Validation Missions: A Practical Guide

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Abstract—Space technology experiments and validation missions share a common dilemma with the aerospace industry in general: the high cost of access to space. Whether the experiment is a so-called university cubesat, a university measurement experiment, or a NASA New Millennium Program (NMP) technology validation mission, the access to space option can be scaled appropriately for the particular constraints. A cubesat might fly as one of a number of cubesats that negotiate a flight on an experimental vehicle. A university experiment might do the same. A NASA flight validation might partner with an Air Force experimental mission.[1,2]

But what is the range of options, and what are the benefits of one approach over another? What are the limitations of one approach over another? How can one assess the viability for implementing a particular experiment? How does one go about acquiring such a space access?

A methodology is presented which identifies the approach used by the New Millennium Program to understand what access-to-space options are available. A range of spacecraft, adaptors and launch vehicles are available for any particular mission. But which combination is the most cost effective? Which has the least technical risk? Which has the least programmatic risk? All of these elements play into the final choice for access to space.

The approach for a cubesat or small flight experiment will certainly be different than the approach for NMP. But what are the common elements, fundamentally, in 'finding a ride to space'? And what information is useful to a flight experiment that does not yet know the method that will be used for launch?

These issues are addressed and guidelines are suggested for the reader. No single reference exists to address these questions so the guidelines present a summary meant to point the reader to further information.

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1. BACKGROUND

The NMP is chartered to explore and utilize alternative access to space approaches for its technology validation projects. The fundamental goal is to maximize NMP's funding of high-payoff new technologies for NASA missions. One of the ways to accomplish this goal is to reduce cost for access to space for NMP missions.

Key to this discussion is the use of the term "alternative" access to space approaches. The classic space access approach is essentially to assign a dedicated launch vehicle to a particular mission. Diverting from this classic approach very quickly leads one into a sort of analog to terrestrial carpooling. In fact, the term "ridesharing" has been coined over the last several years within the aerospace community to refer to the sharing of launch services by more than one spacecraft or experiment.

Just as in the terrestrial analog, if one carpools there are a number of different vehicles and methods to use to commute to work—instead of driving solo in a personal automobile, one can share a vehicle and commute costs, or change to a totally different vehicle: a van, or a bus or light rail system. The space rideshare, in turn, can include sharing a rocket (co-manifest or secondary), or possibly riding on a spacecraft with a larger project (piggyback).

Terrestrial carpooling is augmented in U.S. cities by the addition of carpool lanes, local government information dissemination amongst businesses and institutions to coordinate the carpooling, and established regulations for cost and other incentives to the carpoolers. At this point, the

1 1-4244-0525-4/07/$20.00 ©2007 IEEE.
2 IEEEAC paper #1175, Version 2, dated 12/20/06.

terrestrial analog breaks down because the space ridesharing community is currently only a loose affiliation of a number of institutions in the aerospace community[3]— there is not yet an infrastructure to support space ridesharing.

The point of this terrestrial analog is to provide a simple context to point out that

(1) It is the infrastructure (for example, car pool lanes) provided by local and state governments that enables effective terrestrial carpooling

(2) A single carpooler would be hard-pressed to find a ride match without the information dissemination amongst businesses and institutions in the large cities that provide carpooling options

(3) A carpooler may find a transportation option other than an automobile.

For the space analog, it can now follow that

(1) There is no infrastructure to support space ridesharing, although a loose alliance exists between NASA, DoD and industry. Some emerging capabilities, however, foretell the evolution of such an infrastructure.

(2) To date, there are only ad hoc examples of space missions finding rideshares. There is certainly information dissemination amongst institutions, but still only ad hoc.

(3) Space rideshares can vary from riding along on someone else's spacecraft, adapting to available excess launch capability, or partnering to share a launch vehicle and launch costs.

2. INTRODUCTION

This guide is written for the space experimenter seeking an understanding of space-access issues that could drive the design of a space experiment. The use of the term "practical guide" is deliberate and meant to distinguish from the fundamental, known practices of space mission design versus the pragmatic cost issues which cause us to sometimes seek alternative approaches for space access and mission design.

The underlying premise is that the <u>cost</u> of space access is the main problem [1] and that addressing that problem may suggest *how technology missions can be designed to take advantage of space ridesharing*. And continuing with the terrestrial carpooling analogy, there is a traffic jam of technologies trying to get to space. Some alternative space access approaches, including ridesharing, can ease this traffic jam.

To begin this discussion, some terms are briefly discussed that will provide a context for the rest of this paper. The term "access to space" is vague enough that it will mean different things to different people. It is intended here to focus on payloads, spacecraft and launch vehicles. This is still quite broad a set of information, so the focus areas are further refined below by the terms "access to space," "science missions," "technology missions," and "secondaries."

Access to Space (ATS)

In seeking alternative ATS, we are not limited to understanding launch vehicles. Some alternatives involve two or more spacecraft adapted to a structure on a single launch vehicle (*co-manifest* or *secondary*), or perhaps a smaller experiment attached as an additional payload on a spacecraft (*piggyback*). These alternatives to classic ATS are more broad reaching (and more complicated).

Science Missions

The distinction here is between a technology mission and a science mission. NASA science missions are typically risk-averse, high Technology Readiness Level (TRL), and can cost a half-billion dollars or more. Alternative space access is usually considered too risky.

Technology Missions

Technology missions by their very nature are meant for risk reduction, and are also at a low TRL. The cost varies drastically from 100's of \$K (or less!) for a subsystem payload to over \$100M for a full mission, but still much less costly than NASA science missions.

Secondaries

The term is used here loosely[4] to encompass a range of space access options including piggyback, secondary and co-manifest options. Further definition and classification of these options is presented in the next section of this paper. Using the NMP as an example, however, one can note that secondaries vary widely in mass and power. There really is no standard secondary.

Figure 1 is a graphical collage of technology missions which include the exciting ST9 technologies (in competition at the time of this writing) to be validated for aerocapture; entry, descent and landing; precision formation flying; large deployable telescopes; and solar sail. The mass and power requirements for these free-flying experiments are in the 150–250 kg and 100–200 W ranges, respectively. Figure 1 also includes an illustration of NMP's ST5 [2], which flew in 2006 and was comprised of three 25-kg spacecraft that were all launched on a single launch vehicle.

[3] The Small Payload Rideshare Conference has been alternately sponsored by the NRO and NASA since 1999.

[4] Use of this term varies in the community, hence a definition is presented here for reference only.

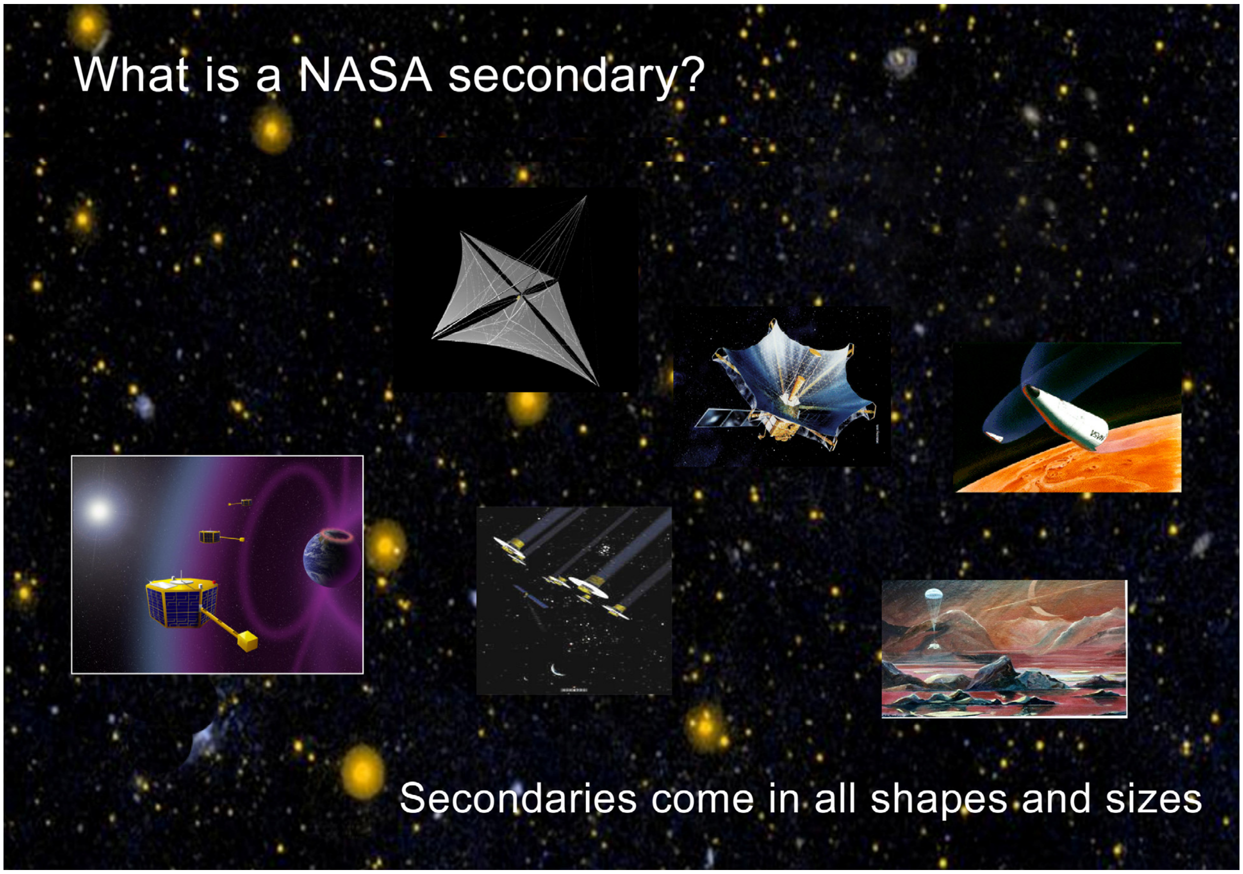

Figure 1. NASA secondaries come in all shapes and sizes

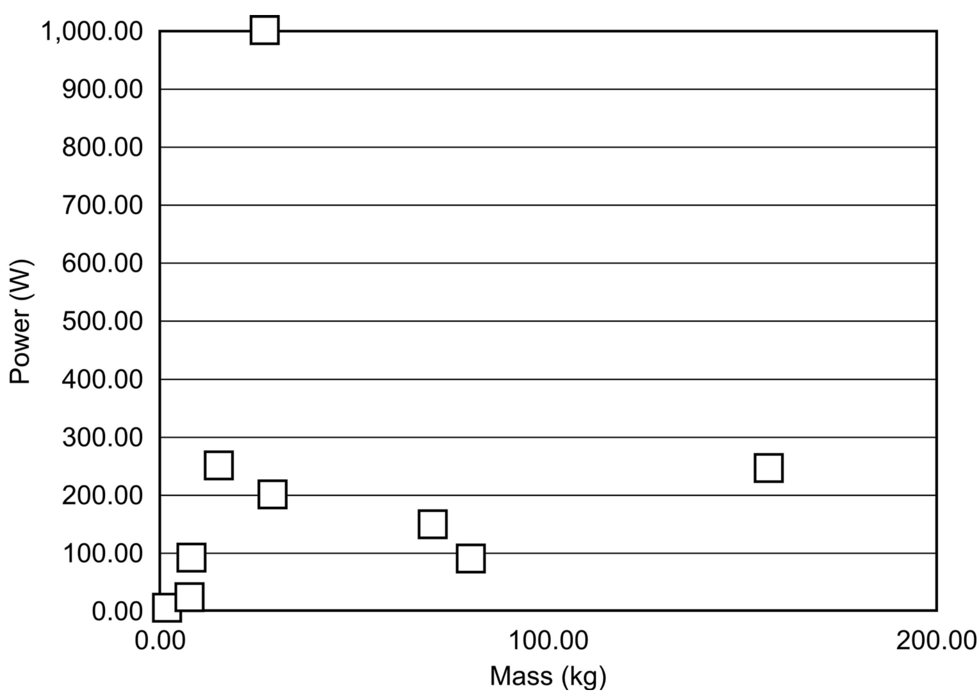

Figure 2. NMP subsystem technologies, range of mass and power

Note that these potential secondary missions vary a great deal in mass and power: a 25 kg spacecraft for ST5, and an approximately 200 kg spacecraft for ST9. To make the point further, note the range of competed subsystem technologies in Figure 2 from NMP's ST6 [3]—the subsystems' mass and power needs also vary significantly, from 5–160 kg, and 5W to 200-300 W (with an out-lyer at 1000 W), respectively.

Figure 1 and 2 are presented to make the point that secondaries can actually come in all shapes and sizes, so the discriminator amongst secondaries is not mass and power.

3. Classification of Rideshare Options

The Introduction to this paper was meant to lead the discussion of this paper to payloads, spacecraft and launch vehicles that are relevant to technology payloads seeking an alternative approach for access to space. Note that there is no standard secondary, and hence the approach to these alternatives must instead be classified in terms of option capability. In terms of an experimenter: what are the likely range of options for your experiment and what is the impact to the experiment design?

Returning to the terrestrial carpooling analogy for space ridesharing, it isn't what vehicle you choose to carpool, it is the optimum option available for the commuting needs that you have.

Three rideshare options are offered here: piggyback, secondary, and co-manifest ridesharing.

As discussed above, the distinction is not as much mass and power as it is that each has a different programmatic and cost impact. Table 1 highlights distinctions amongst these options as they apply to risk and cost. Table 2 will classify this same group of rideshare options by launch service. Which option is best for an experiment will require an assessment of a combination of these.

Table 1. Classification of secondaries, by risk and cost

Mission:	Piggyback	Secondary	Co-manifest
Type	Single/experiment sensor	Spacecraft & Payload	Spacecraft & Payload
Lead	NO	NO	YES, shared
Critical	NO	NO	YES
Class	C,D	C	A,B
Cost	<\$20M	<\$100M	\$100–500M

Table 1 indicates that "piggyback" refers to the addition of an experiment to a spacecraft. The experiment, or payload, is subservient to the mission lead, cannot impact the critical events of the main mission, and is responsible for paying integration costs onto the spacecraft, but is not responsible for spacecraft and launch integration. The payload goes along for the ride, if you will.

A Secondary will be a spacecraft carrying a payload that is meant to be transparent to the primary spacecraft. The secondary is also not considered mission critical, is subservient to the main missions, and responsible for integration onto an adaptor and for the separation after launch from the primary spacecraft. Any changes in launch plans are at the discretion only of the primary partner.

A Co-manifest includes the same responsibilities as the secondary, but the two spacecraft nominally have equal say and budgetary responsibility. Although not always the case, a co-manifest will usually involve the larger launch vehicles like the Delta II or the EELV.

Table 2. Classification of secondaries, by launch service

	Piggyback	Secondary	Co-manifest
Mission Type	Single/experiment sensor	Spacecraft & Payload	Spacecraft & Payload
S/C I&T	YES	YES	YES
Launch I&T	NO	YES	YES
Launch adaptor required	NO	YES	YES
Launch Service	N/A (Spacecraft responsibility)	Pegasus Delta II other	Pegasus Delta II EELV

For each classification—piggyback to secondary to co-manifest—Table 1 indicates the cost and responsibility of the flight experiment. The mission cost identified for each option is only meant as a loose guideline to distinguish the scope of each. Essentially the table indicates the increasing responsibility and the resultant increasing cost. Of course, exceptions can be shown in each option!

Table 2 focuses on the launch service aspect of a mission and indicates the level of responsibility for each rideshare option. Piggybacks are responsible for integrating their experiment onto the spacecraft, but subsequently serve as an observer to the main missions' Integration and Test (I&T) process. And piggybacks have no interface with launch vehicle services. As the rideshare moves to a secondary and co-manifest, the launch service interaction is required. Although a bit simplistic, as the rideshare moves from secondary to co-manifest, the type and size of launch vehicle will also change from the smaller Pegasus and Delta II to the more capable Delta II and EELV.[5]

[5] Evolved Expendable Launch Vehicles ((EELVs) are the next generation of launch vehicles (after the Delta II series) that have been developed by the Air Force.

4. METHODOLOGY—RIDESHARE FLIGHT OPTIONS

With a classification of options in place—piggyback, secondary and co-manifest—the next step is to find a way to compare the options. What payloads, for example, are compatible with what spacecraft? What is the range of spacecraft capabilities? What about the capability of different launch vehicles? What about flight operations after launch? Again because there is not yet an established infrastructure for space ridesharing, there is not yet a central source of this information.

Addressing these questions is complicated many times over by the sheer number of parameters needed per rideshare to determine where there are either matches, or the potential for launch compatibility. There are 25-30 parameters that classify payloads. These parameters start with the simple mass, power, volume criteria and are augmented by the sometimes more discerning criteria of pointing control, orbit and inclination requirements, field of view, contamination, thermal control, deployment, and so on. Next, the typical spacecraft capability must be compared to these 25-30 requirements for the payload. Even more complicated is the idea that multiple, independent payloads might be accommodated on a single spacecraft. And finally, a range of launch vehicles must be able to get the payload to the desired orbit. Figure 3 graphically represents the challenge that exists in divining what alternative options might be feasible.

While Figure 3 presents the challenge in graphic form, subsequent discussion (Table 4) will identify the key parameters needed to assess the compatibility of payloads.

Once again, the terrestrial carpooling analogy is invoked—van pool companies establish surveys in which they seek compatibilities and once a critical mass is achieved, a van pool is established to service some minimum criteria for a vanpool. NMP essentially did the same thing by establishing a methodical process to compare payloads vs spacecraft vs launch vehicles. The NMP “rideshare database” is codified in an EXCEL tool [4], which is tied to reliable sources of NASA payload, spacecraft and launch vehicle capabilities, described in a later section of this paper. The resources are

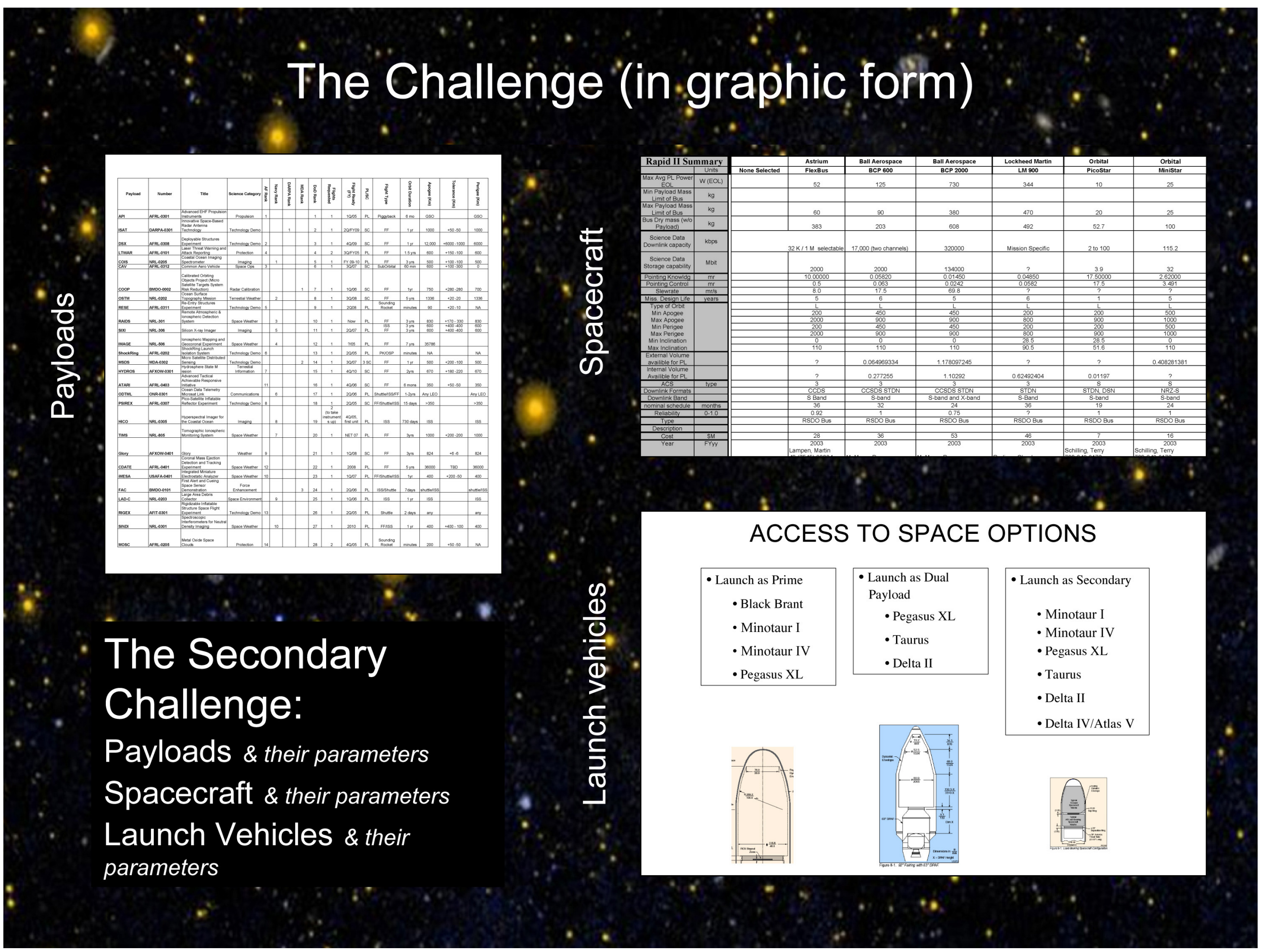

Figure 3. 30 parameters for experiments/payloads, 30 parameters for spacecraft and approximately 10 parameters for launch vehicles form the base of data needed to assess secondary rideshare options.

limited to NASA mission information but could easily be expanded to other sources. One of the difficulties inherent in this kind of matching up is the sparseness of data—especially in early planning phases, the 25-30 parameters are not always known. Anticipating this phenomena, the tool is not confounded by this sparseness of data, and incorporates an iterative process that will actually identify modifications of parameters that could render compatible an otherwise incompatible mission set.

5. Guidelines for Planning a Flight Experiment

So, where to start for a rideshare flight experiment?

There are a large number of parameters to consider, see Figure 3, and absent a rideshare database to aid the experimenter, the assessment can be overwhelming. An insight can be gained, however, by considering several condensed sources of information (discussed later in this section). By reviewing these sources of information, the experimenter can, for instance, review the range of spacecraft power capability. If power is an issue for an experiment—a large cooler, for example—an understanding of typical power draws for spacecraft will provide a design limit to the experiment. There is usually leeway in an experiment design—the experiment need not draw the full power ultimately required for the flight-qualified hardware, thus facilitating a fit on a bus commonly in use in industry. The same would be true for mass of the experimental cooler—a review of typical spacecraft mass capabilities will likely provide a mass limit for the experiment to be designed, providing a higher likelihood of finding an accommodation for space access.

Table 3 presents typical payload/experiment needs that will require matching for a rideshare.[6] Beyond the examples of mass and power, the experimenter is challenged to consider other driving considerations like mission duration (2), pointing control (3-7), configuration (8-14), orbital characteristics (15-20), power modes (22-26), and data handling (27-29). This last one—data handling—also has implications on how the experiment will operate after launch, how it can integrate into the spacecraft command and data handling system, and how the flight data will be acquired by the experimenter.

The following guidelines consider each of the 3 classifications of rideshare—piggyback, secondary and co-manifest. Throughout the discussion below, examples of NMP missions for the rideshare options are provided. Table 4 tabulates the NMP missions as they fit into the classifications of piggyback, secondary and co-manifest.

[6] These are the parameters used in the FLOAT tool.

Finally, the guidelines address the characteristics of payloads, spacecraft and launch vehicles. The reader is then directed to websites that provide further depth of information into each category.

A. Guidelines, by Rideshare Classification

Piggybacks—This is likely the most difficult option to establish. The terrestrial carpooling analogy is most relevant here because the most difficult part is finding the project to partner with! Currently this can be found ad hoc through the Small Satellite Rideshare Conference, hosted in Logan, Utah by Utah State University or the Rideshare Conference mentioned earlier. Additionally, an access to space website [5] has provided information on experiments seeking rides. Given a successful search for a piggyback, the largest risk for this rideshare option is that the host project can change, and with it, sometimes the rideshare option. Flexibility is a requirement!

Table 3. Typical rideshare requirements

	Experiment Requirement	Unit
1	Mass	kg
2	Mission Duration	days
3	ACS: 3-axis, Spin, Gravity	3/S/G
4	Pointing Knowledge (1-sigma)	mr
5	Pointing Accuracy (1-sigma)	mr
6	Slew Rate (1-sigma)	mr
7	Spin Rate	rpm
8	Volume	m^3
9	Volume: Rectangular vs. Cylindrical	R/C
10	Height (shortest)	m
11	Width (middle)	m
12	Length (longest)	m
13	Height	m
14	Diameter	m
15	Orbit: LEO Circular, Elliptical, High Energy	L/E/H
16	Altitude	km
17	Inclination	deg
18	Apogee Altitude	km
19	Perigee Altitude	km
20	Inclination	deg
21	C3	km^2/sec^2
22	Power: Continuous vs. Variable vs. Single Event	C/V/S
23	Standby Power	W
24	Survival Power	W
25	Operating Power	W
26	Peak Power	W
27	Memory (RAM)	Mbits
28	Mass Storage (memory)	Mbits
29	Data Rate – Command	Kb/s

Table 4. Classification of secondaries, by NMP mission

Piggyback	Secondary	Co-manifest	Dedicated Launch
Single/experiment sensor	Spacecraft & Payload	Spacecraft & Payload	Spacecraft & Payload
DS2 on MPL **ST6** ASI on EO-1 **ST6** ISC on	**ST5**, changed to dedicated launch	**EO1**/SAC-C on Delta II	**DS1**, Delta II **ST5**, Pegasus **ST8**, TBD

NMP's DS2 Project leveraged the use of a host (Mars Polar Lander) spacecraft to validate probe technology. The ST6 Project piggybacked both subsystem technologies: (1) ASE's autonomous software was uploaded and successfully validated on the extended mission of NMP's EO1, and (2) the ISE gyro and star tracker subsystem is scheduled to fly in late 2006 on the Air Force's experimental TacSAT-2 satellite. Finally, the ST7 [6] DRS will fly as a piggyback payload on ESA's SMART-2.

Secondary Spacecraft—In common with piggybacks, secondaries are slave to the primary project. Advanced planning and flexibility are required to enable successful secondaries. A number of secondary opportunities are emerging with the advent of the new Evolved Expendable Launch Vehicles (EELVs). The Air Force Research Lab's ESPA[7] ring, a new multi-spacecraft adaptor fixture, has its debut flight in 2007, hosting several small payloads at the base of the EELV fairing. Other adaptors are also in development for use as secondaries on EELVs.

NMP's ST5 was originally slated as a secondary but the timing did not lend itself to finding a rideshare match, and the program chose to delay subsequent NMP projects in order to pay for a dedicated launch for ST5. Currently, ST9 is planned for a 2010 launch and is slated to be a secondary.

Co-manifest—To date, co-manifest accommodations have been ad hoc, although NMP's first earth science mission, EO1, was co-manifested with Argentina's SAC-C satellite. The most prominent downfall of this option is the potential for the 2 projects to become out of schedule-sync, leaving one or both projects with difficult cost issues if not planned for in advance. Exit and contingency strategies for both projects are critical for a successful co-manifest. Co-manifest significantly differentiates itself from the piggyback and secondary because the two spacecraft/projects are considered to have equal weight in any flight change decisions. (The other 2 options are slave to the primary mission.)

Other options—Another emerging possibility for space access is the low-cost small launcher, most notably SpaceX's Falcon1, who's stated goal is to change the paradigm of space access for all missions. The significant change here is in the cost of the launch vehicle—less than \$10M per launch, compared to \$40M - \$150M for other NASA launch vehicles.With the advent of a successful Falcon1 vehicle, other not-yet-considered options will likely emerge as the financial constraints are eased significantly.

B. Guidelines for the "Rideshare Infrastructure"

The following references provide the source information referred to in Figure 3: the payloads, the spacecraft and the launch vehicles.

GSFC ATS website: THE PAYLOADS
http://accesstospace.gsfc.nasa.gov/

This website has served as a central clearing house for payloads seeking access to space. Additionally, it provides the payloads with a large number of reference information to plan and design to existing vehicles.

GSFC RSDO catalog: THE SPACECRAFT
http://rsdo.gsfc.nasa.gov/

The purpose of the catalog is to help streamline the procurement process for spacecraft. A side benefit is that it is a defacto repository of a range of spacecraft capabilities, useful to experiment planners. There's no point in designing a mission that will stretch the bounds of most available spacecraft. Careful review of the catalog can confirm the nominal capability for various spacecraft.

NASA KSC website: THE LAUNCH SERVICES
http://elvperf.ksc.nasa.gov/elvMap/

NASA's official website provides insight into launch vehicles and launch vehicle performance.

The Cubesat Infrastructure—This story of the cubesat is added anecdotally to present a successful example of terrestrial carpooling in space. The cubesat concept was promoted and developed by R. Twiggs of Stanford University. The cubesat is small (approximately 4 inches cubed) and can be built in less than a year by a university class. The Rideshare Conference addressed the issues of access to space brought to the conference by the growing number of cubesat builders. The recommendation was to form a consortium of universities—a ridesharing coordination of cubesats. The University of California at San Luis Obispo stepped into the role of coordinator and has successfully launched a set of 14 cubesats (March 2005, on a Dnepr launch vehicle), and a second set of cubesats launched in July of 2006 (unfortunately, the launch vehicle

[7] EELV Secondary Payload Adaptor is the "ESPA ring."

failed). In the meantime, a small industry of so-called "p-pods" have been developed to deploy more than one cubesat at a time from the piggyback ride that is the basis for the cubesat space access. Although the space access for cubesats hasn't always been a smooth ride, the cubesats are a successful example of ridesharing.

6. CONCLUSIONS

The NMP is chartered to explore and utilize alternative space access approaches for its technology validation projects. By their very nature, these alternatives are out of the main stream of classic space mission implementation. These secondary options come in all shapes and sizes with a key discriminator being programmatic—risk and cost.

Currently secondaries must be planned almost in a form of reverse engineering. What is planned for future launches?
Is it compatible to my mission?
Is there room for my payload?
If not, can another launch service accommodate both?
Iterate the above until solution is found.

If a space rideshare infrastructure were to emerge, technology (and other) missions could design directly to established guidelines, avoiding this circuitous, reverse-engineering approach.

The guidelines presented here are admittedly sketchy, but it is a start. An analogy was made to terrestrial carpooling to suggest an everyday infrastructure that we are familiar with. An analogous space carpooling would enable future space ridesharing capabilities. The form of that infrastructure and its components are yet to be determined but the fundamental cross-discipline (payload, spacecraft, launch vehicle) and cross-institutional components (informal Rideshare Conference community across NASA, DoD and industry) presented in this paper will be key to any success.Recent developments within the Air Force's Space Test Program (STP) include the awarding of a Standard Interface Vehicle contract. The STP researched typical payloads for their testing program and established a standard that would accommodate most. Now future STP experimental payloads can design to this standard vehicle.

Could this be the beginning of a space rideshare infrastructure?

REFERENCES

1) Herrell, L., "The New Millennium Program Architecture and Access to Space," 2005 IEEE/AIAA Big Sky Conference

2) ST5 website http://nmp.jpl.nasa.gov/st5/

3) ST6 website http://nmp.jpl.nasa.gov/st6/

4) Flight Options Analysis Tool (FLOAT), www.techbriefs.com/tsp

5) http://accesstospace.gsfc.nasa.gov/

6) ST7 website http://nmp.nasa.gov/st7/

BIOGRAPHY

Linda Herrell has a BA in math/computer science/languages (1972, University of Texas) and a MSME in fluids and heat transfer (1983, City College of New York). In addition to analytical work in computer science and thermal and structural analysis, she has worked as both a payload (instrument) and spacecraft systems engineer on Earth-orbiting (Hubble Space Telescope, Earth Observing System (EOS)) and deep space (Cassini) NASA missions, and as Proposal Manager for several NASA science missions. She currently serves as the Program Architect for NASA's New Millennium Program.