A Systems Approach to Lower Cost Missions: Following the Rideshare Paradigm

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Small-satellite rideshare capabilities and opportunities for low-cost access to space have been evolving over the past 10 years. Small space launch vehicle technology is rapidly being developed and demonstrated, including the Minotaur series and the Space X Falcon, among others, along with the lower cost launch facilities at Alaska's Kodiak Launch Complex, NASA's Wallops Flight Facility, and the Reagan Test Site in the Pacific. Demonstrated capabilities for the launch of multiple payloads have increased (and continue to increase) significantly. This will allow more efficient and cost-effective use of the various launch opportunities, including utilizing the excess capacity of the emerging Evolved Expendable Launch Vehicle (EELV)-based missions. The definition of standardized interfaces and processes, along with various user guides and payload implementation plans, has been developed and continues to be refined. Top-level agency policies for the support of low-cost access to space for small experimental payloads, such as the DoD policy structure on auxiliary payloads, have been defined and provide the basis for the continued refinement and implementation of these evolving technologies. Most importantly, the coordination and cooperative interfaces between the various stakeholders continues to evolve. The degree of this coordination and technical interchange is demonstrated by the wide stakeholder participation at the recent 2008 Small Payload Rideshare Workshop, held at NASA's Wallops Flight Facility. This annual workshop has been the major platform for coordination and technical interchange within the rideshare community and with the various sponsoring agencies. These developments have provided the foundation for a robust low-cost small payload rideshare capability. However, the continued evolution, sustainment, and utilization of these capabilities will require continued stakeholder recognition, support, and nourishing. Ongoing, coordinated effort, partnering, and support between stakeholders is essential to acquire the improved organizational processes and efficiencies required to meet the needs of the growing small-payload community for low-cost access to space. Further, a mix of capabilities developed within the space community for Operationally Responsive Space, an international committee investigating space systems cross-compatibility, and an industry-based organization seeking small satellite "standardization" all work toward a new paradigm: sharing or leveraging resources amongst multiple users. The challenge: where are those users, and what is the best way to leverage them? What is leveraged—mass, power, cost-sharing? And how does one sort through these options? What policies may prevent the use of some options? Who are the "other users" that might share or leverage capabilities? ***This paper presents a systematic look at both the users and the launch options, and suggests a way forward.***

I. Introduction

A "rideshare paradigm" is presented based upon five principles (listed in Table 1). They are representative of the kind of ideas addressed annually at the Small Satellite Rideshare Workshop, a cross-disciplinary and cross-institutional set of aerospace engineers.

The idea of partnerships and sharing costs is not new to space missions: the International Space Station, missions to the Moon or Mars, and Earth science missions all rely on multiple international contributors. What is new is the development of mission contributions that can be shared effectively with more scattered, diverse users. In large part, this is a grass-roots effort to enable more missions with limited budgets by leveraging existing capabilities.

Table 1. Rideshare Paradigm Principles.

1	Develop partnerships
2	Share costs
3	Establish policy
4	Standardize interfaces
5	Do no harm

An excellent example of a group of scattered users is the cubesat community,[1] begun in universities in the U.S. Thanks to their efforts, today there is a very effective approach to flying small experiments inexpensively (less than $50k) on U.S. launchers. In 2002, the nascent cubesat community was given guidance from the Rideshare Workshop (essentially along the lines of these five principles), which ultimately established a strong, community-based consortium and lower cost launch options.

The purpose of this paper is not to focus on or promote the use of cubesats, but to show by their example how the underlying principles of the rideshare paradigm can enable more effective use of limited space resources.

This paradigm also brings new options into a mission design tradespace. The Defense Advanced Research Projects Agency (DARPA) F6 mission and the U.S. Air Force Operationally Responsive Space program address certain aspects of the rideshare paradigm, whether it is the standardization of spacecraft interfaces (Principle #4) or the use of space policy to allow use of Evolved Expendable Launch Vehicle (EELV) excess launch capacity (Principle #3). The principles, it is argued, reduce the fundamental cost of some space missions (not all!) by the leveraging of costs and partnerships, and by the introduction of recently proven access to space options.

Rideshare is applied to a broad range of space access options, from very small satellites (cubesats) to very large launchers (EELV); from the payload that rides along on a satellite to the satellite that shares a launch manifest. The attribute these options share is the idea of partnering. Figure 1 illustrates the stakeholders (not a complete list, but illustrative) that make up the rideshare community: payloads, spacecraft, and launch vehicles (and adaptors). A payload from Column A has an optimum fit (cost, mass, weight, schedule, etc) on a spacecraft from Column B and a launch vehicle from Column C. Column B includes two recently proven and newly available spacecraft—the cubesat and the Standard Interface Vehicle (SIV). The cubesat accommodates 1 kg of mass, obviously limited. The SIV[2] is sized to accommodate a wide range of experiments and missions and is limited to 180 kg. Other spacecraft are loosely categorized to three different mass ranges to illustrate the range of small satellites addressed by the Rideshare community. Launch options begin with the Poly-Picosatellite Orbital Deployer (PPOD), which is an adaptor designed for the launch of cubesats; the EELV Secondary Payload Adaptor (ESPA) ring which is an adaptor for the SIV to launch on an EELV; balloons, airborne, and the Unmanned Aerial Vehicle (UAV) are listed to point out that some missions are amenable to sub-orbital environments; and a variety of launch vehicles, small to large.

Just as the rideshare permutations are large (pick any combinations from A to B to C in Figure 1), the options are complicated by the ideas of sharing a launch vehicle, or adding a payload to an existing spacecraft. It is also impor-

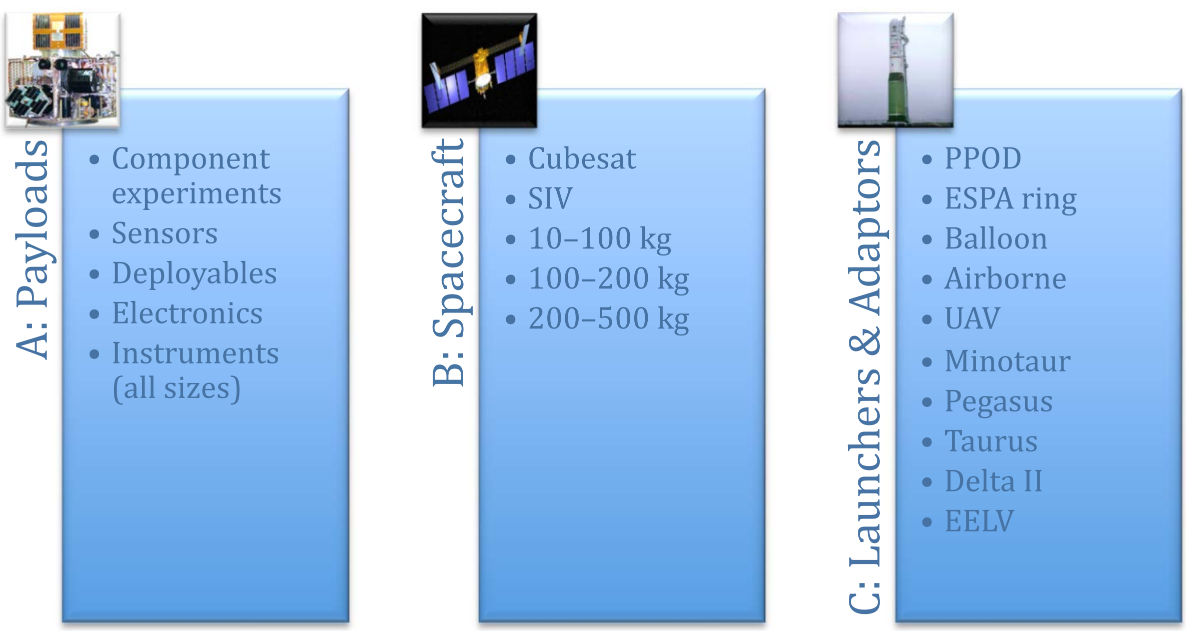

Figure 1. The Rideshare challenge: Find matches across columns A, B, and C (payloads, spacecraft, and launchers and adaptors, respectively).

tant to point out that while the columns in Figure 1 (payload, spacecraft, launch) stand side-by-side, there is no particular path or linkage to connect one column to another. This figuratively represents the challenge of rideshare: connecting the columns to create a pathway to space.

II. Background: Developments Over the Last Decade

Small space launch vehicle technology is rapidly being developed and demonstrated, including the Minotaur series and the Space X Falcon, among others, along with the lower cost launch facilities at Alaska's Kodiak Launch Complex, NASA's Wallops Flight Facility, and the Reagan Test Site in the Pacific. Demonstrated capabilities for the launch of multiple payloads have increased (and continue to increase) significantly. The ESPA ring is the most notable example, where as many as six 180-kg spacecraft can be launched on the new EELV series of rockets. The U.S. Air Force Space Test Program first used the ESPA ring in 2007 with the successful launch of the Space Test Program-1 (STP-1) mission.

Figure 1 is repeated in Fig. 2 to contrast options that were not available 10 years ago with what is available now. In addition to technical developments,[3] there has been a policy change (within the Air Force) that will guarantee at least one ESPA ring available per year, beginning in 2012.[4] This application of Principle #3 provided legitimacy to the rideshare option, until now established through approval on a case-by-case basis. Recent Air Force policy also has approved the use of PPODs on future Minotaur launches. The establishment of these policies provides a credible path to implement a flight experiment or mission, a path that previously did not exist.

In and of itself, a smaller/cheaper launch vehicle does not mean lower cost for a full mission, but a systematic combination of a number of mission elements using the five principles of the rideshare paradigm can result in cheaper mission costs.

III. The Rideshare Paradigm

The five principles of the rideshare paradigm are presented. Then a case study is presented that takes the cubesat community as an example of success with the use of the paradigm.

A. Principle #1 Develop Partnerships

The development of networks and partnerships are established over a period of time. That is the subtle point of this principle—the community crosses boundaries of government (NASA and DoD), industry, and universities. The informal Rideshare Workshop has helped to develop those working relationships and trusts.

Coordinated and cooperative interfaces between the various stakeholders continue to evolve. The degree of this coordination and technical interchange is demonstrated by the wide stakeholder participation at the 2008 Small Payload

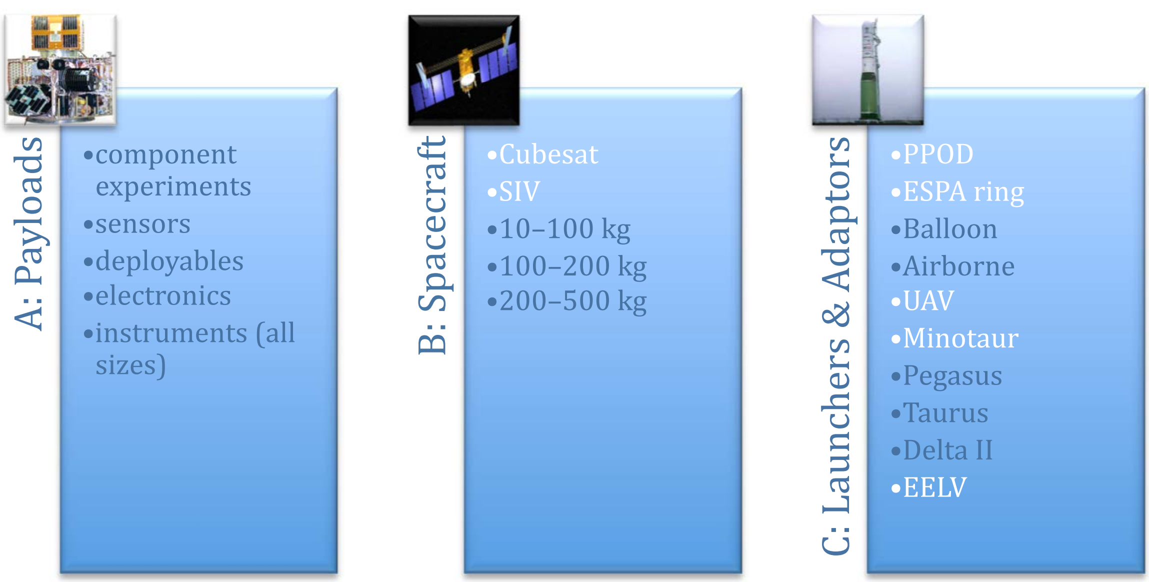

Figure 2. Rideshare options that have emerged in the last 10 years appear in white text.

Rideshare Workshop, held at NASA's Wallops Flight Facility. This annual workshop has been the major platform for coordination and technical interchange within the rideshare community and with the various sponsoring agencies.

B. Principle #2 Share Costs

This is perhaps a corollary to Principle #1, but was kept separate to point out that although one major benefit of partnerships is sharing costs, developing those partnerships is time consuming and they must be in place to leverage opportunities when they occur.

C. Principle #3 Establish Policy

The best example of this principle is the establishment of an Air Force policy to use an ESPA ring on a limited number of EELV launches. Without the policy, the uncertainty of launch makes it difficult for partners to accept the risk or the unknown path to space.

Another venue taking a serious look at both policy and ridesharing is a Working Committee for the International Academy of Astronautics (IAA) on international cross-platform compatibility. The goal of the Working Committee is to develop an approach to simplifying partnerships and addressing existing roadblocks to cooperative efforts. Most notably, International Traffic in Arms Regulations (ITAR) is an issue to be addressed, but also the implementation of standard interfaces to simplify the technical interfaces. The Working Committee report is due out in 2010.

D. Principle #4 Standard Interfaces

There can be an extended debate on the use of standards within the aerospace community. The point to be made here is that standard interfaces, instead, can address the incompatibility of most space assets. The space community is still in its infancy, and still building one-of-a-kind; hence, the move toward standard interfaces.

The definition of standardized interfaces and processes, along with various user guides and payload implementation plans, have been developed for cubesats and ESPA. Where there were no options before, there is now a cubesat and ESPA standard that can be designed to with the knowledge that, in turn, there is a policy (Principle #3) that shows a path to launch. Where there was no path before, now there is a way to plan a small mission.

E. Principle #5 Do No Harm

Another (incorrect) variant of this principle is to "add no risk." Although adding no risk is the more common concern over "do no harm," the point is that risk is, indeed, added by the addition of anything to a mission. The need should be, instead, for the addition of manageable risk. This principle was the driving requirement for the design of a deployment option for cubesats.[1]

F. Case Study: The Cubesat Community and the Five Principles

A group of university professors promoting the use of cubesats (see Fig. 3) attended the 2002 Rideshare Workshop. That year, the workshop was organized into 3 working groups to address small payload benefits and roadblocks, small launch vehicle roadmap, and secondary payload accommodations roadmap. Each group worked independently, reporting back to the whole workshop on the second day. The group addressing small payload benefits and roadblocks reported back a number of roadblocks, most notably the intolerable cost of access to space, especially to the many (nearly 100) universities in the process of developing cubesats. Part of the story is already given away by earlier reference to the cubesat "community." At that time, there was a loose affiliation of universities but mostly a large number of independent universities joining the growing interest in the cubesat. Part of the advice from the Workshop was to work together as a group—100 different universities competing for attention from launch services was not a way to success. So here is the advice that was given to the cubesat "community":

1. Develop partnerships

With the growing interest and participation of universities with cubesats as a teaching tool (clever folks are also using cubesats for much more than teaching), some sort of consortium was necessary to coordinate. California's Cal Poly San Luis Obispo emerged as a facilitator/coordinator for cubesats. Finding no possibilities in the U.S. at the time, the group negotiated with Russian launchers and ultimately made two trips to Russia to launch 12 and then 14 cubesats. To their credit, engaging a foreign entity meant dealing with ITAR, so the university became ITAR-certified and had the responsibility to ensure that other cubesats that partner with Cal Poly met the needed requirements.

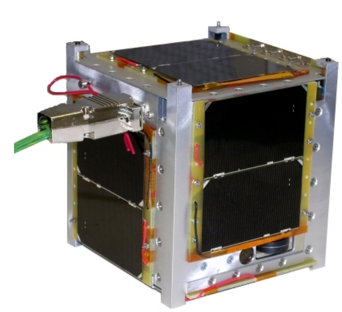

Figure 3. The cubesat standard.

2. *Share costs*

Part of the negotiations for the two Russian launches was establishing a costing structure to be shared amongst the cubesats, under $50k each. The PPOD launcher was designed to launch three cubesats at a time, so the total cost is on the order of $150k for three cubesats. Further clever use of the PPOD has led to the use of the full volume by a single 3-unit-volume (3U) unit. The cubesat and PPOD are shown in Fig. 4.

3. *Establish policy*

This occurred later, but the establishment of an Air Force policy to launch PPODs on each Minotaur finally provided a real pathway to space for the cubesats. Prior to the policy, the cubesat launches were "one-of" events.

4. *Standard interfaces*

Key to the original cubesat design was the idea of standard interfaces. With the standard in place, three separate and unrelated cubesats are mountable into a single PPOD deployer. A subsequent standard has evolved that employs the PPOD to deploy a single 3U unit that takes advantage of more space for the flight experiment. The PPOD can deploy three single cubesats or a 3U unit.

5. *Do no harm*

This manifested itself in the cubesat development by recognizing that the deployment of a cubesat would never be accepted unless some failsafe method was developed. The PPOD was designed with that in mind.

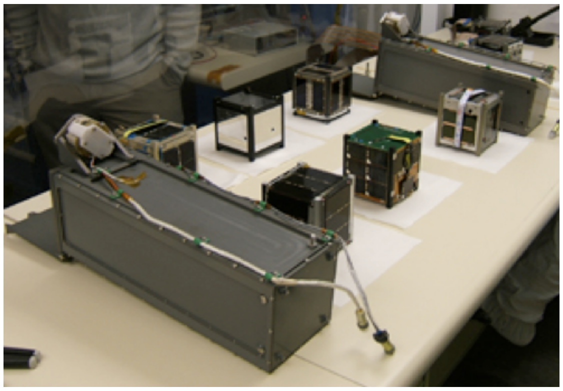

Figure 4. Cubesat next to standard PPODs.

IV. A Systems Approach to Rideshare

This is the most challenging area of this discussion: where are those users, and what is the way to leverage them? What is leveraged—mass, power, cost-sharing? And how does one sort through these options? What policies may prevent the use of some options? Who are the "other users" that might share or leverage capabilities?

To understand these issues and to put structure/organization to this diverse community, one needs a high-level systems engineering view of what is involved across these different communities.

The New Millennium Program (NMP), a NASA space technology validation program, addressed this by surveying several sources of space mission information,[5] and consolidating the information into a database. Figure 5 presents a snapshot of a small part of the database—mass and power. In particular, the study was assessing what technologies might actually use a cubesat, SIV or ESPA, but the survey also produced an interesting insight into "who and what" the users (payloads) are. As mentioned in the introduction, the rideshare community is a diverse and scattered group. Also noteworthy, a portion of the scatter plot is called out as "UnServed," noting that there are a number of users that don't fit any of the studied options.

With this database in hand, the next step is to understand the options available for each payload, a kind of a cross-reference between the payloads, spacecraft and launch vehicles referred to in Fig. 1. Table 2 takes a look at NASA launch options to illustrate the changing nature of the launch and rideshare options. Highlighted in green are the launch vehicle options available to NASA earth and space science missions, annotated as "classic." The "emerging" vehicles add to a tradespace worthy of consideration for lowering costs of future (not all!) missions. Of course, there is a systems approach that can be applied to this tradespace to sort out and eliminate options and find the optimum approach, discussed next.

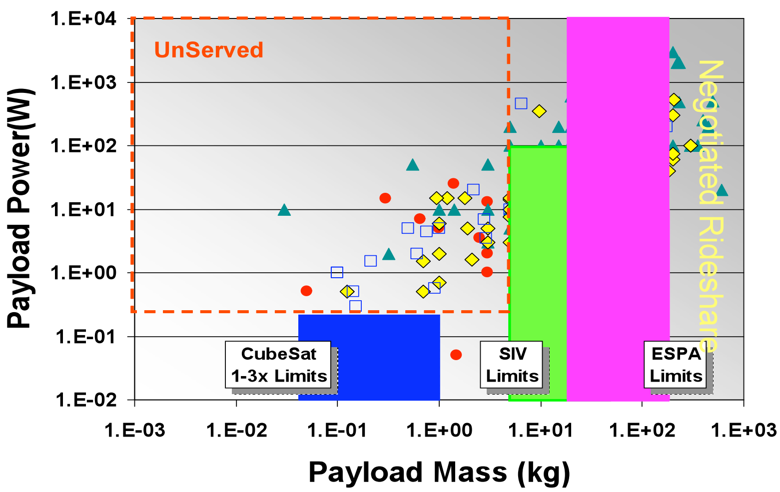

Figure 5. Sample data, mass vs. power, indicates potential payload classification.

Table 2. NASA launch options, existing and emerging.

		TRL	Cost	Comments
Classic	Delta II replaced by EELV	High	> $150M	Cost will limit missions for NASA
Classic	Pegasus, Taurus	High	$50 – 100M	Phasing out
Emerging	Taurus II	Low	Unknown	Available in 2012
Emerging	Minotaur I	High	< $50M	Available today. Limited NASA use
Emerging	Minotaur IV	Medium	< $50M	First launch in 2009. Limited NASA use
Emerging	Falcon I	Medium	< $10M	First successful launch September 2008
Emerging	UAV	High	< $10M	Available for low TRL payload
Emerging	High-altitude platform	Low	< $20M	In development
Emerging	Cubesat	High	< $50M	Good for experiments. Available today
Emerging	ESPA	High	< $20M	Available today but NASA policy not yet in place

V. Applying the Rideshare Paradigm to Future Missions; Lowering Costs

As for lowering cost, the simple reasoning here is that sharing costs of launch vehicles, spacecraft or operations does lower mission cost for an individual payload, although not necessarily for a spacecraft or launch vehicle. The difficult part of the problem is establishing a systematic way to build these cooperative efforts—to streamline. The U.S. Air Force and NASA are addressing a streamlining for the use of the ESPA ring by defining standard launch integration services (Principle #4) for the payloads that plan to use the ESPA.

This sharing of launch is non-trivial because of the many parameters that drive the needs of a payload, not the least of which are orbit location or pointing stability (there are 25–30 parameters to consider). But preliminary statistical studies[5] show enough compatibility for it to be of value to pursue. Additionally, limited budgets and increasing numbers of missions to be flown make heretofore "go it alone" approaches to reconsider and sometimes seek a form of rideshare. It adds to the tradespace for mission design.

Again, the NMP took a preliminary look at systematically assessing the options, of assessing (from Fig. 1) the various combinations of payloads, spacecraft and launch vehicles. The Flight Options Analysis Tool is an extensive Excel spreadsheet that ultimately identifies combinations and indicates where there are matches and where there are not matches. Sometimes the "not matches" provide more insight than the matches. And that is the point—having an overall, high-level view of these options gives insight into where time and effort could pay off, and where it would not.

Further, a mix of capabilities developed within the space community for Operationally Responsive Space, an international committee investigating space systems cross-compatibility, and an industry-based organization (CANEUS) seeking small satellite "standardization" all work toward a new paradigm: sharing or leveraging resources amongst multiple users.

VI. Summary and Conclusion

This paper begins by defining 5 principles that make up the Rideshare Paradigm. The Paradigm is discussed with the example of the evolution of the cubesat community. Then a systems look at the rideshare options is presented, to finally pull the information together to show a way forward to use this scattered information to make more informed decisions about fitting more missions into a limited budget.

Figure 1 is presented one more time, this time as Figure 6, showing the rideshare pathway to space that is emerging through the specific examples of the cubesat and SIV to the PPOD and ESPA ring, respectively.

The above developments have provided the foundation for a robust low-cost small payload rideshare capability. However, the continued evolution, sustainment, and utilization of these capabilities will require continued stakeholder recognition, support, and nourishing. The continued coordinated effort, partnering, and support between stakeholders is essential to acquire the improved organizational processes and efficiencies required to meet the needs of the growing small payload community for low cost access to space.

Although most of the ridesharing has been amongst government institutions, recent interest from the commercial sector[6] includes a rideshare concept of a commercially hosted payload, a payload that will pay for a ride on a commercial communications satellite. A serious look by the Air Force at this kind of commercial utilization promises to add to the rideshare options, and possibly bring it much more into the mainstream. Other efforts are also underway to formally track excess launch capacity that is known to exist but has not previously been tracked.

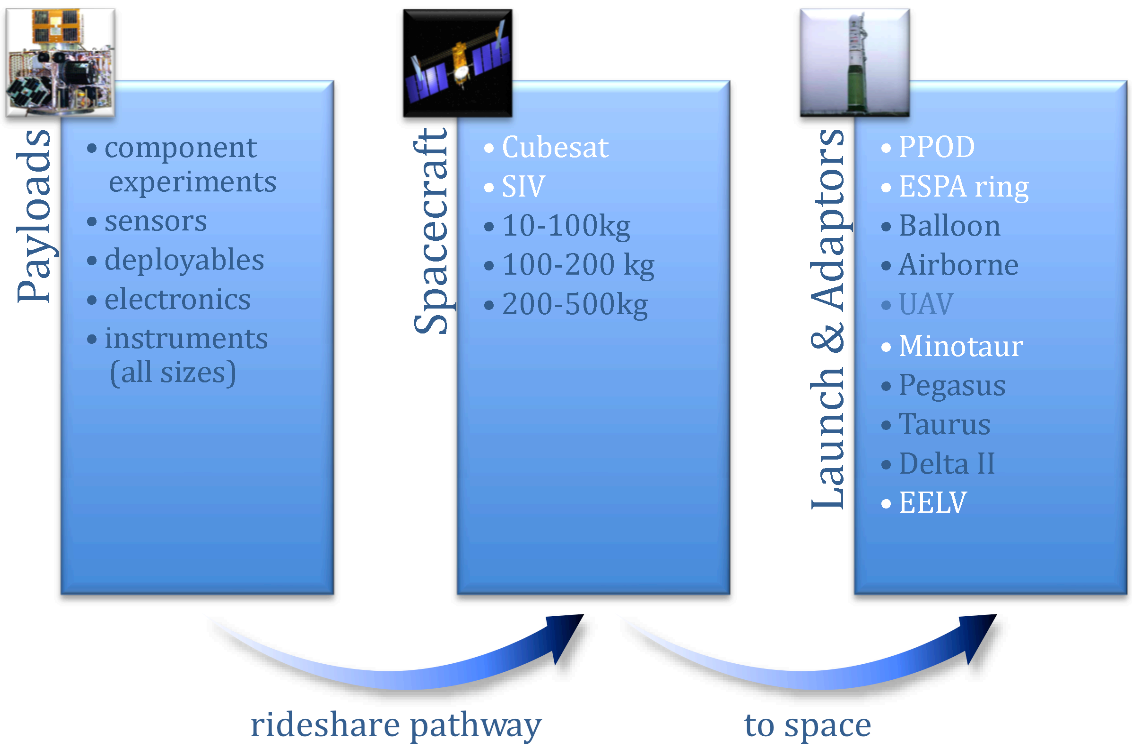

Figure 6. Highlighted in white, new rideshare pathways to space.

Acknowledgments

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