Universal Small Payload Interface – A Design to Ensure Cost-Effective Small Satellite Access to Space

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Abstract. Launch vehicle economies of scale are one of the biggest hurdles to cheaper space access for small satellites. Overhead and facilities and other costs are constant regardless of the launch vehicle size. Therefore for smaller launch vehicles, cost efficiency drops, increasing the per-kilogram launch vehicle costs. Consequently, the cost advantage of small satellites is rapidly diminished because the overall mission cost remains high.

One solution is launching piggyback on a large launch vehicle. Large launch vehicles have opaque procedures and lack clear requirements and standardized piggyback accommodations. The Ariane ASAP 5 provides reliable and easy launch for small satellites, but there is no U.S. counterpart to it. The Universal Small Payload Interface (USPI) project sponsored by the NRO will remedy that situation.

The USPI will provide standardized accommodation on large launch vehicles for small payloads. USPI provides a standard requirements document, a detailed integration flow, separation system, and payload platform design for the widest possible flexibility in terms of reliable and cost effective access to space.

1. Introduction

Piggyback launches on large launchers offer small satellites the cheapest and most reliable access to Low Earth Orbit (LEO) and Geosynchronous Transfer Orbit (GTO). Foreign small satellites use standardized piggyback accommodations on large launchers or cheap commercial launches on decommissioned Russian and Ukrainian ICBM's but US small satellites do not have access to these resources. The Universal Small Payload Interface (USPI) – a National Reconnaissance Office (NRO)-sponsored standard auxiliary launch interface for small and micro satellites – aims to remedy that situation.

We propose implementing USPI as an open standard like the Linux operating system. Participants in the USPI standard will have access to the requirements, the design template, and – security and launcher policy willing – access on US launch vehicles using the USPI standard. In return, the users will help update the standard as new information becomes available. This concept should drastically increase USPI's chances of acceptance as a *de facto* piggyback standard.

For USPI's purposes, a satellite is defined an auxiliary or piggyback payload when:

- The launch manifest lists it as an auxiliary payload
- Its mass is less than 40% of the overall mass launched – typically around 10% of launched mass
- Its orbit is dependent upon the final insertion orbit of the primary payload

The USPI standard proposed here has a hardware and a process component. The process is a design template and a requirements document. The hardware component is a standard interface. This paper will introduce the USPI standard, but not fully describe it. The USPI standard may be obtained from AeroAstro or the NRO.

We will first provide some background on the USPI project, followed by a quick assessment of current capability that establishes the need for a standard like the USPI. The design solution section presents a general outline of the USPI standard, followed by AeroAstro's proposal for the implementation of USPI as a piggyback payload launch standard.

1.1. Background

A Launch Vehicle's (LV) payload capability has a strong correlation to its cost per payload kilogram to orbit, as shown in Figure 1. Smaller vehicles like Pegasus and Scout cost about $25,000/kg, while the largest vehicles cost approximately 20% that amount. This holds true despite the fact that a gross comparison is imperfect due to the different orbits and other requirements imposed on the LVs. For instance, the Shuttle is unusually costly for its size because it is manned and is required to return intact to earth rather than be abandoned in space and eventually burn up on reentry.

This inverse relationship between payload and cost per kilogram is due to physics of flight and the inherent fixed costs of launch. Physics favors large vehicles: in terms of air drag alone, we expect the larger vehicle to have half the cost per kilogram. But every LV also carries fixed costs regardless of size. These costs include those for trajectory calculation and the guidance system to execute the chosen trajectory, provision for on-board flight safety devices such as command/destruct systems, telemetry and tracking systems, and the cost of engineering on-board systems, etc. These costs do not scale very closely with size, and in fact may be higher for smaller vehicles where mass is more critical.

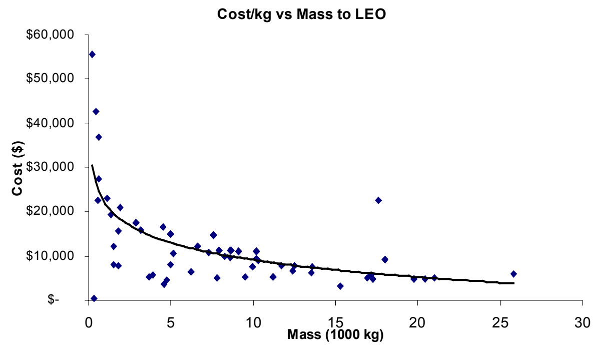

Figure 1: Cost Per Kg ($) Data for Launches to LEO. *(The x-axis denotes launcher capability to LEO in 1,000 kg.[1])*

Small payloads on a dedicated launcher, with mass less than 1% of large satellites, can cost 10 to 100, even 1,000 times more per kilogram to launch than large satellites. In fact, no LV exists for 1, 10 or even 100-kg satellites. These satellites are all launched on vehicles of much larger capacity – either clustered with others, or piggyback with a larger primary payload. The STEDI, TERRIERS, and SNOE spacecraft cost over $4 million each to launch, and current costing for similar accommodation is $6 million to $10 million – not ideal for a quick-response, low-cost tactical mission.[*] The Delta II can accommodate small payloads in the 50-kg class. The accommodation is non-standard and is quite expensive – typically $2 million to $4 million. The STS Get Away Special (GAS) and Hitchhiker programs offer small-satellite accommodations. The costs imposed on the spacecraft, mainly to meet rigorous Shuttle safety requirements, can be enormous.

Secondary launches offer a dramatic improvement to this situation. There is a major LV launch every few weeks, sometimes as often as every week.[**] More standard piggyback accommodations on US launchers and a commonality across launchers could revolutionize small-satellite mission development and launch. Missions designed to a common interface standard would decrease their dependence on finding and designing for a specific launch option. The need to contract and customize for a secondary launch on a specific vehicle at the very beginning of the program would be eliminated, decreasing cost and mission cycle time. Finally, the piggyback payload launch could be independent of a primary payload launch or LV: when the spacecraft is ready, the next launch available could be used, bringing 'launch on-demand' closer to reality.

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[*] AeroAstro, Inc. internal data.

[**] Aggregating all large LV launches – US, Russian/ Ukrainian, European. Discounting Chinese launches.

1.2. Assessment of Current Capability

US piggyback payload launch rate is on par with the global rate in overall percentages.[2] However, discounting Soviet military launches and the more recent domination of Ariane 4 in commercial launchers, the US should have launched more piggyback satellites compared to the benchmark because US LVs have the same or better payload mass margin available.

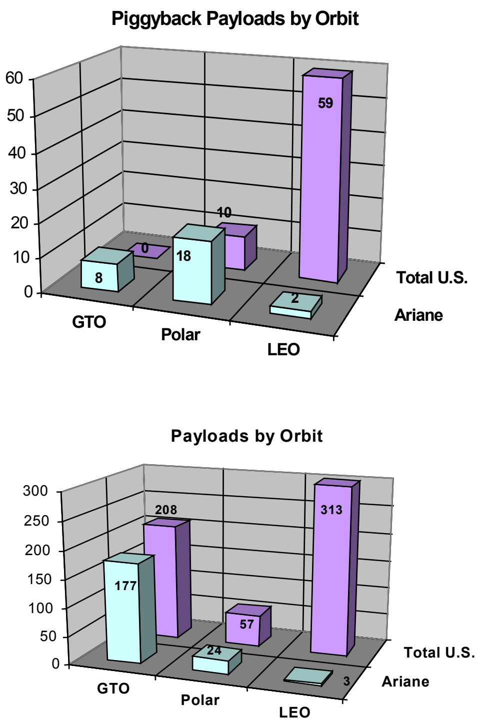


Figure 2: Distribution of Payloads According to Orbit Type.
(Some of the small payload data is skewed by small US payloads launched as primaries. Note no US piggyback launches to GTO[3])

Piggyback payload data by orbits in Figure 2 above show the majority of US small satellite launches went to LEO but the data are skewed by Pegasus and older vehicles launching smaller primary payloads. Most remarkable is the large percentage of Ariane piggyback payloads. Even the least popular GTO orbit has 4.5% Ariane piggyback launches, contrasting with 0% (of 208 total) for US launchers. Almost 75% of total Ariane 4 LEO launches and 75% of Ariane 4 launches to Polar and sun-synchronous orbits have had piggyback payloads. This contrasts with less than 18% for US Polar and sun-synchronous launches. These data contrast with the fact that a considerable number of US small satellites have had to pay for dedicated launches or have had to wait for lack of cheap access.

Piggyback launches– especially for US organizations – have been literally or nominally free. But that does not reflect the hidden costs for qualifying and integrating the payloads. ASAP 4 & 5 customers pay for the service: the cost covers everything from the costs required for integration, launch etc., to a portion of the launch insurance. Arianespace has a standard contract and a standard payment schedule for the piggyback payload. This standardization offers – albeit at some cost – stability to the payload customer. Consequently, piggyback customers, given a choice between:

- Paying for the convenience of ASAP piggyback launches, albeit to limited orbits and on limited launches

or

- Free US piggybacks launches, to more orbits, on more launches, with some inconvenience and on sufferance from the primary payload

have opted for the former. We can only speculate on the effect on US small satellite technology if US policy had also dictated transparency and convenience for its free piggyback launches.

1.3. The Need for USPI

Figure 3 below establishes USPI's outline as a solution to the small satellite launch problem. USPI is expected to provide a standardized process and interface that would allow small and micro satellites to access available launch mass margin on large LV launches.

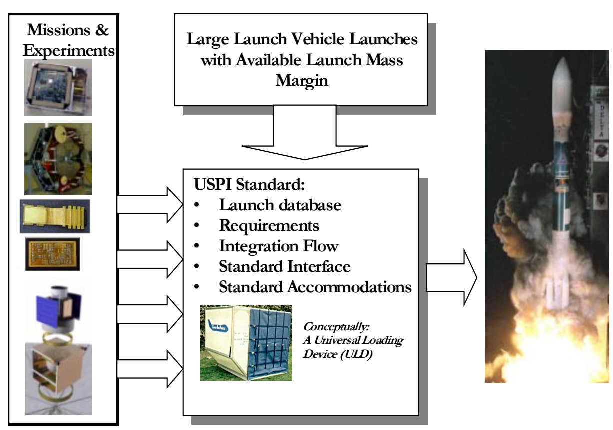


Figure 3: Logistical Concept for USPI.

Essentially, we need a process to get missions and experiments on large LVs with capacity using a standard that provides the maximum possible number of missions.

2. USPI – The Design Solution

Figure 4 describes the application of the USPI standard in more detail.

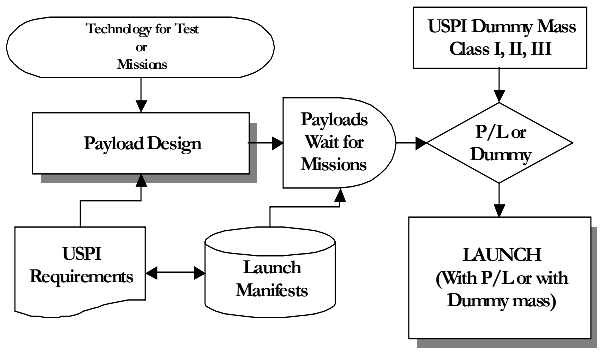


Figure 4: USPI Application Flow Chart

A new technology that needs to be tested rapidly before deployment, a small satellite mission, or a strategic/tactical mission for a small or micro-satellite starts the process. The payload is designed according to the USPI requirements document. Meanwhile, the launch manifest database identifies the launch that best fits the payload launch requirements. As soon as the payload is complete, it is launched as a piggyback payload on the first available launch that fits. The LV already has the payload mass margin available. It also has the standard accommodation and adapters. If the payload is ready, it flies on the mission; if not, the dummy payload flies as ballast. The launch schedule and integration process is not affected by piggyback payload availability.

2.1 An Analogy

Conceptually, USPI is the LV version of the Universal Loading Device (ULD) used extensively for air-cargo. ULDs allow air-cargo loading to be fast and standardized, notwithstanding the large number of disparate pieces carried. In effect, ULDs take the aircraft cargo loading process offline. If it was online, each small package, parcel, box, etc. would have to be individually loaded and made room for. The aircraft – to maximize capacity utilization – would also have to wait while each package was loaded.*

Using the ULD analogy for USPI would allow piggyback payload customers and suppliers to:

- Have a standard set of requirements to design to – the user knows that if their design fits the USPI requirements, they will fit on a large number of LVs.
- Have a standard accommodation template – allows the piggyback payload to fit in the widest possible variety of LVs.
- Allow LV contractors easy integration – as long as the piggyback payload complies with USPI, the contractors know they can easily integrate the payload onto their LV.
- Allow quick mission turnaround – it does not matter how long the piggyback payload takes to design, build and test. Once it is ready, it can go on the next most convenient mission because the USPI standard allows it to fit on any of the USPI LVs.
- Disengage the LV from the piggyback payload schedule – the LV can take the piggyback payload or a standard dummy mass instead. If the piggyback payload is late, the LV can launch with the dummy mass and not worry about the mass balance of the LV.

Using the ULD analogy, USPI shall provide standardized accommodation and requirements that take the piggyback payload design and integration process offline from the launcher-payload integration process.

2.2. The USPI Standard

Table 1 below shows the launch vehicles covered by the USPI standard.

Table 1: Launch Vehicles Considered for USPI

Ariane 4, 5	K 1	PSLV
Atlas II, III, V	Kosmos	Sea Launch
Delta II, III, IV	Minotaur	STS
Eurockot	Pegasus	Taurus
H II A	Proton	

The Pegasus XL, Taurus, and Minotaur are not large LVs and they do not confer the cost benefits associated with piggyback launch on large LVs. However, the Taurus and Pegasus are also potential dedicated launchers for small and micro-satellites that may first be proven with piggyback launches. Therefore, maintaining commonality between the piggyback launch and the – potential – dedicated launch reduces the reengineering required and the cost to the eventual customer.

The USPI standard involves the USPI requirements, mass volume classes, design template, standard separation system, and accommodation platform. The accommodation platform is a concept presented to the

* Lowering the aircraft's overall utilization and increasing per-unit costs.

NRO for further development. Unlike the other aspects of the USPI, it is not ready for immediate implementation yet.

2.3. USPI Requirements

The USPI requirements document is structured as a design requirements document with the launcher specific requirements filled in. A payload designer using the USPI standard would use this document as the starting point for the project design requirements document. The USPI requirements document ensures that, if followed:

- The payload shall fit in the piggyback accommodations provided on any of the USPI-compatible LVs shown in Table 1 above.
- The payload shall comply with the worst-case environmental requirements for the USPI LVs, ensuring maximum possible LV flexibility.

The requirements document provides the design discipline for the tradeoffs essential for mission success. The requirements document is also a living document: as configured now, it only provides the minimum system-level requirements controlled by the LV. Payload system, sub-system, and component level requirements peculiar to a particular project should be added to this document as the design matures. The requirements – like the rest of the USPI standard – are not described in detail in this paper but are available upon request.

2.4. USPI Mass-Volume Classes

USPI defines a standard payload sizing template for piggyback satellites. This template allows maximum flexibility in terms of piggyback launch availability. Payloads usually try to maximize the available volume and mass on a particular launch but that ties a design to a particular LV. Therefore, USPI defines three mass-volume classes to maximize mission flexibility without created an overly restrictive standard. The three classes are shown in Table 2 below. The mass volume classes are discussed in some detail below.

Table 2: USPI Mass and Volume Classes.

Class	Volume	Mass	Comments
Class I	400 mm X 400 mm X 250 mm	50 kg	Smallest class, still can fit ASAP 5 38.5 sep. system
Class II	440 mm X 440 mm X 500 mm	75 kg	Will fit on ASAP 5 sep system Also fit on small launchers
Class III	600 mm X 600 mm X 710 mm	120 kg	ASAP 5 Micro piggyback payload standard.

2.4.1. Class I

Mass-volume Class I is the smallest USPI standard. The general aspect is flat for this class because the 400 mm X 400 mm footprint is required as a minimum to accommodate the 348 mm diameter baseline separation system. The bolt pattern is common with the other mass-volume classes. As configured, Class I USPI payloads will fit as piggyback payloads on the following LVs without modification:

- Pegasus XL DPAF
- Taurus DPAF
- Minotaur – using the OSSS* Multiple Payload Adapter
- Delta II Secondary Payload accommodations
- ASAP 5 Standard – Ariane 5, Soyuz ST-Fregat, Eurockot, PSLV**, K 1
- STS Hitchhiker
- Kosmos – using a DPAF-like structure in place of the “load bearing satellite”
- Proton – in the non-standard accommodations for piggyback launches on Proton

The Sea Launch vehicle has not shown interest in piggyback launches. Discounting that LV, Class I payloads can fit on any of the LVs considered.

2.4.2. Class II

Mass-volume Class II is the second largest USPI payload class. This class has a 440 mm X 440 mm X 509 mm volume with an allowable maximum mass of 75 kg without the separation system. This class also accommodates the 348 mm diameter baseline separation system and has the bolt pattern common with Class I and Class III. As configured, Class II USPI payloads will fit as piggyback payloads on the following LVs without modification:

- 50 inch and 63 inch Taurus DPAFs
- Minotaur – atop the OSSS Multiple Payload Adapter
- ASAP 5 Standard – Ariane 5, Soyuz ST-Fregat, Eurockot, PSLV, K 1
- Kosmos – using a DPAF-like structure in place of the “load bearing satellite”
- Proton – in the non-standard accommodations for piggyback launches

* One Stop Satellite Solutions.
** The Indian Space Agency Polar Satellite Launch Vehicle

Discounting the Sea Launch vehicle, Class II payloads can fit on the LVs above without modification on existing piggyback accommodations or on the standard piggyback payload accommodations proposed for USPI by AeroAstro.

The Class II mass – at 75 kg – makes them very dense for satellites. Therefore, although the mass and volume may cause the least inconvenience for the primary payload, packaging inside the piggyback payload may be difficult. On the other hand, 75 kg is a respectable mass for nano-satellites and this class may find rather a lot of favor with the users.

2.4.3. Class III

Mass volume Class III is the same size and mass as the ASAP 5 Micro class payload. Class III has 600 mm X 600 mm X 710 mm volume and 120 kg without the separation system. The bolt pattern and interface remain the same as the other two classes. As configured, Class III USPI payloads will fit as piggyback payloads on the following LVs without modification:

- 63 inch Taurus DPAFs
- Minotaur – using the OSC 63 inch DPAF
- ASAP 5 Standard – Ariane 5, Soyuz ST-Fregat, Eurockot, PSLV, K 1
- Kosmos – using a DPAF-like structure in place of the "load bearing satellite"
- Proton – in the non-standard accommodations for piggyback launches

Discounting the Sea Launch vehicle, Class III payloads fit on a smaller subset of LVs with existing piggyback accommodations.

2.5. USPI Design Template

A secondary payload launch follows virtually the same process as the primary payload, except a secondary payload needs the LV and the primary payload's cooperation. In general, secondary payloads must meet the mass, volume, and structural requirements set by the payload fairing. The primary payload may also impose schedule and cleanliness requirements on the secondary payload. The primary payload also determines the altitude and inclination of the final orbit.

The integration and launch process varies by LV. However, the overall structure of each process is very similar. These elements can be grouped together into four categories:

1. Spacecraft development and test
2. Spacecraft characteristics
3. Launch requirements and characteristics
4. Launch facility requirements and preparations.

Additionally, the process can be divided into 5 phases:

1. Spacecraft preliminary design
2. Spacecraft detailed design
3. Spacecraft assembly
4. Spacecraft verification testing
5. Launch preparation and range operations.

These categories and phases were used to derive an integrated flow process across all LVs. This integrated flow process is captured as a flowchart and is available with the USPI standard.

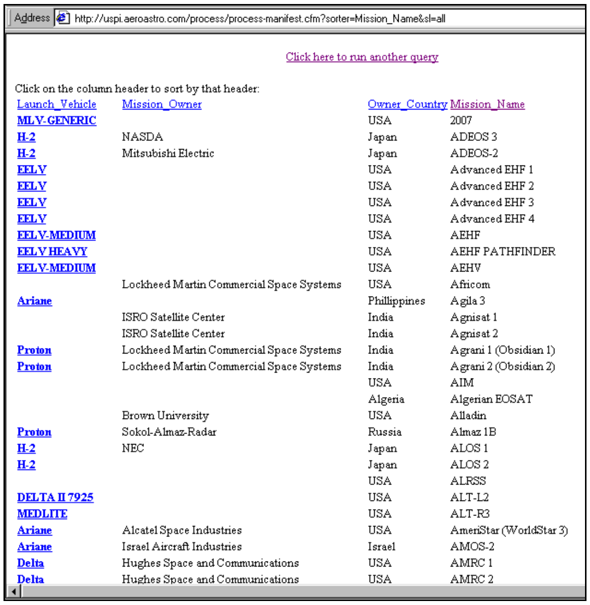
The USPI integration flow considers the time index of similar processes across each LV and chooses the worst-case scenario for each process. If the USPI timeline is followed, it should be possible to meet the deadlines of each of the LVs. This integration flow, coupled with the actual details of the LV interface, is the launch template. Piggyback payload developers need only to follow this template to be eligible for launch on any vehicle considered in the template's development. The common integration flow and the launch template for all secondary launch providers will allow a payload to seamlessly switch from one LV to another, to take advantage of the most immediate and economical available transportation.

AeroAstro has also created an online interactive database to present relevant information to prospective small payload mission planners using USPI. The USPI Interactive Database allows users to run queries to find:

- Launch manifest information for future launches
- Information on historical piggyback launches
- Information on launchers and their launch sites
- Launch environment information.

The database presents information in a clear, easy to understand format. A sample launcher information query of the Interactive Database is shown in Figure 5.

The USPI database can be accessed at http://uspi.aeroastro.com.



Address http://uspi.aeroastro.com/process/process-manifest.cfm?sorter=Mission_Name&sl=all

Click here to run another query

Click on the column header to sort by that header:

Launch_Vehicle	Mission_Owner	Owner_Country	Mission_Name
MLV-GENERIC		USA	2007
H-2	NASDA	Japan	ADEOS 3
H-2	Mitsubishi Electric	Japan	ADEOS-2
EELV		USA	Advanced EHF 1
EELV		USA	Advanced EHF 2
EELV		USA	Advanced EHF 3
EELV		USA	Advanced EHF 4
EELV-MEDIUM		USA	AEHF
EELV HEAVY		USA	AEHF PATHFINDER
EELV-MEDIUM		USA	AEHV
	Lockheed Martin Commercial Space Systems	USA	Africom
Ariane		Phillippines	Agila 3
	ISRO Satellite Center	India	Agnisat 1
	ISRO Satellite Center	India	Agnisat 2
Proton	Lockheed Martin Commercial Space Systems	India	Agrani 1 (Obsidian 1)
Proton	Lockheed Martin Commercial Space Systems	India	Agrani 2 (Obsidian 2)
		USA	AIM
		Algeria	Algerian EOSAT
	Brown University	USA	Alladin
Proton	Sokol-Almaz-Radar	Russia	Almaz 1B
H-2	NEC	Japan	ALOS 1
H-2		Japan	ALOS 2
		USA	ALRSS
DELTA II 7925		USA	ALT-L2
MEDLITE		USA	ALT-R3
Ariane	Alcatel Space Industries	USA	AmeriStar (WorldStar 3)
Ariane	Israel Aircraft Industries	Israel	AMOS-2
Delta	Hughes Space and Communications	USA	AMRC 1
Delta	Hughes Space and Communications	USA	AMRC 2

Figure 5: Sample Launcher Query

2.6. USPI Standard Separation System

USPI proposes a standard adapter design and separation system bolt pattern for all piggyback payloads. One of the major disadvantages in present US piggyback systems and the ASAP 5 standard is that a payload cannot switch LVs late in the design process because each LV has a different, often proprietary, separation system and bolt pattern. USPI uses the ASAP 5 Micro separation system as a baseline to which the other separation systems have to conform. The baseline uses the volume and bolt pattern of the ASAP 5 Micro separation system. Therefore, USPI separation systems must:

1. Fit within a cylinder with inner radius = 142.2 mm, outer radius = 174 mm, and height = 91 mm
2. Use 12 SI M 6 bolts placed 30° apart at 298 0.1 mm diameter on the payload side
3. Use 12 SI M 8 bolts placed 30° apart at 298 0.1 mm diameter on the LV side
4. Have separation system mass 5 kg
5. Have zero-force electrical connector with the following facilities:
    - i. Wire 1 – separation system
    - ii. Wire 2 – separation system
    - iii. Wire 3 – separation system
    - iv. Wire 4 – separation system
    - v. Wire 5 – power
    - vi. Wire 6 – ground
    - vii. Wire 7 – generic
    - viii. Wire 8 – generic
    - ix. Wire 9 – generic

The baseline connector standard is DBAS 74 12 OSN 059.* To allow flexibility in LVs, any connector standard may be used as long as the services mentioned above are included.

The ASAP 5 separation system is a cylinder with mating flanges on the top and bottom. The overall height is 91 mm, inner radius is 142.2 mm, and the outer radius is 174 mm. The top flange mates to any of the three payload classes through a common 12 x M6 bolt pattern. It is a shaped-charge explosive separation system. The inside of the ring is tapped with explosive-filled tubing, on separation signal the explosive ignites, bulging the tubing out and cutting along a precut ridge, separating the ring. The separation springs then push the payload away. The system is very robust and reliable: it has never failed in service before. It also provides a very high separation shock to the payload. Arianespace lets ASAP 5 customers use other systems as long as they conform to their bolt pattern and are qualified to their satisfaction. Therefore, baselining the ASAP 5 Micro separation lets the payload use the Arianespace separation system or one of the other alternatives. AeroAstro has identified two other separation systems that could comply with the USPI baseline separation system requirements:

- The Lightband Separation System – designed and built by the Planetary Systems Corporation
- The Clampband Separation System – designed and built by STARSYS Research Inc.

It would be easiest to require USPI compatible piggyback payloads to use the ASAP 5 micro separation system: it is the most reliable, the most rugged, and the most proven in flight. However, it is manufactured by a non-US manufacturer – Avions Marcel Dassault of France – and is also considered munitions for US Customs. Therefore, unless a US manufacturer can be found for it, the ASAP 5 Micro separation system may not be the best option.

The PSC Lightband separation system is a very elegant design with the lowest mass and the lowest volume. It also provides the lowest shock to the payload. However, the Lightband is not yet fully mission-proven. The manufacturer is also very small – a startup with less than 5 employees – and it is unknown if they can handle the production of this device on a large scale. The STARSYS Clampband Separation system is the most complex, and the heaviest, but it is also the most familiar to US LV and payload engineers.

* An Arianespace proprietary connector standard for connectors supplied by Arianespace.

STARSYS research also has the size and experience to handle the design and fabrication of such a system on a large scale. But the complexity and lack of flight heritage is still a worry.

2.7. USPI Accommodation Platform

The mass-volume classes provide the physical design volume for the piggyback payloads; the separation system design provides a standardized separation system. These two parts of the USPI design are applicable to LVs that presently have standardized accommodations for piggyback payloads. The USPI accommodation concept is a platform upon which USPI piggyback payloads and the USPI separation system can be accommodated. The primary requirements for the accommodation platform were:

- It shall be for launchers without piggyback accommodation
- The accommodation platform shall be out of primary payload load path
- There shall be minimum volume loss to the primary payload
- Minimum PAF modification shall be required to accommodate the platform
- The platform shall fit within payload fairing envelope
- The platform shall accommodate mass-volume classes
- The design shall use "negotiable volume" as much as possible
- The design shall allow "off-line" processing of piggybacks

Of course, the accommodation platform shape must fit all the LVs considered by USPI. The ASAP 5 concept for accommodation payloads was considered the most feasible of all the designs initially considered. The ASAP 5 platform is essentially a torus that sits on top of the Payload Attachment Fitting (PAF). The PAF is extended upwards to allow the piggyback payloads sufficient clearance. This design solution is open to the most resistance from the primary payload customers but it is also the one design that most closely fits all the requirements mentioned above.

Figure 6 below shows the general arrangement of the payload accommodation platform. The platform will be made of carbon epoxy face sheets over foam core. This is the same material used in the EELV PAFs and it is the best choice in terms of integration with the PAF, mass, and stiffness. The torus width is dependent on the mass volume classes being carried. The accommodation of the mass volume classes is determined by the space available between the fairing dynamic envelope and the PAF. The different torus widths are:

- Class I – 570mm
- Class II – 630mm
- Class III – 850mm

The torus is then fitted over the standard PAF as shown in Figure 6 below.

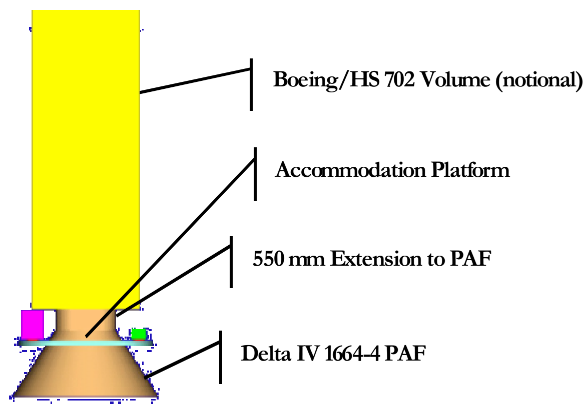


Figure 6: Proposed USPI Accommodation Platform.

The arrangement shown is for the Delta III/IV 1664-4 PAF. It is the worst case in terms of height "lost" to the primary payload, but still has sufficient room to accommodate a notional Boeing 702-class payload. This design is applicable to the EELV – Atlas V and Delta IV – LV families.

The mass margin required to launch the USPI combination ranges from 250 to 675 kg. 175 kg is the mass for the largest platform, the platform can be much lighter. Preliminary analyses suggest that reinforcements and minor changes in material and processing will make the platform considerably stiffer with consequently less mass.

2.8. USPI Design Assessment

The USPI project's success criteria were:

1. Define a standard interface for piggyback payloads on :
    a. LVs that currently accommodate piggyback payloads

    b. Current and/or planned LVs that do not accommodate piggyback payloads
2. Define a design template for piggyback payload designers that:
    a. Allows them the maximum LV flexibility
    b. Allows them to design to clear requirements
3. The USPI standard has to be open – without anything proprietary or competition sensitive that would hinder its acceptance as a standard.
4. Define conceptual designs for an accommodation platform for:
    a. LVs that currently do not accommodate piggyback payloads
    b. LVs that are soon to become operational*

The last criteria was a "stretch" goal for the project and we were only required to present a conceptual design that would then be evaluated for further studies. AeroAstro – with a vested interest in more piggyback access for small and micro-satellites – had some additional success criteria:

1. If possible, the USPI standard should include foreign LVs that accommodate piggybacks
2. In keeping with the open standard theme, the USPI standard should be easy enough to be implemented by the users

Based on these criteria, AeroAstro has successfully proposed a standard interface and design standard for piggyback payloads on large LVs that does not use any proprietary technology. AeroAstro is now proposing the USPI standard as an open standard for implementation by the US and international community of small satellite designers.

3. USPI – The Implementation

A lesson learned from the establishment of the ASAP interface as a *de facto* standard is that ASAP has become a standard through use. The ASAP standard does not maximize piggyback mass capacity, nor is it the cheapest launch option, but it is used the most by small satellite users. In that, Arianespace had the dual advantages of minimal competition and active European Space Agency (ESA) political and financial support. We have no such luxury, so the US small satellite user community has to rely upon itself to make this standard a reality.

* e.g., the EELV – Atlas V and Delta IV – and the Kistler K-1.

AeroAstro had proposed to the NRO[4] the following phased implementation procedure:

- Phase I – implement the requirements and design template for government-funded piggyback missions. Get users used to the system and get enough iterations on the system to work out the bugs.
- Phase II – test and implement the standard separation system and use the mass volume classes on LVs with existing piggyback capability.
- Phase III – detail design of the standard accommodation for LVs that currently do not have piggyback accommodation. Test and implement the design on an LV in conjunction with the design template, USPI requirements, and standard separation system.

The phases emphatically do not have to be sequential. They can have significant overlap or can even be simultaneous.

As proposed, USPI implementation requires government funding and support for Phase III implementation. However, Phases I and II can be implemented now. Phase I can be implemented for any mission – government funded or otherwise – using piggyback capability on any launch vehicle used in the USPI standard. Phase II can be implemented by any project using a USPI-compliant LV piggyback launch and one of the two separation systems** without flight heritage. AeroAstro proposes to use the Linux concept of implementation for Phases I and II to avoid the pitfalls of government participation or lack of funds.

3.1. Another Analogy

Dennis Ritchie invented the "C" language for use under the UNIX system invented by Ken Thompson at the Bell labs in 1969. UNIX and C shared some important strengths: portability amongst different hardware, a flexible toolkit, and KISS as the guiding philosophy.[5] The two – operating system and software – had no formal support from their employer – Bell Labs – but that was no hindrance in their rapid acceptance within AT&T. By 1980, UNIX and C had widespread acceptance at universities and research departments. These two had become a virtual computing standard almost wholly because of their enthusiastic adoption by users.

** The PSC Lightband and the STARSYS Research Clampband. The ASAP 5 Micro has flight heritage with 100% success.

Adoption by use was taken further with the adoption of the Linux version of UNIX. Linus Torvalds, a student at Helsinki University, developed Linux as a UNIX kernel for 386 processor machines. He distributed the software free, with the source code available to the users. As a result, a vast number of programmers have taken the Linux source code, added functionality to it, and released it to the user community to increase Linux's overall utility.

Eric Raymond suggests that before Linux, the received wisdom was that "any software as complex as an operating system had to be developed in a carefully coordinated way by a relatively small, tightly-knit group of people. Linux evolved in a completely different way. From nearly the beginning, it was rather casually hacked on by huge numbers of volunteers coordinating only through the Internet. Quality was maintained not by rigid standards or autocracy but by the naively simple strategy of releasing every week and getting feedback from hundreds of users within days, creating a sort of Darwinian selection on the mutations introduced by the developers."[5]

Linux is now a stable and reliable system, used on many corporate networks, hosting more software than commercial UNIX. And the implementation method means that the Darwinian process continues, rapidly evolving the system to meet new challenges. The USPI standard was based on the ULD analogy. We propose that its implementation be guided by the analogy of Linux.

3.2. USPI Implementation

We propose to implement USPI as an "open source standard": all participants in the USPI standard shall receive the information on this standard free of charge with an agreement to the stipulation that they in turn actively help in the maintenance and update of the standard by free sharing of information.

3.2.1. Participation in USPI

AeroAstro is mandated* to provide the USPI standard to any US organization as long as the security and ITAR requirements of the US government are not violated. Any organization – small satellite designer, LV provider, or piggyback broker – shall be given the details of the USPI standard. Users can add to the standard or enhance it in any way. However, user's have to ensure that any enhancements or additions do not violate the requirement for piggyback payload launch flexibility on the largest possible number of LVs in the US and abroad.

3.2.2. What You Get

Participants in the USPI standard shall get:

- The USPI requirements document
- The USPI design template

The information in the standard will grow as more users provide feedback to the standard. Users cannot limit the use of the information they provide. All information added or updated to the standard shall be available to all participants in USPI as updates to the document.

3.2.3. What You Give

Any flaws in the standard shall obviously be updated. In addition, if users find any enhancements that could further the standard, they will add to the standard. Any information that a particular user considers competition-sensitive or proprietary will not be required to be added to the standard. However, by the same token, this information will not become part of the standard and be less widely accepted.

3.2.4. A Living Standard

The "Darwinian evolution" model of Linux implementation will be used to ensure that the standard remains usable and flexible. Additions that users do not find useful will be proposed for deletion in subsequent revisions or replaced by new ones. This living document will ensure that the USPI standard evolves with changes in the market, LV requirements, and the end-users requirements.

4. Conclusions/Recommendations

Piggyback launch on large LVs offers one potential solution to the problem of high launch costs for small and micro satellites. USPI is a first effort at a standard for small satellites to launch as piggyback payloads on large LVs. The USPI provides: detailed requirements, a set of mass volume classes, and a design template. The USPI will allow small satellite designers the maximum flexibility in terms of piggyback launch availability. If a satellite is designed to the USPI standard, it will be capable of launch on any of the large LVs covered by USPI. An accommodation platform concept for LVs currently without piggyback accommodations was also required by the NRO and it is described in this paper. However, the platform is not necessary to the

* By the sponsors of this standard, the National Reconnaissance Office.

establishment of USPI as a standard for piggyback accommodations.

AeroAstro proposes to implement USPI as LINUX was implemented in the software community. NRO required the USPI standard to be open – without any proprietary standards. We are taking that direction to heart and offering USPI as a truly open standard where the modification and update of the standard will be left to the user community and their constant feedback and improvements. We believe that, if USPI has fulfilled its goal of proposing a usable standard for piggyback payload launch, the "open source" approach will rapidly make USPI a *de facto* standard for piggyback accommodation on US and foreign LVs.

Acknowledgments

AeroAstro would like to gratefully acknowledge the support of the National Reconnaissance Office, Office of Space Launch (NRO-OSL) in the definition of the USPI standard. We appreciate their support for the small satellite community and believe that their support shall further foster US small satellite development.

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