National Aeronautics and Space Administration

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SUMMARY REPORT

Increased Science Return through Rideshare

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NOTE: This document summarizes results from the 2020 NASA Access 2 Space Workshop. It is for informational purposes only and does not specify Agency plans or directives.

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Overview and Findings

This report summarizes the Access to Space (A2S) Workshop[1] held on February 25-27, 2020 at the Johns Hopkins University Applied Physics Laboratory (APL) and hosted by NASA's Science Mission Directorate (SMD). This workshop solicited community input on the creation and management of an ESPA-class[2] payload pipeline for NASA SMD launches. The workshop brought together roughly 180 participants including scientists, engineers, instrument developers, launch providers, and policy makers across NASA centers, government agencies, commercial industry, research institutes, and academia.

NASA SMD has identified ESPA-class spacecraft as part of its overall small satellite (SmallSat) strategy to create more opportunities for science return. While CubeSats will remain part of the current and future portfolio of technology demonstration and operational science missions, ESPA-class spacecraft provide additional capabilities and design-trade alternatives to enable new and specific classes of scientific measurements and observations—including those driven by the National Academy of Science Decadal Surveys. Given that SMD will continue to procure launch vehicles that may potentially have sufficient excess capacity for ESPA-class rideshare payloads (RPLs), and the 2020 release of the National Academies' report on Agile Responses to Short Notice Rideshare Opportunities for the NASA Heliophysics Division[3], NASA believed the time was right to engage the broad community in four key areas that would drive future agency planning for ESPA-class rideshare:

- *Science Observations and ESPA-class Instruments* – Science enabled by ESPA-class payload pipeline development based on the following destinations of interest: Low Earth Orbit (LEO), Geosynchronous Orbit (GEO), cislunar space, and deep space; and ESPA-class instruments enabling identified science observations.
- *Launch Vehicle Barriers* – ESPA-class satellite design and configuration concerns that impact access to space, including an assessment of alternatives to traditional rideshare approaches.
- *Technology Challenges* – Development challenges impacting propulsive ESPA and constellations, and fundamental technologies that could hinder ESPA-class satellite pipeline development.
- *Programmatic Issues* – Announcement of Opportunity (AO)/Mission of Opportunity (MO) process changes, the level of project oversight, diversity initiatives, and standardization impacting ESPA-class payload solicitation and delivery for launch.

Workshop participants took part in consecutively conducted splinter session discussions to address these topics.

[1] https://civspace.jhuapl.edu/News-and-Events/events/Access2Space/

[2] EELV Secondary Payload Adapter (ESPA). Although the term Evolved Expendable Launch Vehicle (EELV) is no longer used the terms ESPA-class (spacecraft) and ESPA-Ring (interface adapter) remain in common use.

[3] National Academies of Sciences, Engineering, and Medicine. 2020. *Report Series: Committee on Solar and Space Physics: Agile Responses to Short-Notice Rideshare Opportunities for the NASA Heliophysics Division*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25726.

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Science Observations and ESPA-class Instruments

The attendees identified many observations that were uniquely enabled by ESPA-class spacecraft. From LEO and GEO, these were largely survey missions benefitting from constellations such as all-sky surveys and exoplanet observations in Astrophysics, long-term continuity measurements in Earth Science and Heliophysics, and simultaneous multi-point measurements of boundaries in Earth's space environment for Heliophysics, and rapid identification and characterization of near-Earth objects for Planetary Science. In general, payload pipelines would support sustainable measurements that could be refreshed with launch opportunities to LEO/GEO. Specific science objectives included simultaneous multi-point measurements of the time-evolved distribution of heliospheric energetic particles and magnetic fields; continuous global coverage of time-varying phenomena such as atmospheric water vapor content; exoplanet atmospheric characterization using synthetic aperture telescopes; and rapid near-Earth asteroid characterization.

Discussions of cislunar science with ESPA-class payload pipelines largely focused on the potential of multiple lunar landers as well as new measurements enabled at the Earth-Moon Lagrange points where gravitational stability would be advantageous for the observation. Disaggregated observations in radio quiet zones with measurements both affected by, or beyond the sphere of, Earth's influence were identified. For deep space, the increased capability of ESPA-class spacecraft to carry additional propulsion, higher-power communication, and larger instruments to perform multi-point in situ observations of planetary magnetospheres, atmospheres, and surfaces was especially compelling. In addition, the potential to perform higher-risk observations, and more of them, were strong drivers for ESPA-class pipeline development, provided a sufficient number of launch opportunities and excess mass capability are available to support "reasonable numbers" of RPL ESPA-class spacecraft.

There were no active or passive remote-sensing instruments that the community found to be incompatible with ESPA-class spacecraft integration (pending mass/volume constraints). From the science drivers identified above, such instruments spanned magnetometers, particles and fields instruments, radar, lidar, spectrometers, interferometers, coronagraphs, imagers across all relevant wavelengths, and thermal, laser, and synthetic aperture instruments to name a few. The community classified the readiness of ESPA-class instruments into three categories: (1) as-is instruments that could be integrated with little to no modification, (2) instruments that could be integrated with minor modifications, and (3) instruments requiring significant technology development to be ESPA-compatible.

Interface standardization amongst instruments and the host platform was identified as a means to enhance pipeline development, increasing flight opportunities and flight readiness, while lowering integration costs. Instruments with compatible orbit parameters could fly together on the same platform or multiple platforms supporting ESPA-class constellation observations via frequent launch opportunities or launches to rarely explored destinations.

<u>Finding 1</u>: A pipeline of ESPA-class spacecraft will enable new system science and sensor development, but significant upfront planning is needed to ensure these missions are compatible with primary mission launch parameters and environments.

Finding 2: Development of a multi-spacecraft ESPA-class payload pipeline enables sustainable long-duration continuity observations.

Finding 3: ESPA-class instrument development fills a capability gap between CubeSat and flagship missions for novel science observations.

Finding 4: Pipeline development for ESPA-class instruments should concentrate on standardization, interfaces, and design for mass production without compromising measurement quality.

Finding 5: Strategies are needed to ensure future ESPA-class instruments are designed to minimize the degradation effects from long-term storage.

Finding 6: A strategy is required for the pipeline development of large numbers of identical, high-Technology Readiness Level (TRL) instruments to enable ESPA-class SmallSats for constellation missions.

Launch Vehicle Barriers

Identifying potential rideshare payloads early was recognized as a means to limit the impact of launch vehicles on the development of ESPA-class pipelines. From a programmatic perspective, when working with government and commercial organizations that regularly provide launch services or vehicles, a careful balance must be maintained between flexibility and mission success. The need for a centralized rideshare office to coordinate across NASA SMD and the NASA Centers was identified. It was also recognized that some RPLs, many of high national importance, exceed the risk posture of Do No Harm (DNH) requirements. Thus, existing DNH requirements may require continuous reassessment even as primary missions become more accepting of RPLs with propulsion or other higher risk subsystems.

A variety of alternative approaches including dedicated small launch vehicles, the International Space Station (ISS), propulsive ESPA, and custom launch vehicle adaptors, to name a few, were also explored as means to support ESPA-class payload pipelines. While the availability of some alternative approaches is limited today, it was clear that rapid launch cadences for multipoint science observations, as well as risk mitigation via an alternative access-to-space approach, were clear advantages for these approaches, provided interface standards to such systems could be created.

Additional launch vehicle challenges impacting ESPA-class pipelines include contamination control, late access, loads/dynamics, and certainty of orbit insertion. Risk classification also has a direct impact on launch vehicle barriers, but the attendees concluded that creating a special new risk classification for ESPA-class payloads would be inappropriate given these systems could be Class B or Class C missions. Nevertheless, a scheme to classify payloads as “standard” or “unique” could reduce barriers in terms of documentation and interfaces for pipeline development. Indeed, in terms of RPL configuration constraints ensuring the development teams have a comprehensive and cohesive set of guidelines covering orbits, interfaces, requirements, and schedule could substantially reduce barriers to launch vehicle selection and integration including a rating system.

Finding 7: ESPA-class payloads that are identified early and minimize complexity increase the manifest options towards a variety of launch vehicles, while lowering the risk to the primary mission.

Finding 8: Dedicated launch services and other ESPA-class launch/deployment options can further enable ESPA-class payload pipeline development via multiple alternative access-to-space approaches.

Finding 9: Development of an ESPA-class payload rideshare rating system upon mission selection could streamline matchmaking of payload pipelines to launch opportunities.

Finding 10: Configuration-constraint expectations of ESPA-class payloads should be established during the solicitation process.

Technology Challenges

Specific technology focus areas explored that either enable or impact ESPA-class payload pipeline development included propulsive ESPA, multi-spacecraft missions, subsystem development, and open technology development issues spanning supply chain gaps through ESPA-class bus qualification. Propulsive ESPA was found to have great potential to enable NASA science missions both as a fully integrated mission capability and as a platform for deployment and support of ESPA-class payloads, which themselves may also be propulsive. The flexibility introduced by this technology is enabling for certain Earth science, heliophysics, and inner planetary constellation missions, but very few propulsive ESPA systems have flown so the technology does require further maturation through flight demonstrations. The current cost of such systems also raises concern about the ability to employ this technology.

Many categories of ESPA-class multi-spacecraft mission architectures were defined including distributed systems, science constellations, dual spacecraft missions, network constellations, and complex constellations of CubeSats. Given that such missions are complex, leveraging the experience of commercial organizations for LEO-based missions was considered prudent and technology development for customized spacecraft in planetary science and missions requiring unique formation-flying capabilities was suggested. Regardless, advances in propulsion, communication, navigation, ground data systems, and flight processors for autonomy were identified as enabling technologies.

The community felt that scaling up CubeSat subsystems, or scaling down flagship mission subsystems, in the long term would not be feasible to support ESPA-class spacecraft. Also, even though numerous legacy space organizations, and even new space companies, are actively developing fully integrated ESPA-class platforms for LEO to deep space applications, questions remain as to whether the market is sufficiently large to sustain such work over time. Adding ESPA-class subsystem development into the Small Business Innovation Research (SBIR) program, growing technology flight demonstration programs, and creating a Rapid Spacecraft Development Office (RSDO) catalog tied to appropriate standards were identified as ways to support ESPA-class subsystem development.

There are other technology challenges that must be overcome to enable successful spacecraft development, from enhanced telecommunication capabilities, radiation-hardened electronics, deployable structures, and attitude control, to the role of additive manufacturing to satisfy specialized design requirements. One method to facilitate the payload pipeline is to implement a modular technology development plan coupled with a rigorous technology demonstration program. Tested modular components would reduce the uncertainty for developers and decrease lead times for payload builds. Technology that could support modularity of spacecraft design was also considered highly desirable.

<u>Finding 11</u>: Propulsive ESPA is an enabling technology for complex multi-spacecraft science missions, but flight demonstrations are needed to prove and mature this capability.

<u>Finding 12</u>: Small satellite subsystem technologies have rapidly matured, improving performance and reliability, but focused investments and strategic partnerships are needed to advance such technologies for deep space ESPA-class systems.

<u>Finding 13</u>: Payload pipeline technology development should be modular, culminating in a rigorous demonstration program.

Programmatic Issues

The main programmatic concern centered on how the AO solicitation process could be improved to support ESPA-class payload pipeline development. Discussions on solicitation development tied to targeted rideshares for specific launch destinations versus generic rideshares for flexible, to-be-determined launch destinations (i.e., those where the launch target parameters are not known in advance), concluded that both categories of solicitations are necessary. Even in instances where payloads may not be solicited simultaneously with a primary mission, there would be value in designing ESPA-class payload pipelines for specific launch targets such as Low Earth Orbits (LEO), Sun Synchronous Orbits (SSO), Geosynchronous Orbits (GEO), Geostationary Transfer Orbits (GTO), or elsewhere. The community also felt that the current means for selecting candidate RPLs independent of the primary mission effectively supports pipeline development and that the development of these missions should be supported at least through their Preliminary Design Review (PDR). These changes to the AO process could potentially open up more opportunities to utilize "excess Principal Investigator (PI) capacity" (i.e., provide more opportunities for PIs to build and launch payloads) as new mission concepts are conceived and developed for these future opportunities.

Regarding oversight and deliverables, a consistent approach to manage the interactions between the primary mission and the ESPA RPLs during implementation was identified as necessary to provide balance between effective and overburdensome oversight.

Both standard services and mission unique options should be supported, but standard services were found to have the greater benefit of supporting flexibility in manifest options for ESPA-class payloads that fully comply with such services.

Producing a pipeline of ESPA-class payloads will rely on work from a broad diversity of investigators and institutions. Programmatically, however, some investigators felt their institutions were discouraging small mission development as a career path, given challenges pertaining to sustainable funding, technical experience, and training opportunities when compared to NASA Center investigators, and the perception that only a subset of universities typically win flight development awards. A number of solutions to these diversity challenges were proposed spanning increased mission cost caps, access to internal NASA training activities, and renaming awards to foster greater recognition within the academic community for tenure purposes, to mechanisms that ensure the risk associated with such missions and payload pipeline development does not inadvertently impact the PI institutions' reputations.

Finding 14: ESPA-class payload solicitations should be designed for two categories of rideshare opportunities: targeted rideshares for specific launch destinations and generic rideshares for flexible, to-be-determined launch destinations.

Finding 15: RPLs should be identified/selected early to align life cycle milestones and gate requirements with the primary payload and to allow procurement of the appropriate launch vehicle on a less constrained schedule.

Finding 16: Standardization of services and solicitation of concept studies for launch opportunities directly enhance ESPA-class payload pipeline development.

Finding 17: Overall mission oversight-related activities amongst the primary and ESPA-class rideshare payloads should align with the lifecycle of the primary mission when practical.

Finding 18: Lack of funding continuity and training opportunities present challenges for small university investigators where strong institutional support is needed for new and/or early career PIs to impact the diversity of payload pipeline development for ESPA-class missions.

Closing Comments

Finally, two key events occurred during the workshop:

- Introduction of the SMD ESPA-class Rideshare Policy (SPD-32)
- Appointment of a permanent SMD Rideshare Lead with a support team to implement the policy

The SMD Rideshare Office follows the SPD-32 SMD ESPA-Class Rideshare Policy and is now the single point of contact for rideshare in SMD.

The remainder of this summary provides greater detail regarding the four subject areas covered above as well as the key issues supportive of ESPA-class payload pipeline development in those areas. While the community clearly favored actions SMD has undertaken to support science enabled by ESPA-class spacecraft, it was also clear that standardization, technology development, and AO/solicitation structural support will be needed to fully realize the potential of these flight systems for new science observations.

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1. Science, Instrument Types, and Configurations that Drive the Pipeline (Splinter Sessions 1 and 2)

1.1 Background

Regular access to space is in great demand in the scientific community, and scientists are highly motivated to utilize rideshare opportunities to advance multiple science objectives. During the workshop, ESPA-compatible scientific missions were identified that could be launched to Deep Space, Cis-Lunar, Geosynchronous (GEO), and Low Earth Orbits (LEO). These mission concepts could use the ESPA ring both as a spacecraft bus as well as a mechanism for standalone spacecraft to be deployed separately.

Various SMD-funded scientific instruments are mature and potentially compatible with existing ESPA platforms and ESPA-mounted SmallSats. In other cases, significant instrument technology development will be necessary to make them compatible with ESPA rideshare spacecraft and payloads.

1.2 Key Issues and Insights

Multi-Spacecraft Missions

As our exploration of the solar system progresses, multiple vantage points are becoming more attractive in aiding our understanding of the causes and effects of phenomena on Earth and in space. Mission concepts from four of the SMD divisions (Earth Science, Heliophysics, Planetary Science, and Astrophysics) make use of multiple spacecraft, a few of which are detailed here.

In heliophysics, multipoint measurements distributed throughout the solar system are required to understand the behavior of the whole heliosphere. The heliophysics community has successfully implemented dedicated multi-spacecraft missions in the past, such as the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission (five spacecraft distributed through Earth's magnetosphere), the Magnetospheric Multiscale (MMS) mission (four spacecraft flying in formation in Earth's magnetosphere), the Van Allen Probes (two spacecraft observing Earth's Radiation belts), and others, including future mission concepts such as the Geospace Dynamics Constellation (GDC) (an array of six or more spacecraft that will explore Earth's Ionosphere).

Two of the missions selected in 2019 through the Planetary Science Division's Small Innovative Missions for Planetary Exploration (SIMPLEx) program—Janus and ESCAPADE (Escape and Plasma Acceleration and Dynamics Explorers)—feature dual spacecraft. ESCAPADE will make multipoint measurements at Mars and Janus will travel to two binary asteroid systems. Two of the original THEMIS spacecraft were also sent to the Moon, forming a mission known as the Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun, or THEMIS-ARTEMIS, to study space weather in a lunar, planetary context. In Earth science, multipoint measurements have been demonstrated using heterogeneous, but synergistic, spacecraft together, as in A-Train type configurations. For both the Earth Science and Astrophysics Divisions, multipoint measurements enabled by ESPA-class constellations mean continuous global coverage, which can enable observations of time-varying phenomena without having to make assumptions about the object's behavior during observation gaps. And in astrophysics, multiple spacecraft could together create a large synthetic aperture instrument beyond what would be possible on a single spacecraft. ESPA rings could similarly be useful as a hub for multiple spacecraft dedicated to a singular space mission.

Instrumentation limitations must be considered when building spacecraft constellations with many tens of SmallSats employing ESPAs. Building large numbers of identical instruments presents a manufacturing challenge that has not yet been addressed within SMD. Furthermore, development of high-Technology Readiness Level (TRL) miniaturized instruments for ESPA-compatible SmallSats has not been an SMD-wide focus but should be considered in the future.

Measurement Continuity

Long-term continuity measurements are critical to investigate many long-outstanding questions in Earth science and heliophysics while also preserving and sustaining specific data records. Long-duration observation is necessary to tease out long timescale trends, and failing to conduct a cross-calibration activity for an aging spacecraft and its replacement risks losing an entire data record taken over many successive missions. Earth science in particular relies upon measurement continuity for its long-term climate studies. Space weather and space weather prediction in heliophysics require continuity of measurement both upstream in the solar wind as well as in situ at targets of interest. Likewise, continuous measurements of solar irradiance over time pertain to both heliophysics, planetary science, and Earth science. As robotic and human outposts become more established at other planets, atmospheric and space weather predictions at those locations will become more important. Lastly, for astrophysics, continuity of measurements is important to enable exoplanet detection.

As rideshare opportunities on ESPA rings become more available, replacement spacecraft could be created in advance and stored until an orbiting spacecraft nears its end of life. Instrumentation considerations for spacecraft storage include long-term stability of coatings and materials used in building the spacecraft. Current mission designs typically do not account for a long pre-launch storage period, so the "storage environment" would need to be addressed in the design and build phases to reduce risk. Ironically, spacecraft that are designed to function for decades in space may not survive months in storage on Earth. Few precedents for long-term spacecraft storage exist, but the Triana/Deep Space Climate Observatory (DSCOVR) spacecraft's case might be a good starting point for such a study.

Rapid Launch Cadence

As science missions with rideshares on ESPA rings become more frequent, targeted missions for conducting opportunistic observations could enable new science. Examples include interception of interplanetary asteroids or comets and observation of Earth-based disasters. Rapid launch also facilitates satellite replacement and reduces risk to continuity measurements as described in the previous section. Rapid launch cadences also enable efficient replacement of missions whose orbits decay quickly, such as missions within Earth's lower ionosphere, or low-altitude missions at airless bodies, such as Earth's Moon or Mercury, where localized gravity variation contributes to orbital decay.

With a very rapid launch cadence, ESPA spacecraft with hosted payloads and ESPA-mounted SmallSats could be used as testbeds to qualify new instrumentation and novel mission concepts. In this scheme, each ESPA port could host one or many instruments or technologies. The process for raising instrument TRL or qualifying science-enabling technology is costly and time consuming; hence, rideshare might provide an opportunity to speed the process.

In the rapid-launch mission schemes described above, standardization of interfaces could simplify integration and reduce risk in a compressed rideshare schedule. Workshop participants identified the sounding rocket program as an example of successful standardization of interfaces, but did not discuss specific standardizations.

Instrumentation Suitability

Scientists have been developing instrumentation for highly resource-limited missions since the dawn of the space age. Rather than listing all of the different types of instruments that are rideshare-compatible based on power, size, and mass, it is easier to classify instruments into three rough categories of rideshare "readiness:"

1. Instruments either ready for integration onto ESPA rideshares as-is, or that require only very small modifications, such as interface updates
2. Instruments that require minor, but notable, modifications to fit on an ESPA platform, such as miniaturization of components or more stable materials
3. Instruments that require significant technology development to be ESPA compatible, such as new instrumentation types under development, or instruments that require large volumes, deployables, or apertures to make scientifically significant measurements

Most instruments within the SMD catalog belong in category 1 or 2. A few specific instrument and SmallSat technologies that would facilitate rideshare readiness for ESPA include:

1. Long-duration stability of electrical parts and optical coatings for storage
2. Deployables, particularly SmallSat-compatible booms and antennas
3. Chip-based detectors and specialized application-specific integrated circuits (ASICs) for miniaturization of instrument components

The above should not be considered an exhaustive list. Many instruments with high heritage are customized and bespoke instruments, each ideally suited for a specific science mission and environment. Current instrumentation suitable for a "ride to anywhere" mission is limited; aperture sizes, detector sensitivity, temperature, and so on are not easily standardized for any environment or orbit. Hence it might make sense to allow broader interpretation when meeting level 1 science requirements for ESPA missions. Many instruments on multiple spacecraft could make valuable measurements as an ensemble even if they are not individually tailored to a specific mission.

Other Instrument Challenges in Achieving Rideshare Science

Parts availability, particularly for Electrical, Electronic, and Electromechanical (EEE) parts and long-lead items, is a perennial challenge, especially for the fast-paced rideshare schedule. Very long lead times for specialized parts could prohibit inclusion of some instruments from the rideshare pipeline altogether if alternatives cannot be sourced from partner institutions or projects.

Measurements made by some instruments might not be worth taking in isolation. For example, a magnetometer might make a useful measurement on its own, but a magnetometer coupled with a plasma detector would result in greater science than a lone sensor mounted on an empty ESPA bus port. When choosing instruments to host on an ESPA spacecraft bus, grouping candidate instruments into cohorts with similar environmental requirements and science objectives could prevent time-consuming and costly concessions later in the project. Similar cohorts could be paired to compatible primary payloads for integration without conflict.

1.3 Observations

The following observations were gleaned from Splinter Sessions 1 and 2:

Observation 1a: A strategy is required for the pipeline development of large numbers of identical, high-TRL instruments to enable ESPA-class SmallSats for constellation missions.

Observation 1b: Because current instrumentation suitable for a “ride to anywhere” mission is limited, it may make sense to allow broader interpretation when meeting level 1 science requirements for ESPA missions

Observation 2a: To enable continuity of measurements, future ESPA-class instruments must be designed to minimize the degradation effects from long-term storage and provide stable measurements that support the existing data record.

Observation 2b: Establishing standardized services and interfaces would enable rapid ESPA-class launch cadence.

Observation 2c: To enable the ESPA-class payload pipeline, strategies are needed to (1) develop instruments that do not include components that require long lead times, and (2) group complementary instruments with similar science goals together on an ESPA spacecraft bus

2. Launch Vehicle Barriers and Issues that Hinder the Pipeline (Splinter Session 3)

2.1 Background

Issues concerning launch vehicles can significantly impede the ESPA-class payload pipeline. The experts participating in this splinter provided insights into key topics including launch vehicle programmatics, documentation, standardizing interfaces, the payload’s physical configuration constraints, and various methods to deliver ESPA-class payloads to orbit.

2.2 Key Issues and Insights

Programmatics

The establishment of a directorate-level rideshare office, with the authority to develop policy and implement an SMD-wide rideshare strategy, now provides a much-needed leadership role within SMD and across the rideshare community. As the single point of contact for rideshare-related matters within SMD, the office will consolidate guidance and quickly resolve disparate challenges. Key functions of the SMD Rideshare Office include:

- Standardizing Announcement of Opportunity (AO) language and reviewing each AO for consistency
- Maintaining an authoritative list of SMD launch opportunities and tracking potential external launch opportunities
- Developing key documents including a Rideshare Implementation Plan, Rideshare Users Guide, Reimbursable Rideshare Policy, etc.
- Managing a repository of key information available internally to NASA (external information is made available on the Small Spacecraft Systems Virtual Institute [S3VI] website)
- Performing a top-level payload compatibility analysis of rideshare missions to identify potential impacts to the primary payload or the success of the RPL.
- Fostering a close relationship with the NASA Small Spacecraft Working Group

SMD should standardize rideshare mission project implementation throughout the directorate and clearly identify communication paths among participating entities. Program Offices for the primary mission form a key role in streamlining communications between the rideshare payloads and the Launch Service Program (LSP). Complex models and products from the rideshare payloads must be formatted properly and verified before they reach the launch service contractor. This process is especially important when a new RPL team with little experience is striving to follow the processes defined in NPR 7120.5, NASA Space Flight Program and Project Management Requirements and NPR 7120.8, NASA Research and Technology Program and Project Management Requirements.

Additional suggested programmatic approaches to populate an ESPA-class pipeline include:

- Select 2-3 projects via the AO and fund them through the paper study phases up to preliminary design review

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- Solicit ESPA-class payloads early via the primary mission AO process instead of matchmaking payloads to primaries later
- Ensure rideshare payloads are not complex or custom-designed
- Fly missions that consist of ESPA-class payloads only (i.e., no primary mission) with a predetermined destination
- Define two categories of payloads: (1) generic (standard interfaces), and (2) special; incentivize projects to choose the generic approach to foster a more robust pipeline
- Institute a “rideshare-ability” rating to gauge the degree to which payloads can be accommodated on the mission

Documentation and Standardization of Interfaces

Crisp communication is required across the community regarding terminology as well as processes, implementations, and interfaces. Government agencies who implement rideshares use completely different sets of terminology and documentation.

For example, the term “Do No Harm” (DNH) should be clearly defined to mean that RPLs cannot physically harm the primary payload, the launch vehicle, or other RPLs. SMD needs to coordinate with LSP to develop a document to define the DNH concept. While the primary spacecraft is the focus of the mission, the needs of the rideshare payloads should be considered throughout the mission lifecycle.

A minimum suggested set of documents required to foster a better understanding of the rideshare concept and process was identified: Rideshare 101 Instruction Manual, System Interface Specification, Do No Harm Requirements, SMD Rideshare Users Guide, Reimbursable Rideshare Policy, and a Rideshare Implementation Plan.

Standardization of interfaces between the ESPA payload and the spacecraft and between the spacecraft and the science instruments was deemed important. The consensus was that an industry-led approach would be more preferable to an SMD-led approach.

Configuration Constraints

Primary mission target parameters including injection characteristic energy (C3) and the declination of the launch asymptote (DLA) can impose large constraints on rideshares. However, these parameters are not finalized until after the launch vehicle is selected. In any case, launch vehicle resources will likely not be available to rideshare payloads to enhance performance.

Rideshare arrangements are facilitated when RPLs are deployed to the same orbit as the primary payload. Deployment order is not considered a high risk by the launch providers, but primary payloads prefer to be released first. Performance tradeoffs between the primary and RPL missions would also facilitate the pipeline.

Contamination control is always a concern for science instruments, whether they are primary or RPL missions. Contamination control requirements need to be communicated to the rideshare payloads in the solicitation opportunity as part of the system interface specification. Tradeoffs between mission-unique cost versus mass and risk will occur. To enable more launch options, rideshare payloads should be encouraged to meet such requirements using engineering solutions (e.g., purging the instrument with Argon) instead of additional processes on the launch vehicle (e.g., post-encapsulation access and T-0 purge). Late access is a major concern and any change in design or process approach enacted to reduce late access reduces risk for the mission.

The rideshare community is also concerned with structural stiffness and load dynamics. NASA has not flown ESPA missions with a primary payload and consequently has no historical data on how the rideshare load dynamics could potentially affect the primary spacecraft. For the Interstellar Mapping and Acceleration Probe (IMAP) mission, LSP has initially directed the rideshare payloads to design to a 75Hz stiffness requirement—a fairly conservative value; however, once the launch vehicle is selected for IMAP, NASA will immediately conduct a coupled loads analysis to refine the stiffness requirement for this and future missions.

Alternative Methods for Access to Space

Options for methods to deliver ESPA-class payloads to orbit beyond traditional ESPA-ring integration onto a traditional launch vehicle were examined. The discussion covered dedicated small launch vehicles and propulsive ESPA to determine the role these alternative approaches could serve in enabling payload pipeline development.

Use of dedicated small launch service providers to support ESPA-class spacecraft would result in several benefits that would stimulate pipeline development for future science observations and technology demonstrations:

- Greater, more flexible, and more direct control of the launch schedule
- Relaxed Do No Harm (DNH) requirements
- Lower programmatic complexity
- Higher launch cadence

Nevertheless, there were certain disadvantages identified with a dedicated small launch capability in terms of development of a payload pipeline:

- Lack of standard system interfaces and environmental requirements could limit available launch providers and could increase risk
- Cost commitments may be fluid and may be affected by variable timelines of the organizations involved
- Uncertain or inaccurate pricing information
- Limited mass capability

Propulsive ESPA adds the capability for greater control of deployment of ESPA payloads. Typically, the propulsive ESPA is integrated with a traditional large launch vehicle, although the potential for propulsive ESPA on a dedicated small launch vehicle was not ruled out. Propulsive ESPA systems have been demonstrated and some organizations are developing ESPA-class spacecraft as part of an integrated offering. Advantages of propulsive ESPA include enabling higher payload mass than a standard ESPA rideshare mission and the capability to extend mission operational life and/or allow for limited orbit modification. Propulsive ESPA could also support variable delta-V up to a few kilometers per second, which could enable science payloads requiring higher injection energies.

In summary, alternative access-to-space approaches could further enable ESPA-class payload pipeline development. Dedicated ESPA-class launch systems with a rapid launch cadence foster multipoint science observations to satisfy science requirements more effectively than rideshare missions alone. Standardization of interfaces could open the trade space to include alternative approaches to space and drive payload pipeline development, as payloads would have additional deployment opportunities. Alternative approaches could serve as a backup to traditional rideshare mechanisms, as a risk mitigation strategy during concept development or mission implementation, and/or to minimize schedule risk for the primary mission launch vehicle.

2.3 Observations

The following observations were gleaned from Splinter Session 3:

Observation 3a: An SMD Rideshare Office should be established to provide leadership and coordinate rideshare efforts throughout the directorate.

Observation 3b: ESPA-class payloads that are identified early and exhibit lower complexity increase the ability to manifest on a variety of launch vehicles and lower the risk to the primary mission.

Observation 3c: Dedicated launch services and other ESPA-class launch/deployment options can help drive payload pipeline development.

Observation 3d: Development of an ESPA-class payload “rideshare-ability” rating system would streamline matchmaking of payload pipelines to launch opportunities.

Observation 3e: Configuration-constraint expectations of ESPA-class payloads should be established during the solicitation process.

3. Small Spacecraft Technology Challenges that Hinder the Pipeline (Splinter Session 4)

3.1 Background

Issues concerning availability and affordability of technologies for SmallSat architectures—especially existing technology gaps—can significantly constrict and hinder the ESPA-class payload pipeline development. The experts participating in this splinter provided insights into key topics including propulsive ESPA, multi-spacecraft missions, subsystems development, and technology development.

3.2 Key Issues and Insights

Propulsive ESPA

The propulsive ESPA has tremendous potential for science and science technology development, but requires further study and strategic planning for incorporation into future missions. The propulsive ESPA as a standalone vehicle (or entry vehicle) can be a central unit that provides coordinated services to a varied set of attached or deployed payloads, or act as a carrier spacecraft that allows various individual missions to be independently inserted into different locations or orbits. A propulsive ESPA allows flexible scenarios enabling several capabilities including changes in altitude, inclination changes (albeit limited), in-plane phasing, multi-plane deployments, insertions, and hosting of dissimilar payloads. When conducting trade studies to examine flying multiple payloads on a propulsive ESPA ring vs. using alternative launch approaches, both cost and capability must be considered.

Various propulsive ESPA use-cases include:

1. Loiter missions – A propulsive ESPA could be parked at a certain location where it would lie mostly dormant until a research opportunity presented itself. This scenario would be particularly useful to observe an interplanetary Oort-cloud comet or other target of opportunity.
2. Bus Route Mission – The science payloads must be deployed in close, but not identical, orbits or vicinities; one payload could be inserted into one orbit or to one destination, and then the propulsive ESPA would move to another location to drop another payload and so on. In this case, some payloads could also stay attached to the "end of the line" and final orbit and could then take advantage of the entire capability of the ESPA.
3. The relay or "mother ship" – A concept similar to the "bus route" missions except that the payloads could use the propulsive ESPA to relay communications or supply other resources for a suite of instruments. This scenario could be very helpful for deep space, and near-Earth, or Earth observing missions.
4. Technology Demonstration – A propulsive ESPA could be used as a "flying lab" to try out different technologies with a low burden of resources since the ESPA provides power, communication, etc.

Key systems and capabilities required to enable such mission concepts include:

- Propulsion systems (solar electric, cold gas, green propulsion)
- Propellants
- Power subsystems such as solar panels
- Aerobraking or other related technologies
- Improved communication solutions (Ka-band, X-band)

The above technologies are critical, especially for missions to distant targets where the propulsive ESPA serves as a power, propulsive, and communications hub.

To enable propulsive ESPA use, it would be useful to:

- Perform a mission trade study to compare a standard ESPA ring with advanced payloads vs. a propulsive ESPA ring with more basic payloads to determine where the complexity should reside
- Determine if "ESPA as a Service" could be established within NASA
- Conduct a trade study to understand the destinations that propulsive ESPA could enable
- Understand the industry offerings and their capabilities and cost

However, there are disadvantages of utilizing propulsive ESPA including potential risks to the primary mission given the pressure vessel propulsive elements, a current lack of standards related to services a propulsive ESPA system could provide for attached ESPA payloads, as well as potential mass inefficiencies. Furthermore, it is not clear how an integrated propulsive ESPA system might be managed: via the principal investigator, the launch service provider, or a combination of both. This lack of clarity could drive requirements impacting how a payload pipeline could be developed and sustained for a propulsive ESPA system.

Pipeline development of propulsive ESPA-class RPLs may be highly dependent on requirements as specified by the propulsive ESPA system.

Multi-Spacecraft Missions

In the past, certain types of observations such as magnetic or electron/ion measurements made by a single spacecraft would be inherently ambiguous either due to the motion of the spacecraft or due to temporal and/or spatial variations of the environment. Small spacecraft capabilities have matured to the point that we are able to build and deploy reliable multi-spacecraft missions to realize missions such as NASA's Cyclone Global Navigation Satellite System (CYGNSS) and mission concepts such as Magnetospheric Constellation (MagCon) to achieve spatially and temporally distributed measurements at an appropriate resolution to satisfy science requirements.

Multi-spacecraft mission concepts include:

- **Distributed Architectures:** missions comprised of multiple spacecraft in a loose configuration, where each spacecraft is performing a part of the mission or taking one part of a measurement, or the spacecraft are potentially working together to take one measurement that requires large-scale distances between elements of the "system." An example mission is the proposed Virtual X-ray Observatory (VTXO) that utilizes an ESPA spacecraft and a 6U CubeSat, separated by as much as a kilometer, to serve as a telescope with a long focal length to gather X-rays. This mission concept highlights the need for intra-spacecraft communication as well as the capability to maintain spacecraft formation for large portions of an orbit.
- **Constellation Architectures:** missions would utilize multiple potentially identical spacecraft in a fixed configuration to collect science data or enable essential services, providing nearly continuous observational coverage. A related capability also enabled is the concept of "tip and cue," where one spacecraft in a network detects something and then alerts another spacecraft to the event. As with distributed architectures, constellation architectures may be composed of a variety of spacecraft from ESPA satellites to CubeSats.

NASA could benefit from technical advances made by the small spacecraft industry. Industry-developed technologies for autonomous commissioning, formation flying, collision avoidance, de-orbit systems, etc., could enable NASA to develop constellation missions. However, there are key and distinct differences between NASA's technology needs in LEO vs. cis-lunar or deep space.

To build a pipeline for multi-spacecraft ESPA-class missions, the following key technologies are essential:

- **Propulsive ESPA:** Enables more rideshare destinations/insertions on a single launcher/mission.
- **Advanced propulsion:** More reliable and improved propulsion systems including cold gas systems, green propulsion, and solar electric propulsion.
- **Improved Communications Solutions:** Communications technology and communications infrastructure development to provide higher data rates/volumes for ESPA-class science missions.
    - Intra-spacecraft communication capability (radio ranging, spacecraft-to-spacecraft optical communications)
    - Improvements in Ka- and X-band communications, such as an X-band capability for intra-spacecraft communications and Ka-band systems with enhanced data transmission rates.
    - Cross-link/networking between spacecraft. To date nothing has been reliably demonstrated
    - Deep space communication frequency bands, including communication systems that are interoperable with commercial ground stations and the NASA Deep Space Network (DSN) (multi-band or "multi-slice" radio)
    - Better antennas (X-band reflectarrays, steerable, etc.)
    - Reliable ground data and ground communication architecture that can handle large throughput

    - Systems that are compatible with NASA-STD-1006, Space System Protection Standard, and the National Institute of Standards and Technology's FIPS140-2, Security Requirements for Cryptographic Modules
- **Improved Navigation Solutions:** Navigation methods including precision pointing and positioning are necessary to properly operate a "network" of satellites flying in a pre-determined pattern or formation.
- **Reliable Ground Data Architecture:** Constellations and multiple spacecraft will produce substantial amounts of data and there is a need to process results, interpret data, and handle throughput at levels not previously experienced. This scenario will require improved ground systems and processes for handling large volumes of data.
- **Faster Processors that enable autonomous operations:** For multi-spacecraft missions that are maneuvering relative to each other, it will be necessary to employ faster and smarter processors with the goal of taking the "human operator out of the loop."
- **Software and information technology** enabling constellation operations and management.

Strategic investments in key technologies are required to realize the potential of multi-spacecraft ESPA-class missions.

Subsystems Development

At present, there are few suppliers of ESPA-class small spacecraft subsystems. The absence of suitable, capable, and reliable technologies for small spacecraft that are loosely correlated to the various spacecraft subsystems such as propulsion and communications can result in prohibitive spacecraft or observatory costs.

Scaling up CubeSat subsystems or scaling down large spacecraft subsystems to service the small spacecraft class of buses is not considered universally feasible. Since CubeSat subsystems have been traditionally derived from commercial off-the-shelf (COTS) components, they may not be able to adequately support small spacecraft missions, especially in deep space applications. In addition, larger spacecraft subsystems are inherently incompatible with the small spacecraft form factor and cost categories. Therefore, there exists a "small spacecraft supply chain (technology) gap" for ESPA-class spacecraft subsystems. Addressing the gap requires identifying key subsystems required and seeking industry partners to build, develop, and mature these subsystems by flying and validating them in the relevant flight environments.

A related confounding issue is that the current demand (volume) for ESPA-class spacecraft technologies is relatively low. New entrants into the SmallSat supply chain, especially emerging "new space" companies, often do not consider the NASA small spacecraft market a large customer base that is worthy of internal research and development investments. Even when the SmallSat pipeline is fully populated with NASA missions, the volume of this demand may still be secondary to other commercial customers and markets.

Key ideas to mature and flight validate ESPA spacecraft subsystems include:

- Identify ESPA-class technology gaps and mature required technologies via new and/or ongoing programs.
- Create an ESPA-class flight demonstration program to validate ESPA technologies. This effort could include technology demonstration of science instruments and related key subsystems to establish flight heritage.
- Link identified ESPA-class subsystem technology needs to targeted SBIR sub-topics in collaboration with industry to build industrial capability and capacity.
- Create a catalog or indefinite delivery/indefinite quantity (IDIQ) contract mechanism specifically for ESPA-class spacecraft. This initiative would require industry vendors to provide generic spacecraft solutions for science mission developers. A high degree of standardization is also implied.
- Establish standards for spacecraft-to-launch vehicle interfaces, safety, and operations.

Ideas to incrementally mature and flight validate ESPA-class subsystems include shepherding specific identified technologies through a flight demonstration and validation program, establishing appropriate partnerships with industry via programs like SBIR, establishment of practical interface standards, and creating procurement contracts specifically for ESPA-class spacecraft.

In general, small spacecraft should have a higher risk tolerance posture than traditional large SMD flight projects, but at the same time should be more robust and reliable than CubeSats, which are often used for educational and technology demonstration missions. This middle ground represents a unique, unchartered area for NASA. As mission designers desire to make more sophisticated and complex measurements and observations, the issue of risk tolerance and risk management will be increasingly significant.

Technology Development

Flight validation of the technology in the following subsystems can benefit the ESPA payload pipeline:

- Advanced small spacecraft attitude control and propulsion systems
- Power-efficient and high-bandwidth advanced radio capabilities (e.g., Ka-band for Mbit capability from deep space)
- Pointing systems with arc-second accuracy (e.g., star trackers)
- Standardized digital processing unit (DPU) with advanced processing capabilities
- Peer-to-peer satellite communications technology
- Body-mounted magnetometers/spacecraft magnetic cleanliness (spacecraft charging)

These capabilities would also enable many more new applications including multiple-spacecraft missions and deep space missions.

One method to facilitate the payload pipeline is by implementing a modular technology development plan coupled with a rigorous technology demonstration program. Tested modular components would reduce the uncertainty for developers and decrease lead times for payload builds. Where possible and practical, the modular approach would enable a "built-up pantry" of tested and proven components that could be ready for "plug and play" into ESPA-class payloads. These modular spacecraft components could be designed to meet multiple user requirements with the designs evolving as the field evolves.

A technology flight demonstration program to validate specific ESPA-class spacecraft technologies and subsystems for science applications is also critical. This ESPA-class payload validation program would be analogous to the Space Technology Mission Directorate's Small Spacecraft Technology Program (SSTP), and Human Exploration and Operations Mission Directorate's CubeSat Launch Initiative (CSLI) both of which are currently targeted at CubeSat platforms. SSTP is funded to develop and mature technology, and CSLI is funded to provide flight (launch) opportunities for technology demonstrations, in addition to other mission types. Instituting a similar program could enable a high-paced technology pipeline for development and validation for ESPA-class payload technologies. Such a program could validate small spacecraft (i.e., bus) technologies and innovative or novel sensor and instruments and related technologies, providing those technologies with vital flight heritage. This approach would also be enhanced by the standardization initiative referenced previously.

Other areas related to technology development and advancement include standardized and well-defined interfaces, radiation-hardened component options, advanced image-compression techniques including background removal, minimization of spacecraft-deployable structures where possible (to reduce risk to the primary mission from RPLs), improvement in ground-based infrastructure to maximize rideshare communications/data download, advanced thermal control, additive manufacturing (to facilitate modification of modular components for specialized requirements), and providing opportunity for technology demonstrations without direct scientific application (to gain experience with the technology).

Pre-built subsystems and instruments will require investigation of effective methods to store instruments (e. g., coatings with longer shelf-life, etc.).

Where practical and achievable, an agile approach to ESPA-class small spacecraft technology development includes flight demonstration and validation.

A final key insight addresses the potential for achieving scientific goals incrementally or in a distributed manner. Since small spacecraft are inherently low cost, a science campaign could be spread across multiple spacecraft/missions, either launched at once or with multiple launches. This approach will allow for the continual improvement or evolution of sensors/instruments, spacecraft bus subsystems, and analytical techniques. It also relieves the pressure for a single, one-of-a-kind, observatory to perform flawlessly to achieve the stated scientific objectives, thus reducing overall cost and risk.

3.3 Observations

The following observations were gleaned from Splinter Session 4:

Observation 4a: Pipeline development of propulsive ESPA-class RPLs may be highly dependent on requirements as specified by the propulsive ESPA system.

Observation 4b: Strategic investments in key technologies are required to realize the potential of multi-spacecraft ESPA-class missions.

Observation 4c: Where practical and achievable, an agile approach to ESPA-class small spacecraft technology development includes flight demonstration and validation. Ideas to incrementally mature and flight validate ESPA-class subsystems include shepherding specific identified technologies through a flight demonstration and validation program, establishing appropriate partnerships with industry via programs like SBIR, establishment of practical interface standards, and creating procurement contracts specifically for ESPA-class spacecraft

4. Programmatic Challenges that Hinder the Pipeline (Splinter Session 5)

4.1 Background

The development of ESPA-class payloads depends heavily on programmatic factors including how such payloads are solicited, the oversight needed to manage them, common understanding of acceptable risk, adherence to standards, and available workforce. The experts participating in this splinter provided insights into key topics including approaches for announcement of opportunity and mission of opportunity calls, oversight and deliverables, standards and risk assessment, and diversity.

4.2 Key Issues and Insights

Announcement of Opportunity and Mission of Opportunity Solicitation Approaches

Two fundamental types of solicitations for rideshares both have their place: soliciting rideshares for specific launches and soliciting rideshares for to-be-determined launches (a.k.a. “generic” launches). “Generic” launch opportunities are best suited for RPL missions that are not particular about their destination, although it would be good to specify “lanes” such as Sun synchronous or polar-orbiting opportunities. For both cases, standard instrument suites could be identified (e.g., space weather packages) to improve the pipeline readiness.

Targeting rideshare solicitations to specific launch opportunities was the approach preferred by the scientists, engineers, launch providers, and LSP representatives in attendance. This approach is best suited for RPL missions that need to conduct science at specific destinations. The Interstellar Mapping and Acceleration Probe (IMAP) and Small Innovative Missions for Planetary Exploration (SIMPLEx) models work well and the sequence of soliciting the primary and RPL missions before soliciting the launch vehicle is strongly supported by the community. In particular, the very early solicitation of RPLs for IMAP and the information included in the interface control document worked well. It is important to provide as much information about the launch targets as possible, because changes can strongly affect the RPL design. This approach of early solicitation with a specified target leads to a shortened development time for the RPLs, which could be alleviated somewhat by issuing solicitations for mission concept studies as soon as future launch opportunities are even somewhat known (such as the destinations for New Frontiers, Medium-Class Explorers [MIDEX], or the selected Discovery missions). Even if a study project is not selected for flight, these studies would educate future PIs about the full range of mission elements that need to be considered—e.g., mission design includes more than simply science. Another suggestion to reduce the schedule crunch is to solicit the primary and RPL missions simultaneously, or at least solicit the RPL mission at the start of the primary’s Step 2 award. To encourage lower cost missions, the solicitation could specify the total available funds rather than individual payload cost caps.

For “generic” launches, the availability of rideshare missions ready for the pipeline would be increased by the creation and adoption of both standard interfaces and standardized rideshare services. These AOs should specify a more limited set of options to ensure that affordable rides are available, and include information about rideshare, interface requirements, and launch opportunities. Information should be provided about the delivery timeline to meet launch requirements and techniques to facilitate/expedite payload development and launch readiness to support small underfunded payload groups. A standard platform should be specified, followed by a solicitation for instruments to fit that standard. Examples of this process include the Shuttle Get Away Special Cannister, Commercial Lunar Payload Services (CLPS), and U.S. Space Force SpaceTech Program. Note that when developing payloads to be launched on to-be-determined opportunities, the cost of storing the payload may be higher than the cost of not using the excess launch capacity.

The community appreciates that there are independent means of selecting the RPL missions rather than allowing (or making) the primary mission make that determination.

In addition, funding an RPL mission through Preliminary Design Review (PDR) (even if it gets terminated at that point) still provides invaluable experience for the teams.

The motivation for developing rideshare missions is to use excess launch capacity, but another way to view this situation is that NASA could create agreements with other organizations to use this excess capacity and use the savings to buy dedicated launches for small spacecraft missions. Such small spacecraft missions are intrinsically valuable and should not be considered as merely afterthoughts. In addition to excess launch capacity, there is tremendous "excess PI capacity" that is bursting to be tapped.

Oversight and Deliverables

Once an RPL accommodation is established, LSP has a well-defined process for providing guidance to the small mission PI and team regarding the mission assurance and verification steps required for successful integration with the primary payload. However, during the proposal stage, PIs of RPLs lack information on the level of oversight and related products (documentation, meetings, reporting, test results, etc.) expected from them during the implementation phase. Consequently, the resources and cost required to establish the oversight and reporting framework are often underestimated. Because the oversight requirements levied on the RPL are often dependent on the criticality and risk class of the primary payload, PIs of RPLs may be subjected to inconsistent oversight and verification requirements that can lead to hardware over-testing and can put the RPL at risk. Therefore, the AO should include specific guidelines about review milestones, documentation, reporting and the level of oversight expected, and also standardized and easily accessible specifications for RPL launch accommodations and requirements compliance. The specific guidelines can be estimated based on statistics from previous missions and broken-down for all mission types and the standardized specifications can be provided by LSP using examples from past missions. Also, a consistent approach should be established regarding how the primary payload missions should interact with the RPLs during implementation.

At a minimum, oversight and requirements verification of RPLs are required to establish that they comply with the DNH requirements with respect to primary payloads and the launch vehicle. This minimum level of verification can be extended to mission assurance provisions as long as it provides a value-added to the RPL. However, establishing Standing Review Board (SRB) reviews for ESPA-type missions is perceived to fall into the range of too much oversight. No more than 10-15% of the RPL mission financial resources should be devoted to oversight-related activities, and management oversight should be used as a means to provide continuous guidance and mentoring to RPL missions on how to meet rideshare accommodation requirements.

If the RPL mission assurance effort for launch integration is focused on “do no harm,” as opposed to “mission success,” then the current practice of requiring the RPL mission to meet the same criteria as the primary (i.e., undergoing most/all gate reviews and providing the associated mission assurance products) may be more than needed. To allow the RPL mission to better fulfill its mission assurance gate requirements in better alignment with the schedule and milestones of the primary payload, RPLs should be identified and/or solicited earlier than is the current practice. Early selection will also allow LSP to procure the appropriate launch vehicle on a less constrained schedule. In addition, similar major mission assurance gates and milestones for the primary and RPL missions should be maintained, in particular at Key Decision Points (KDPs). However, reporting and reviews should be streamlined to require only those that provide added value to the RPL mission.

Standards and Risk Assessment

With the caveat that not all RPLs can be standardized, the solicitation of rideshare spacecraft standardized on mass, stiffness, volume, etc. could allow for interchangeable launch opportunities. Standardized RPL spacecraft would allow NASA to swap out an RPL that experienced technical or programmatic problems that delayed its development with another RPL, rather than fly a dummy mass, and would increase the subsequent launch opportunities for the delayed RPL. Standardized spacecraft would also enable instrument providers and scientists to concentrate on the science rather than the spacecraft bus, remove the burden of managing the spacecraft from the PI, and could allow for more flight opportunities.

Whether the RPL spacecraft uses a standard bus or not, a standardized acquisition process would be helpful. In particular, the AO should include standardized deliverables and schedules and specify the types of ESPA rings that will be available. A clear definition of standard services and mission-unique options relating to rideshare/ESPA should be provided.

There should be a different set of Mission Assurance Requirements (MAR) for Class D technology demonstrations and Do No Harm missions than is currently required for other Class D missions, and acceptable risks should be clarified. Should risk be inversely proportional to cost? What is meant by the expectation that some number of failures are tolerated? Is the expectation different for Class D science and technology demonstration missions?

Developing ground network standards for rideshare payloads may be something that needs to be explored in the future.

Diversity

One of SMD's objectives for flying rideshare missions is to provide more hands-on flight experience to the community. Small universities, small sensor teams, new entrants to the space industry, early-career Principal Investigators (PIs), and under-represented groups (e.g., gender, ethnicity, age, first-generation college students) may encounter difficulties that could be reduced by attention to obstacles.

A significant challenge, especially for small universities and new PIs, is that steady funding is needed to prepare spacecraft and instrument systems for flight readiness. As an example, the development of a new sensor requires electrical, mechanical, system, and software engineering expertise. Typically, four to five development grants are needed to provide sufficient funding for such a team.

Training is also needed for the groups identified above, not only for PIs but also for program managers and system engineers, including education on the following: understanding flight systems, how to find funding opportunities within NASA, how to communicate with NASA, how to develop and build partnerships, and how to promote their capabilities to the larger community. Suggestions for training opportunities include: 1) include a simplified page on the S3VI website that consolidates a list of funding opportunities, PI/Project Manager (PM) resources, organizations open to partnerships, and available student internships from NASA, subcontractors, and labs; 2) open current NASA PI/PM/Systems Engineering (SE) training to non-NASA personnel; 3) require RPL missions to include deputy PI, PM, and SEs; 4) require a research experience for undergraduates (REU) (i.e., summer internships) for the life of the RPL development to encourage students to enter the field; 5) disseminate information and conduct outreach beyond the typical and regular go-to universities; 6) extend the Planetary Science summer school for graduate students (where participants design a mission) to all SMD disciplines; and 7) establish a sabbatical program to, for instance, allow a new PI/PM to go to an institution that has completed a sensor build but has parts to build another. During the sabbatical the visiting PI/PM could manage the spare sensor build along with the experienced engineering team. This program would provide experience to PI/PM and the sensor could become a part of the pipeline.

Early-career and new-entry PIs at universities also encounter some unique issues. There is a perception that RPL programs are immature and present both a reputation and cost risk to the PIs and their institutions. This perception is grounded in the lack of control and/or stability of the launch vehicle interfaces and parameters, and therefore some university leaders are actively discouraging PIs from applying to RPL opportunities, specifically in reference to the last Small Explorer (SMEX) competition. Second, university leaders are looking for PIs to obtain grants with the word "career" in the title (such as "early career grants"); because this terminology acknowledges that the recipient has a career in the field. The lack of the word "career" in an award title is especially presents a challenge for PIs that focus on instrument and technology development grants.

4.3 Observations

The following observations were gleaned from Splinter Session 5:

Observation 5a: Identify/select RPLs earlier than is the current practice to allow the RPL mission to meet its mission assurance gate requirements in better alignment with the schedule and milestones of the primary payload. Early selection will also allow LSP to procure the appropriate launch vehicle on a less constrained schedule.

Observation 5b: When soliciting generic rideshares not tied to a specific launch opportunity, specify “lanes” (e.g., Sun synchronous or polar orbiting opportunities), standardize the rideshare services for each lane, and proactively seek existing rideshare payloads for particular lanes.

Observation 5c: When soliciting targeted rideshares tied to a specific launch opportunity, continue soliciting the rideshares before soliciting the launch vehicle, and consider soliciting mission concept studies for particular launch opportunities in advance of soliciting the rideshare mission itself.

Observation 5d: Consider soliciting the primary and RPL missions simultaneously, or at least solicit the RPL at the start of the primary’s Step 2 award. To encourage lower-cost missions, consider specifying the total available funds rather than individual payload cost caps.

Observation 5e: Lack of funding continuity is a challenge for small university investigators, especially new and/or early career PIs, potentially impacting the diversity of payload pipeline development for ESPA-class missions.

Appendix A. List of Findings

Finding 1: A pipeline of ESPA-class spacecraft will enable new system science and sensor development, but significant upfront planning is needed to ensure these missions are compatible with primary mission launch parameters and environments.

Finding 2: Development of a multi-spacecraft ESPA-class payload pipeline enables sustainable long-duration continuity observations.

Finding 3: ESPA-class instrument development fills a capability gap between CubeSat and flagship missions for novel science observations.

Finding 4: Pipeline development for ESPA-class instruments should concentrate on standardization, interfaces, and design for mass production without compromising measurement quality.

Finding 5: Strategies are needed to ensure future ESPA-class instruments are designed to minimize the degradation effects from long-term storage.

Finding 6: A strategy is required for the pipeline development of large numbers of identical, high-Technology Readiness Level (TRL) instruments to enable ESPA-class SmallSats for constellation missions.

Finding 7: ESPA-class payloads that are identified early and minimize complexity increase the manifest options towards a variety of launch vehicles, while lowering the risk to the primary mission.

Finding 8: Dedicated launch services and other ESPA-class launch/deployment options can further enable ESPA-class payload pipeline development via multiple alternative access-to-space approaches.

Finding 9: Development of an ESPA-class payload rideshare rating system upon mission selection could streamline matchmaking of payload pipelines to launch opportunities.

Finding 10: Configuration-constraint expectations of ESPA-class payloads should be established during the solicitation process.

Finding 11: Propulsive ESPA is an enabling technology for complex multi-spacecraft science missions, but flight demonstrations are needed to prove and mature this capability.

Finding 12: Small satellite subsystem technologies have rapidly matured, improving performance and reliability, but focused investments and strategic partnerships are needed to advance such technologies for deep space ESPA-class systems.

Finding 13: Payload pipeline technology development should be modular, culminating in a rigorous demonstration program.

Finding 14: ESPA-class payload solicitations should be designed for two categories of rideshare opportunities: targeted rideshares for specific launch destinations and generic rideshares for flexible, to-be-determined launch destinations.

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Finding 15: RPLs should be identified/selected early to align life cycle milestones and gate requirements with the primary payload and to allow procurement of the appropriate launch vehicle on a less constrained schedule.

Finding 16: Standardization of services and solicitation of concept studies for launch opportunities directly enhance ESPA-class payload pipeline development.

Finding 17: Overall mission oversight-related activities amongst the primary and ESPA-class rideshare payloads should align with the lifecycle of the primary mission when practical.

Finding 18: Lack of funding continuity and training opportunities present challenges for small university investigators where strong institutional support is needed for new and/or early career PIs to impact the diversity of payload pipeline development for ESPA-class missions.

Appendix B. Acronyms and Abbreviations

A2S	Access to Space
AO	Announcement Of Opportunity
APL	Applied Physics Laboratory
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
CLPS	Commercial Lunar Payload Services
COTS	Commercial Off-The-Shelf
CSLI	CubeSat Launch Initiative
CYGNSS	Cyclone Global Navigation Satellite System
DLA	Declination of the Launch Asymptote
DNH	Do No Harm
DPU	Digital Processing Unit
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
EEE	Electrical, Electronic, and Electromechanical
EELV	Evolved Expendable Launch Vehicle
ESCAPADE	Escape And Plasma Acceleration And Dynamics Explorers
ESPA	EELV Secondary Payload Adapter
GDC	Geospace Dynamics Constellation
GEO	Geosynchronous Orbit
GTO	Geostationary Transfer Orbits
IDIQ	Indefinite Quantity
IMAP	Interstellar Mapping And Acceleration Probe
ISS	International Space Station
JHU	Johns Hopkins University
LEO	Low Earth Orbit
LSP	Launch Service Program
MAR	Mission Assurance Requirements
MIDEX	Medium-Class Explorers
MMS	Magnetospheric Multiscale
MO	Mission Of Opportunity
NASA	National Aeronautics and Space Administration
NPR	NASA Procedural Requirement
PDR	Preliminary Design Review
PI	Principal Investigator
PM	Project Manager
REU	Research Experience for Undergraduates

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RPL	Rideshare Payload
RSDO	Rapid Spacecraft Development Office
S3VI	Small Spacecraft Systems Virtual Institute
SBIR	Small Business Innovation Research
SE	Systems Engineering
SMD	Science Mission Directorate
SMEX	Small Explorer
SRB	Standing Review Board
SSO	Sun Synchronous Orbits
SSTP	Small Spacecraft Technology Program
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TRL	Technology Readiness Level
US	United States
VTXO	Virtual X-ray Observatory