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NASA Launch Services Program Small Satellite Processing Capabilities at Kennedy Space Center and Vandenberg Air Force Base

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ABSTRACT

The NASA Launch Services Program (LSP) Launch Site Integration Branch (LSIB) conducted a study to identify options for accommodating launch site support requirements for the next generation of NASA small satellites and secondary payloads launched from the Kennedy Space Center (KSC) and Vandenberg Air Force Base (VAFB). The anticipated needs range from cleanroom facilities, to long-term secure hardware storage, to propellant loading/unloading, to stacking and fairing encapsulation. Existing commercial and government payload processing facilities (PPF) are highly capable and commonly used to support satellite processing, while alternate options may be better tailored for the needs and budgets of small satellites. These include peripheral facilities such as PPF airlocks or partitioned spaces, existing facilities which can be refurbished or upgraded, and portable facilities such as cleanroom trailers. The LSP LSIB continues to evaluate its capability to meet the needs of small satellites and secondary payloads. The author requests input from the small satellite community, to help identify any emerging launch site requirements for future NASA small satellite and secondary payload missions.

INTRODUCTION

As the quantity and complexity of small satellites increase, the NASA Launch Services Program (LSP) Launch Site Integration Branch (LSIB) seeks to accommodate any launch site support requirements that may be required for the next generation of NASA small satellites and secondary payloads.

PURPOSE

The NASA LSP LSIB conducted a study to identify how emerging small satellite and secondary payload launch site support requirements can be met with current infrastructure at Kennedy Space Center (KSC) and Vandenberg Air Force Base (VAFB), and to identify whether new capabilities will need to be established. This study was especially intended to identify any requirements that would drive significant facility upgrades, investments, or long lead preparations.

SCOPE

This study considered small satellites and secondary payloads, but did not focus on U-Class (CubeSat) payload processing requirements which are routinely accomplished by off-site integrators prior to delivery to the launch site.

METHODS

The author solicited input from NASA personnel who are familiar with past, current, and future small satellite missions, to compile a list of potential launch site capabilities that may be required to support upcoming small satellite and secondary payload missions. The potential requirements are not limited to the needs of past missions, but are intended to encompass more complex missions that are on the horizon.

The author then compared the list of potential launch site requirements with the actual capabilities of existing facilities at KSC and VAFB. Information regarding the facility capabilities was gathered during site visits, from facility documentation (Ex., facility handbooks), and from discussions with personnel within NASA.

TYPES OF SMALL SATELLITES AND SECONDARY XPAYLOAD MISSIONS

The term “small satellite” refers to a spacecraft with a launch mass much smaller than most traditional spacecraft, often a few hundred kilograms or less. The term “secondary payload” refers to a spacecraft that is manifested with another “primary spacecraft” where the primary mission commands primary authority over the launch configuration and timeline.

Small satellites and secondary payloads may be categorized by their launch interface. Many small-satellite interfaces exist, including custom mission-specific launch vehicle interfaces. However, the most common interfaces are CubeSat dispensers and the Evolved Expendable Launch Vehicle (EELV)

Secondary Payload Adapter (ESPA) interfaces. These interfaces are discussed below.

Secondary payloads are sometimes mated with the primary spacecraft, or adapter, prior to encapsulation in the launch vehicle payload fairing. In such cases, the secondary payload may be processed in a separate (perhaps adjacent) facility, then mated to the primary spacecraft in the primary spacecraft's payload processing facility (PPF). Some secondary payload to launch vehicle interfaces are not located close to the primary spacecraft, such as the Atlas V Aft Bulkhead Carrier (ABC). In those cases, the secondary payload may integrate directly to the launch vehicle without ever entering the primary spacecraft's PPF.

CubeSat Payloads

CubeSats, which are also referred to as U-Class Payloads, follow a standard set of specifications which ensure compatibility with standardized CubeSat dispensers. The CubeSat dispensers contain the CubeSats during launch and provide the interface to the launch/host vehicle until the CubeSats are ejected from the dispenser on orbit. Some CubeSats which are deployed from the International Space Station (ISS) can be integrated to their dispenser on orbit. CubeSat size specifications exist as multiples of the one-unit (1U) CubeSat baseline, which has an approximate envelope of a 10 cm cube and a mass on the order of 1-2 kg. A two-unit (2U) CubeSat occupies the volume and mass range of two 1U's, and so on, up to 3U, 6U, 12U, and 27U.

With few exceptions, CubeSats are canisterized within their dispenser by a payload integration contractor prior to delivery to the launch site. Therefore, government launch site support for CubeSat missions does not require substantial facility provisions. For this reason, CubeSat processing is not specifically addressed in this study. Government launch site support does normally include coordination with the responsible safety authority, provisions for entry and transportation on base, secure storage on base, and accommodation for external inspection and checkout of the dispenser prior to handoff to the Launch Services Contractor (LSC) for integration with the launch vehicle.

Situations may arise that demand more launch site support for CubeSats than normal, such as on-site propellant loading. In such cases, the discussion pertaining to small satellites and secondary payloads are applicable also to CubeSats.

ESPA-Class Payloads

ESPA-class payloads are generally more massive than CubeSats and have a ring interface with an ESPA. An ESPA is a cylinder-shaped adapter that interfaces between the launch vehicle and the primary spacecraft (in the load path), generally on EELV-class vehicles. Up to six ring-shaped secondary payload mounting interfaces are located around the curved surface of the ESPA cylinder, orthogonally to the primary spacecraft interface. ESPA-class payloads generally have a mass up to 180 kg.

Variants on the ESPA concept exist which are larger, smaller, or have built-in features such as propulsion systems. Similar secondary payload interfaces are used by other adapters so that the term "ESPA-class" refers to a class of payloads, whether or not they use the original ESPA as their launch vehicle interface.

Multi-Payload Missions

In addition to standalone payload processing, some missions involve a collection of small satellites and secondary payloads. Such missions may require launch site facilities for integration, regardless of whether each satellite is processed there individually. These operations may include integration of satellites to adapters (ex., ESPA), stacking of multiple adapters, integrating multiple types of adapters, and encapsulation.

LAUNCH VEHICLES

Small satellites and secondary payloads have flown, or are planned to fly, on every class of vehicle on the NASA Launch Services (NLS) II and Venture Class Launch Services (VCLS) contracts.

LOCATION OF SMALL SATELLITE PROCESSING

Small satellite and secondary payload processing may occur in a number of different locations, or a combination of locations, as discussed below. The scope of this study is focused on evaluating NASA's payload processing capabilities at KSC and VAFB. The decision of where to process NASA small satellites and secondary payloads is made on a mission-by-mission basis. In cases where a satellite is processed off-site, or launched at another launch site, a subset of the processing may still occur at KSC and VAFB.

For some missions, NASA small satellites and secondary payloads may be processed at an offsite government or commercial facility, then transported to the launch site for integration to the launch vehicle. Other missions may perform all of their processing at the launch site. For missions that are processed off-site, some amount of payload support will be needed at the launch site. For example, post-shipment inspections, stacking, encapsulation, and propellant loading may need to be performed at the launch site, though some green propellant mixtures may allow for transportation after propellant loading.

Small launch vehicle providers Rocket Lab and Virgin Orbit do not currently base their launches from KSC or VAFB. Therefore, final payload processing occurs in their commercial facilities. However, cases may arise where the payload needs to be processed at KSC or VAFB prior to shipment to the commercial facility. Firefly Aerospace is establishing a launch site at VAFB for its small launch vehicle and also plans to establish an East Coast launch site. They advertise their own PPF as part of their launch site layout concept.[1] Depending on what is in the best interest of the government, NASA missions that launch on these vehicles may still use other processing facilities, including commercial and government facilities at KSC and VAFB.

Other small launch vehicles may emerge, which could drive the need for payload processing at VAFB and KSC. While small launch vehicles are expected to operate in a variety of launch sites, the Air Force has taken steps to accommodate small launch vehicles at VAFB and CCAFS. If future NASA missions launch on such vehicles at VAFB or KSC/CCAFS, those missions may rely on existing commercial and government processing infrastructure at the launch site. In some cases, a small launch vehicle payload fairing may be integrated in one facility and shipped to be mated to the launch vehicle. In those cases, the payload may be processed anywhere, including at VAFB or KSC.

Table 1: Facilities Overview

	VAFB	KSC
Existing PPFs Used by LSP	• Astrotech PPF • Harris IPF • NGIS Bldg. 1555 • SpaceX PPF SLC-4 • Bldg. 836 Lab 1	• Astrotech PPF • PHSF

Potential Upgrades / Refurbishments	• Cleanroom tent (Ex., at Bldg. 836 High Bay)
	• Mobile / modular cleanroom trailer
		• Hangar AE High Bay
		  ○ Refurbish Cleanroom, or
		  ○ Install Cleanroom tent
		  ○ Modify/Repurpose
		• Cleanroom tent (Ex., at RTGF)
		• Mobile / modular cleanroom trailer

Requiring Coordination Outside LSP	• Air Force Facilities	• MPPF • SSPF Off-Line Processing Areas (OLPA) • SSPF High Bay • Air Force Facilities
Peripheral Facilities	• Airlock of any PPF • Side room of any PPF	• Airlock of any PPF • Side room of any PPF • MOSB rooms • RTGF

LAUNCH SERVICES PROGRAM (LSP) PAYLOAD PROCESSING FACILITIES (PPF)

NASA LSP has access to a range of commercial- and government-operated PPFs that support KSC and VAFB. Within the PPFs and other facilities, there are sites which are normally not used for processing primary spacecraft, which may be suitable for processing small satellites and secondary payloads. These sites are especially attractive since occupancy scheduling may be less affected by the primary spacecraft manifest.

Existing PPFs Used by LSP

LSP uses a variety of highly-capable commercial- and government-operated PPFs for primary missions. Astrotech operates commercial PPFs on both coasts which are used by LSP. Harris operates a commercial PPF at VAFB. These facilities are capable of accommodating all foreseeable needs of small satellites and secondary payloads. Their cost of their standard services may be prohibitive for small satellite and secondary payload program budgets, but these facilities could be partitioned for use by multiple spacecraft simultaneously. The LSIB has engaged in discussions with the commercial PPF providers regarding solutions to support future small satellites and secondary payloads in their facilities.

Northrop Grumman Innovation Systems (NGIS) and SpaceX operate PPFs at VAFB which are primarily used for missions that launch on their vehicles.

The Payload Hazardous Servicing Facility (PHSF) is a government-operated facility at KSC that is used to process primary spacecraft. The Multi-Operation Support Building (MOSB), located at the entrance to the PHSF, serves as an office area and payload control center for payloads processing in the PHSF. While the MOSB was not constructed for payload processing, there are some areas which may be suitable for small satellites and secondary payloads.[7]

The Bldg. 836 Lab 1 Rm. 10 Cleanroom at VAFB is a government-operated facility that is too small for many primary spacecraft, but it is large enough for all classes of small satellites. This facility is not approved for hazardous propellant operations. Handling and storage of small quantities of ordnance has been approved in the past in the Bldg. 836 High Bay and Cleanroom at VAFB. That rating is not currently in place, but can be returned as needed. It is unlikely that this facility will ever be approved for operations related to hydrazine since the facility is permanently co-occupied.

As is discussed in more detail later, some of these existing PPFs include peripheral processing areas, such as airlocks and side rooms, which may be useful to small satellites and secondary payloads.

Potential Upgrades / Refurbishments

When the existing PPF cannot meet the needs of the program, additional government-operated facilities could be refurbished or upgraded.

The Hangar AE High Bay Clean Room at KSC requires refurbishment in order to return function as Level 2 CWA. Alternately, the Hangar AE High Bay Clean Room is large enough that a cleanroom tent could be constructed there instead of performing a refurbishment of the old system. A trade study would be required to evaluate the costs and benefits of this option. LSP is also evaluating an option to modify the Hangar AE High Bay Clean Room and replace it with a control room, additional office space, and a lab.

The large PHSF Airlock at KSC can achieve ISO 14644 Class 8.5 cleanroom levels. If a payload needs ISO 14644 Class 8 or ISO 14644 Class 7, a cleanroom tent could be constructed there as well. A separate cleanroom tent could be used inside the airlock so that the airlock could continue to be used in support of a primary spacecraft in the main Service Bay. This would reduce the impact of a small satellite or secondary payload that would have otherwise prevented the airlock from being used as an airlock.

Some additional non-cleanroom facilities are large enough that cleanroom tents could be constructed inside. For example, Bldg. 836 High Bay at VAFB, the Hangar AE Airlock at KSC, and the Radioisotope Thermoelectric Generator Facility (RTGF) at KSC.

Some missions may benefit from the use of mobile or modular cleanroom facilities. Such facilities are not an option for larger spacecraft that require more space and normally require crane operations. However, in cases where the existing facilities are unavailable, mobile and modular cleanroom facilities may satisfy the needs of some small satellites. These mobile facilities can meet ISO 14644 Class 8, ISO 14644 Class 7, and better.[10] Some modular cleanroom facilities are built out of motorized vehicles (ex. van or bus), towed trailers, and prefabricated modular facilities.[9]

Mobile cleanroom facilities are commercially available for rent or purchase.[3] Their mobility means that these facilities could be deployed wherever they are needed, and could be shared across multiple programs and multiple launch sites. Their use may also reduce cost and lead-time, compared with constructing a permanent facility. If this solution is to be considered, more study would be needed to determine the cost and risks, in comparison with upgrading and refurbishing existing facilities.

Facilities Requiring Coordination Outside of LSP

Additional facilities that are operated by KSC and Air Force entities may be available if the need arises. These facilities are not commonly used by LSP, so they would be subject to schedule coordination with other entities and their priority would be with another program.

The Multi-Payload Processing Facility (MPPF) at KSC is a facility that is currently being used by the Orion program. It has a high bay bridge crane and the high-bay and low-bay are rated as Level 4 clean work areas (CWA), and a cleanroom tent can be used. The MPPF could be a suitable facility for processing small satellites, though it would require coordination and scheduling outside of LSP.[5]

The Space Station Processing Facility (SSPF) at KSC has 16 Off-Line Processing Areas (OLPA). These facilities maintain at least a Level 5 CWA with temperature and relative humidity control.[4] Access to these facilities are subject to availability. One of the OLPAs was previously used by LSP as a planetary protection lab for the Mars Science Laboratory (MSL) mission. The OLPAs are fully occupied in support of International Space Station (ISS) cargo missions that occur multiple times per year on a changeable schedule, but the SSPF High Bay may be more available. The High Bay does not offer privacy, but may be well suited for small satellite processing.

Peripheral Facilities

Small satellites and secondary payloads may be able to utilize areas which are peripheral to other PPFs, including airlocks and side rooms. In particular, these peripheral facilities may be an attractive option for secondary payloads when the primary spacecraft is processing in the same building.

Most PPFs feature an airlock between the outside ambient environment and the main processing area. Some include additional smaller airlocks to support the transfer of smaller equipment into the cleanroom without cycling the larger airlock. Some PPFs include adjacent side rooms for equipment processing. To illustrate the potential uses of one of these peripheral facilities, consider the configuration of the KSC PHSF, shown in Figure 1. The PHSF uses an airlock that is nearly the size of the Hazardous Operations Service Bay, as well as a smaller equipment airlock. While a small satellite could utilize the larger airlock, the equipment airlock might meet the requirements of the small satellite without blocking use of larger airlock.

The use of an airlock, an equipment airlock, or a side room is an especially attractive option for secondary payloads when their primary spacecraft is processing simultaneously in the same building. When the time comes to integrate the primary and secondary payloads prior to encapsulation, there would be no need to transport the secondary payload between facilities. In contrast, this option may not be as attractive in cases where the small satellite is not processing or integrating in the same facility as its host primary spacecraft. The small satellite might tie up capabilities that could be used by a payload that is processing in the main bay. As discussed in an earlier section, a cleanroom tent could be constructed for use by a secondary payload inside an airlock or equipment airlock. This would allow the airlock to be used as an airlock without exposing the secondary payload to the ambient environment when it is opened.

It has been suggested that Room 105 and Control Room 117 in the Multi-Operation Support Building (MOSB) at KSC could be cleaned and used to process small satellites. These facilities are not cleanrooms, but could meet Generally Clean (GC) or Visible Clean (VC) requirements. Room 105 is used to store facility support equipment, and is accessible through a series of hallways. Control Room 117 is accessible from the outside via a double-door. Control Room 117 normally functions as a ground station for checkout and testing of spacecraft located in the PHSF, so its use would need to be de-conflicted with any payloads using the PHSF.[7]

The KSC RTGF is primarily used for storage, testing, and monitoring of Radioisotope Thermoelectric Generators (RTG) and Radioisotope Heater Units (RHU). When RTG’s and RHU’s are not present, the RTGF may be an attractive option for small satellite missions. The facility includes a poured concrete/epoxy floor, and a bridge crane system. The environmental control system uses High-Efficiency Particulate Absorber (HEPA) filters, but is not advertised as a cleanroom. It provides temperature/humidity control and can operate with either positive or negative pressure. The facility was previously used to store ordnance, so it may be useful for small satellites that contain ordnance. All light fixtures meet National Electrical Code (NEC), Class 1, Division 2, Group C/D. Therefore propellant operations may be possible there.[8]

The RTGF is not continuously occupied, has limited office space, and does not have toilet facilities. However, office space can be provided using a trailer and portable toilets can be installed as needed.

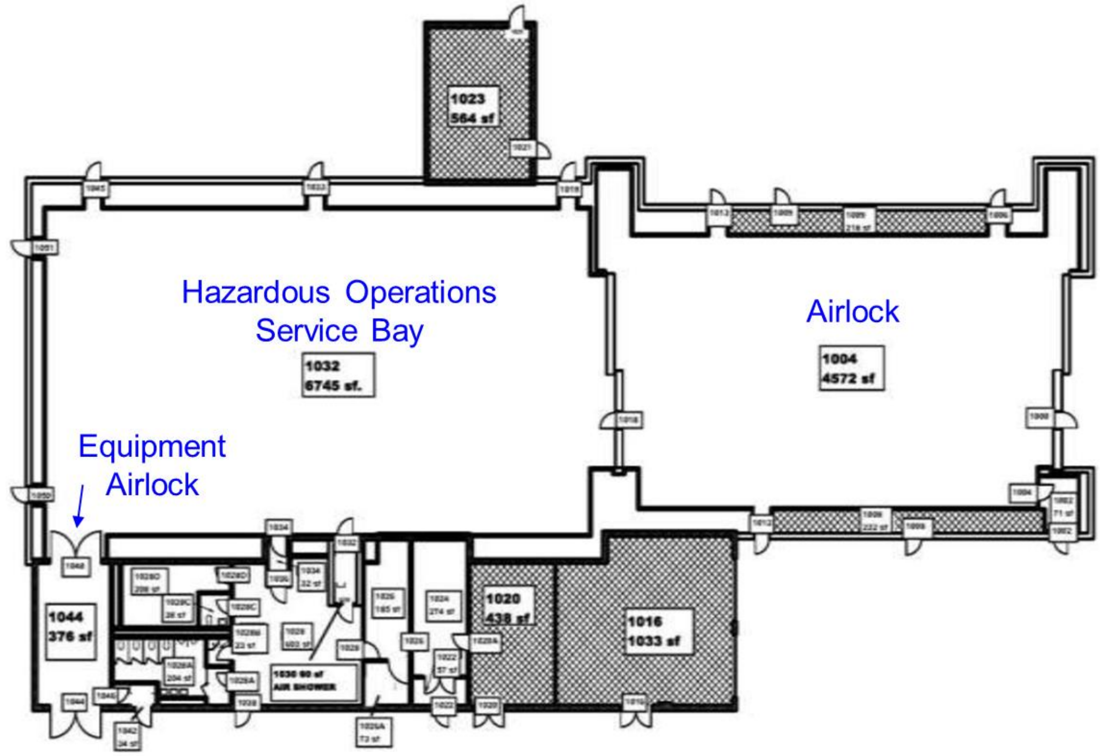

Figure 1: PHSF Airlock and Equipment Airlock (Markings Added)[7]

Table 2: Potentially Required Capabilities of LSP Facilities at KSC and VAFB (Ongoing Assessment)

Potentially Required Capability		VAFB			KSC		
		836 Lab 1	836 High Bay	AE High Bay	RTGF	MOSB 105	MOSB 117
Environment & ESD	Cleanroom	ISO 7 (10k)	Add Tent	Refurbish ISO 7 (10k)	Add Tent	Add Tent	Add Tent
	Generally/Visibly Clean	Y	Add Tent	Y	Y	Y	Y
	Gas Purge, Vent	Portable	Portable	Portable	Portable	Portable	Portable
	Gowning Area	Y	Portable	Y	Portable	Portable	Portable
	Temp. & Humidity Ctrl.	Y	Portable	Y	Y	Y	Y
	ESD Static Diss. Floor / Mat	Portable	Portable	Portable	Portable	Portable	Portable
	ESD Air Ionizer	Portable	Portable	Portable	Portable	Portable	Portable
Haz. Fluid / Ord. / Radio.	Rated for Haz. Propellant	N	N	N	N (TBC)	N	N
	Rated for Ordnance	Y*	Y*	N (TBC)	Y (Prev.)	N	N
	Rated for Radioactive	N	N	N	Y	N	N
	Trenches or Portable Dikes	Portable	Portable	Portable	Portable	Portable	Portable
	Absorbent Mat., Waste & Vent	Portable	Portable	Portable	Portable	Portable	Portable
	Emergency Shower / Eye Wash	Portable	Portable	Portable	Portable	Portable	Portable
	Air Monitoring, Vent & Purge	Portable	Portable	Portable	Portable	Portable	Portable
	PPE	Portable	Portable	Portable	Portable	Portable	Portable
Facility Accommodations	Elect. Pwr. (120 V, 60 Hz AC)	Y	Y	Y	Y	Y	Y
	Elect. Pwr. Converter to 220V	Portable	Portable	Portable	Portable	Portable	Portable
	C&T, Internet	Y	Y	Y	LSST	Y	Y
	Door locks, Alarms, Badge	Y	Y	Y	Y	Y	Y
	Surveillance, Security Guard	Y	Y	Y	Y	Y	Y
	Long Term Secure Storage	Y	Y	Y	Y	Y	Y
	GSE / EGSE Area	Y	Y	Y	Y	Y	Y
	Office Space and Conf. Room	Y	Y	Y	LSST	Y	Y
Lift/Roll	Crane	Y	Y	Y	Y	N	Portable
	Continuous Level Floor	Y	Y	Y	Y	Y	Y
	Small LV Fairing / Container Clearance	Y	Y	Y	Y (Horiz.)	N	N

* Handling and storage of small quantities of ordnance has been approved in the past in the Bldg. 836 High Bay and Cleanroom at VAFB. That rating is not currently in place, but can be returned as needed.

POTENTIAL REQUIRED CAPABILITIES

A list of potential launch site support requirements was identified to evaluate the LSIB's readiness to support small satellites and secondary payload requirements. To compile this list, input was collected from LSP Launch Site Integration Managers (LSIM), Mission Managers (MM), and Integration Engineers (IE) who have experience with small satellite and secondary payload missions.

The following sections address these requirements and discusses the LSIB's readiness to accommodate them in the various PPF facilities. Table 2 gives a top-level summary of the potential launch site support requirements which were identified, and lists the capabilities for a subset of the facilities. The PPFs which LSP uses for processing primary spacecraft are highly capable, but are not included in this subset. These "target facilities" are facilities that may be suited for small satellites and secondary payloads without causing occupancy conflicts with larger missions.

Most of these requirements are akin to the launch site support requirements which are commonly established for primary spacecraft. The difference here is that these capabilities may be required in smaller facilities and in facilities which are not normally used to process larger payloads.

Most of these potential requirements are easily achievable in any facility using temporary and portable solutions. For example, Electrostatic Discharge (ESD) safe static dissipative floor mats can be used in places where a permanent static dissipative floor is not present, and portable emergency showers and eye wash stations can be installed in facilities lacking permanent accommodations. The more challenging requirements are associated with handling propellants and ordnance. Even in these cases, portable solutions may achieve an equivalent level of safety in facilities that were not built to handle those hazards. For example, absorbent materials and portable dikes may be used to contain propellant spills instead of permanent floor trenches. Particular solutions like this require further consideration and require buyoff from the responsible safety authority.

Cleanliness

Some small satellites and secondary payloads can be processed in a GC or VC facilities. This level of cleanliness can be achieved in most indoor work environments without facility upgrades. Some satellites require a higher degree of cleanliness, such as ISO 14644 Class 8 or ISO 14644 Class 7. ISO 14644 Class 8 is achievable in all of the existing PPFs used by LSP, and some can accommodate ISO 14644 Class 7.

At VAFB, the Bldg. 863 Lab 1 laminar flow cleanroom can achieve ISO 14644 Class 7 and has smooth walls which can be cleaned relatively easily. The area in Lab 1 Rm. 10 in front (and downstream) of the laminar flow cleanroom is also a cleanroom, but no cleanliness designation has been established.[6] Wall covers can be used there to make cleaning easier.

At KSC, the PHSF Airlock can achieve ISO 14644 Class 8.5 cleanliness, which does not meet ISO 14644 Class 8 levels.[7] If ISO 14644 Class 8.5 is not sufficient, the PHSF Airlock is large enough that a cleanroom tent could be constructed there. This would allow the PHSF Airlock to continue to function as an airlock if another payload is processing in the PHSF Service Bay.

The Hangar AE High Bay Cleanroom at KSC was rated as a Level 2 CWA, but would require refurbishment to achieve that level again. The Hangar AE High Bay Airlock was once rated as a Level 3 CWA.[2] If needed, a cleanroom tent could be constructed in the Hangar AE High Bay Cleanroom, as an alternative to refurbishment, or in the Hangar AE High Bay Airlock. The future availability of this space for a cleanroom is uncertain as LSP is also considering a plan to modify and repurpose the Hangar AE Cleanroom. The plan would convert the cleanroom into a new control room, additional office space, and a lab. The modified configuration may split the current cleanroom volume into two levels. A low-bay lab could be useful for processing small satellites, but a high bay may be needed for processing small launch vehicle payload fairings, depending on ceiling height requirements.

Cleaning supplies and gowning equipment can be provided in any facility. Most cleanroom facilities have a designated gowning area. The Bldg. 836 Lab 1 cleanroom at VAFB uses a portable gowning tent.[6] A similar portable gowning tent could be constructed in any facility. Facility cleaning services can also be provided anywhere. Smooth walls facilitate cleanroom cleaning, especially when the facility is held to planetary protection requirements. In facilities that lack smooth walls, wall covers may be installed to provide a surface that is easily cleaned.

Temperature and Humidity Control

Temperature control is available in each facility, and humidity control is available in most. The requirements of a particular mission would need to be compared with the capability of each facility. The RTGF uses portable air conditioners as an emergency backup in case the built-in air conditioning system fails.[8] Based on this solution, portable air conditioners could be installed in any facility that does not have adequate temperature or humidity control built in.

Gaseous Purge and Ventilation

Some missions require a gaseous purge. For example, a gaseous purge may be used to protect a sensitive instrument from contamination. Gaseous purges, such as Gaseous Nitrogen (GN2), are routinely provided by the LSIB. This can be provided in any facility, as long as there is sufficient ventilation to prevent buildup of any asphyxiating gas. If any facility does not have sufficient ventilation, temporary ventilation capabilities can be provided using temporary ventilation fans and flexible air ducts.

ESD Control

Electrostatic Discharge (ESD) protection can be implemented in any of the facilities. Some of the facilities have built-in static dissipative floors. Where this is not the case, static dissipative floor mats can be installed. Grounding straps, grounding heel straps, and ESD-safe garments can be provided in any facility, as needed. Air Ionizers can also be installed in any of the facilities. When humidity control is required to mitigate ESD, portable humidity control systems can be installed.

Propellants

Due to resource constraints and the typical requirement that secondary payloads pose no threat to the primary mission, many small satellites do not contain hazardous fluids, pressure systems, nor ordnance. This section discusses the capabilities needed to support the less common small satellite missions which use hazardous materials, pressure systems, or ordnance. Few small satellites and secondary payloads have propulsions systems. Many of those that do have propulsion systems use relatively benign electric propulsion systems and cold gas thrusters, which usually utilize non-toxic propellants. Some missions utilize hazardous propellants such as hydrazine, and others have opted for the less-hazardous “green propellants.” The following sub-sections discuss some of the capabilities that a propulsive spacecraft may require.

Conventional Propellant Operations

Propellant loading and unloading operations tend to be very hazardous due to the toxicity and the chemical energy found in many propellants. Conventional monopropellants and bipropellants, such as hydrazine and nitrogen tetroxide, are very toxic and usually require precautions such as spill containment, personal protective equipment (PPE), and an environment free of ignition sources. These materials also require special facility safety ratings for the building containing them. The lower quantities used on small satellites and secondary payloads, compared to larger spacecraft, may reduce some of the processing requirements. The particular solutions require coordination with the responsible safety authority.

Personal Protective Equipment (PPE) for Propellant

PPE is not facility-dependent, and can be provided wherever it is needed. These include the Self-Contained Atmospheric Protective Ensemble (SCAPE), Splash Suits, Emergency Life Support Apparatus (ELSA), and Hooded Demand Valve (HDV). Portable emergency shower and eye wash units can also be installed wherever needed.

Air Monitoring for Propellant

Air monitoring devices are not facility-dependent. They can be installed wherever needed. These can be used to monitor the oxygen level and can be used to detect hazardous vapor, such as propellant vapor. If needed, these monitors can be connected to an alarm system or they can be used to trigger the activation of a safety device. For example, an air monitor can be set as a trigger to automatically disconnect facility electrical power if a flammable propellant vapor is detected.

Hazardous Rated Facility for Conventional Propellants

Most of the existing PPFs used by LSP are adequately rated for handling hydrazine at quantities which are used for large spacecraft during loading and unloading operations. If the smaller facilities are needed for a mission that involves processing small amounts of hydrazine, the facility would need to be evaluated and approved for this use.

The small quantities of propellant that would be used in small spacecraft may reduce the requirements and increase the number of potentially compatible facilities. For example, for a certain quantity of propellant, a spill kit with absorbent material and temporary dikes may meet the intent of a trench system that is built into the floor. This temporary solution may allow more facilities to be deemed acceptable. However, other factors come into play as well. For example, it is not likely that Bldg. 836 Lab 1 at VAFB and Hangar AE and KSC could support hydrazine operations because those facilities are also occupied by offices. On the other hand, the RTGF may be a candidate for these types of operations because it is not permanently occupied.

During propellant operations, or when a leak is present, a flammable atmosphere might exist. Some of the facilities use an NEC Class 1 Div. 1 or Div. 2 electrical system to preclude ignition sources when a flammable atmosphere is present. In other facilities, portable equipment meeting NEC Class 1 specifications could be used during hazardous operations, and the built-in facility power could be locked off. An equivalent level of safety could be achieved using a single point cutoff switch that disconnects hardware that is not hazard proofed from electrical power when a flammable atmosphere is detected. A purge system may also be used to preclude the presence of a flammable atmosphere. Precautions such as these may help achieve a level of safety equivalent to using a facility with a NEC Class 1 electrical system. The particular solution would require buyoff from the responsible safety authority.

Emergency Propellant Offloading

Some missions may require the ability to perform emergency propellant offloading. In general, if the facility is rated for loading the propellant, then it can also be used to unload the same propellant at the same quantity. After integration to the launch vehicle, this capability depends on the capabilities of the launch vehicle ground support equipment and the level of access on the vehicle.

Propellant Spill Containment and Protection

Most of the existing PPFs that LSP uses include spill containment systems, such as trenches and dikes, necessary for handling hydrazine at quantities which are used for large spacecraft. For facilities where trenches or dikes are not built-in, temporary dikes could be installed and absorbent materials could be kept ready, to contain any spills at the quantities expected for small satellites and secondary payloads. These solutions would be coordinated with the responsible authority before the facilities are used in this way. Portable waste and vent systems, which include hoses, containers, and dump tanks, can be brought to any facility. Portable emergency showers and eye wash stations can also be installed wherever they are needed.

Green Propellant Operations

Some propellants have been developed which are less hazardous than conventional propellants. These are commonly called "green propellants," and have attracted much attention from the small satellite community. Green propellants may allow some small satellite developers to load their propellant before transporting the spacecraft to the launch site.

In cases where the propellant is loaded at the launch site, some green propellants may be safe to handle in facilities where conventional propellants are not permitted. Future work could be done, in collaboration with the responsible safety authority, to evaluate whether any of the smaller facilities could support green propellant operations. While these propellants still contain significant amounts of energy, the diminished toxicity may allow them to be handled similarly to materials like gasoline, which does not require spill protection and SCAPE.

Ordnance Operations

In general, small satellites and secondary payloads do not contain ordnance. They often use non-explosive actuators instead of explosive actuators. This avoids the hazards associated with the storage, installation, and transportation of ordnance. However, there may be exceptions, including the use of solid rocket motors, which could drive the need to handle and store ordnance at the launch site.

Handling and storage of ordnance requires special facility ratings. Among facilities that are rated for storage or processing of ordnance, the permitted quantity of ordnance varies. The presence of ordnance can be a facility driver. Handling and storage of small quantities of ordnance has been approved in the past in the Bldg. 836 High Bay and Cleanroom at VAFB. That rating is not currently in place, but can be returned as needed. The RTGF at KSC was once used as an ordnance storage facility, so it may be a good candidate for processing small satellites and secondary payloads that contain ordnance. The facilities without the appropriate rating would require coordination with the responsible safety authority to determine whether these facilities can safely accommodate storage and handling of ordnance.

Transportation of ordnance is not facility-dependent, so the same protocols that currently apply to transportation of ordnance for larger spacecraft would apply for transportation of small satellite ordnance before and after installation.

Radioactive Material

Radioactive material is very rare among small satellites, and secondary payloads are especially unlikely to use radioactive material. However, as the level of sophistication continues to increase, it is possible that radioactive material could be used as part of a science instrument or perhaps as a power source.

Depending on the hazard level, the presence of radioactive material may have no significant consequence, or it may drive special requirements. Heightened security measures may be necessary, which can be accomplished in any facility. If a personnel clear zone is needed, this may drive the selection of the processing facility. For example, Bldg. 836 at VAFB and Hangar AE at KSC have permanently-occupied offices and could not be evacuated for an extended period of time. At KSC, the RTGF would be a likely option for processing payloads with a significant amount of radioactive material since it is normally used to process RTGs and RHUs. At VAFB, some Air Force facilities are significantly far from permanently-occupied facilities, and could be attractive options, depending on their available for use. The mission unique solution would involve coordination with the responsible safety authority.

Electrical Power

Small satellites are not expected to pose any special electrical power requirements. Most will accept the standard 120 V 60 Hz AC power available in each of the existing facilities. For missions that involve international partners, a portable converter can be used anywhere to provide 220 V 50 Hz AC, if needed.

Backup generators and uninterruptable power supplies are available in some of the existing facilities. However, the presence of uninterruptable power is not expected to be a hard requirement for most small satellites and secondary payloads.

Communication

LSP can provide telemetry, internet, and other communication capabilities in all of the existing PPFs. Additionally, LSP maintains a mobile Launch Site Support Trailer (LSST) at VAFB and KSC, which can provide wireless and wired communication capabilities where there is not an existing connection.[6]

Many small satellite and secondary payload programs utilize a support team at their home location during integration operations. Their budgets do not always allow for a large team to accompany the spacecraft at the launch site. For this reason, internet connectivity can be very important. Wireless internet connectivity via Wi-Fi can also be established anywhere to help streamline access.

Processing Area Floor Space

Small satellites and secondary payloads generally do not require as much processing floor space as larger spacecraft. Therefore, all of the facilities mentioned are generally capable of accommodating individual small satellite programs. Some missions involve a collection of small satellites manifested together. Their integrated stacks sometimes rival the mass and volume of larger primary spacecraft. In such cases, the larger facilities may be appropriate. For satellites that utilize small launch vehicles, their shipping container and fairing can likely be processed in smaller facilities such as Bldg. 836 Lab 1 at VAFB and the Hangar AE High Bay at KSC. The RTGF could also be an option, depending on vertical height requirements. Fairing and shipping container operations are discussed further in another section.

Security

Small satellite and secondary payload security requirements may be driven by communication security requirements, proprietary data and hardware, export controlled data and hardware, and hazardous substances. The same facility security measures which are normally available to larger payloads can be implemented in any of the facilities discussed. These include door locks (ex., cypher and padlock), door alarms, 24/7 surveillance, and security guards. Small satellites requiring security during transportation can be accommodated in the same way that larger spacecraft are accommodated. Additional protections may be necessary if classified data or hardware is present, but this topic is beyond the scope of this study.

Long Term Secure Storage

Many small satellite and secondary payload missions are joint missions with multiple small satellites, and/or with a primary spacecraft. Cases may arise where some spacecraft arrive at the launch site before others. For example, the primary mission may not be ready for secondary payload installation when the secondary payload arrives. In these situations, secure long-term storage can be a useful resource.

This capability is possible in each of the facilities discussed. Depending on the spacecraft requirements, storage lockers can be installed in cleanroom environments or in office space environments with the same security measures which are available in all facilities. Similarly, entire rooms may be designated for secure flight hardware storage. The only limiting factors here would be occupancy scheduling with respect to other programs that may need the space.

GSE / EGSE Support

For most small satellite missions, Ground Support Equipment (GSE) and Electrical Ground Support Equipment (EGSE) can be installed directly in the processing area where the spacecraft is located, in nearby control rooms, or in nearby office space. All of the existing PPFs that are used by LSP have areas where GSE and EGSE can be installed. Bldg. 836 at VAFB, and Hangar AE and the MOSB at KSC, have spaces that can be used for this purpose. In cases where there is not a control room in close proximity, such as at the RTGF at KSC, a mobile LSST trailer can be used for this purpose. Additionally, the GSE or EGSE equipment can be installed in a nearby facility, such as the MOSB for the case of the RTGF.

Office Space

Office space can be made available in close proximity to each of the PPFs for use by small satellite programs. Nearby facilities can also be used for office space. Bldg. 836 at VAFB, and Hangar AE and the MOSB at KSC, each have transient office space that can be used. The mobile LSST trailer on each coast has some office space to complement its communication capabilities. At VAFB, LSP also maintains a mobile SpaceCraft Office and Utility Trailer (SCOUT), which contains office space and a more modest communication infrastructure, compared to the LSST.[6] There is a current study considering the possibility of adding additional capabilities at KSC to match the capabilities of the SCOUT at VAFB. When needed, the LSST (KSC and VAFB) or the SCOUT (currently VAFB only) can be located near a remote facility to provide office space and network connectivity.

Hand Tools

Hand tools and other supplies can be provided in any facility.

Lift/Roll Operations

Depending on the mass of the payload, some small satellites and secondary payloads cannot be safely lifted by hand. In those cases, lift and roll equipment may be necessary. For example, small launch vehicle fairing encapsulation or removal/installation of the spacecraft from a shipping container may involve lift/roll operations. Some small satellites, fairings, and shipping containers, can be moved using rolling fixtures and fork lifts, while others may require crane.

Rolling fixtures and fork lifts require access through a continuous level floor. Except for some mobile cleanroom options, all of the facilities discussed have continuous level floors from the outside or they have methods to accommodate variations in floor height for certain applications (ex., forklifts, ramps, etc.). Fork lifts can be provided by LSP in any facility with a wide enough door.

Many of the existing facilities have a built-in bridge crane. Some facilities have multiple cranes, which can be used for rotating hardware. The bridge crane in Bldg. 836 Lab. 1 at VAFB can only be moved along one horizontal axis within the laminar flow cleanroom, but it can be moved in two horizontal axes outside the cleanroom.[6]

In facilities without built-in cranes, and when a forklift does not meet the requirements, it may be possible to employ a temporary rolling gantry crane, shop crane, or a truck mounted crane. These options may also require a continuous level floor.

Fairing Encapsulation and Shipping Container Removal/Installation

Similar to other missions, small satellites and secondary payloads require adequate space for removal from – and possibly installation within – their shipping container. In the case of dedicated small satellite missions on small launch vehicles, it may be necessary to perform fairing encapsulation in the processing facility. For the purposes of this discussion, fairing encapsulation will be considered as a bounding case, compared to shipping container operations. Therefore, shipping containers are not considered separately.

According to a back-of-the-envelope assessment of facility dimensions, it is apparently possible to conduct small launch vehicle fairing encapsulation, as well as shipping container operations at VAFB in Bldg. 836 Lab 1, and at KSC in Hangar AE and the RTGF. Coordination with the launch service providers, and evaluation using 3D models, would be needed to confirm this assessment. The crane capacities should also be evaluated with respect to the mass of payloads, fairings, and shipping containers. Furthermore, future study would need to evaluate the mechanics involved with encapsulation, given the encapsulation operation plan for each small launch vehicle. For example, it will be important to understand whether each vehicle's fairings are oriented vertically or horizontally during integration, and whether a crane is needed.

CONCLUSION

This study was conducted to identify how NASA LSP can accommodate launch site support needs for emerging small satellites and secondary payloads using existing infrastructure at KSC and VAFB, and to identify whether new capabilities will be needed. Using input from NASA personnel who are familiar with past, current, and future small satellite missions, a collection of anticipated launch site support requirements were identified. These requirements were compared with the capabilities of existing PPFs used by LSP, facilities that would require upgrades or refurbishments, facilities that are subject to scheduling outside of LSP, and peripheral facilities of the existing PPFs, such as airlocks and side rooms.

All of the capabilities that small satellites would require can be provided using the existing PPFs used by LSP. Unfortunately, these facilities are expected to be cost-prohibitive for many small satellite program budgets, and they may be occupied by other missions. The peripheral facilities of the PPFs may be excellent choices for secondary payloads when their primary spacecraft is occupying the same facility. Most of the requirements can be satisfied by a range of smaller facilities, which are more likely to be available and affordable for small satellite missions. Depending on the particular requirements, portable and temporary accommodations may be used to compliment the capabilities of some of the smaller facilities.

At this time, the study has not identified a need for significant upgrades, investments, or long-lead preparations in the near-term. The capabilities which may be the most difficult to establish in the smaller facilities are related to propellant processing. Regarding fairing encapsulation, an initial assessment identified several facilities where small launch vehicle payload fairing encapsulation could likely be accomplished, but some uncertainty could be resolved with a more in-depth investigation. There is also some uncertainty regarding the future availability of certain facilities, and some preliminary trade studies may prove useful in determining whether facility upgrades and/or refurbishments are beneficial.

The LSP LSIB continues to evaluate its capabilities with respect to the needs of emerging small satellite programs, to ensure that LSP is ready to support any mission that comes down the pipeline. Input from the small satellite community is greatly appreciated, to help identify any emerging launch site requirements for future NASA small satellite and secondary payload missions. The author can be reach at Liam.J.Cheney@nasa.gov.

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