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A Brief Description of Fit Check Exercises for Space Vehicle (Single or Multiple) Integration onto a Launch Vehicle

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Peter S. Chang[1] and Arthur A. Menichiello[2]
[1]Agile Space Acquisition and Implementation, Space Innovation Directorate
[2]Strategic Initiatives and Small Launch, Space Innovation Directorate

Prepared for

Space and Missile Systems Center
Air Force Space Command
3548 Aberdeen Avenue SE
Kirtland AFB, NM 87117-5778

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Abstract

Based on previous experiences of (single and multiple) space vehicle (SV) integration onto the launch vehicle (LV) throughout the Space Test Program (STP) mission history, it was noted that a dry run (or fit check) of the installation/integration exercise was invaluable as a precursor to a successful launch integration activity. This paper is written to introduce and assist any payload and/or launch provider in the fit check objectives, specific sequential (time-based) activities with descriptions and desired outcomes for each step. A flow chart accompanies the write-up to further illustrate the inclusion and insertion of these events within the program integrated master schedule (IMS) during the launch activity flow.

Contents

1. Introduction

Within the last 10 years, the space mission configuration of a single space vehicle (SV) mounted on a dedicated launch vehicle (LV) has evolved into a host (or primary) SV with additional auxiliary SVs, all clustered around a stack on top of a single LV. With tightening budgets compounded by the ever-increasing need to access space by the science/university community that heretofore cannot afford a dedicated launch vehicle for an individual mission, this multiple payload (space vehicle) arrangement that takes advantage of the excess lift capability offered by the launch vehicle is becoming the rule rather than the exception. The Space Test Program (STP) has conducted multiple payload launches for several years, and this phenomenon is occurring more frequently in the National Security Space (NSS) missions. Currently, national political and policy updates have instituted that any excess lift capabilities on each LV must be utilized to host auxiliary payloads to access space. So, it appears that the multiple payloads on a single LV will be the norm in the foreseeable future.

Part and parcel of any STP launch campaign, and essential to both the payload and launch service tasks is the payload integration onto the LV, which in the case of multiple payloads, is generally called the Integrated Payload Stack (IPS). On the surface, this may seem to be a linear increase in the integration efforts. Yet the reality is that the complexities grow in a more exponential manner. A somewhat parallel analogy can start with having a two-kid play date gone awry. Some tears and angst will ensue but can eventually be overcome. To extend this, an unmanaged multi-payload situation is akin to a group of cranky, hungry children in day care without any adult supervision, the end result of which will surely descend into utter chaos and eventual failure.

In all seriousness, one of the ways to systematically manage the chaotic integration efforts for multiple payloads is to police and control the SV to LV integration flow. An overarching integrated master schedule (IMS) tied to a unified giver-receiver list would be a good start to corral the multiple SV integration and test (I&T) efforts into a synchronized process. This provides for an organized way to approach launch integration.

Yet, all the SV must eventually meet for the final stacking (integration) process onto the single LV. To maintain order and efficiency in the integration, a ‘fit check’ (or dry run) prior to the actual event is highly recommended. There have been major lessons learned recorded by STP on the launch integration processes without a fit check. In fact, additional lessons learned from the past fit checks has been recognized to improve and shorten the final stack integration process.

The purpose of this paper is to explain the fit check idea that has been developed via the STP experience and to attempt to list the various components of the process. It is in no way the ‘bible’ for all fit checks, and each mission will have unique requirements that should necessitate tailoring the steps herein. Rather it is hoped that this document can start the program office as well as individual SV providers in thinking, planning and execution for a fit check that would lead to an eventual successful integration onto the IPS.

The basis of the document stemmed from experience gained during the past STP missions. STP was in a unique position as a government broker that oversaw more integration of multiple SVs onto the LV than any other group. It is expected that this methodology will continue in the future for other government organizations, having an over-arching program office that manages and coordinates the launch integration effort. Henceforth, this entity will be referred to as the Program Office.

2. Fit Check Objectives

To achieve a successful integration, early fit check sessions that include hardware match and procedure validation are highly desirable and would greatly reduce the IPS integration cost and schedule risks. Listed below is a reprise of material from several earlier fit check experiences. Note that there are two items that will be repeated frequently in this write up. These are defined below:

- PLD: Payload Dispenser—generically the SV/LV-related adapter components, payload mounting plate or fittings, or the Enhanced Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) or ESPA-like rings on which the payloads will be mounted.

- Spacer: the adapter ring to be furnished by the launch service provider (henceforth just referred as LV) to all payloads. These are to be installed between the LV side of the separation system and the PLD ports. The existence of this ring is to facilitate earlier mounting of the two halves of the separation system, as well as easier installation of the SV-separation system stack to the dispenser.

Additionally, the terms SV and payload are interchangeable in this paper. Integration of sensors or Hosted Payloads on each SV is not addressed here. Finally, there are some comments in italics, which may not relate directly to the fit check activities, but are deemed pertinent for consideration as thought exercises.

In an ideal fit check process, there are four related but distinct general categories.

1. Mechanical and Spatial accommodations:
   This is to verify matching bolt holes; correct clocking during mate; the ability to correctly and safely balance the SV and perform lifts and lateral movements necessary to the mating process; verify stay-out zones and possible excursions (or incursions into other spaces); and finally, expose and resolve any remove (or install)-before-flight (RBF/IBF) accessibility issues.

2. Structural Integrity:
   Tolerance stack up of the as-built PLDs will cause fitment issues during the mechanical stack exercise. As well, the rigidity or lack of, of each PLD will be revealed via distortion or lack of flatness at each mating interface. Finally, in cases of not fully populating all the PLD ports, subsequent mating of a payload after the first one may also cause out of roundness at those interfaces. Early procedural revisions such as simultaneous soft mates or additional stiffening mechanisms are highly recommended. Of course, the dimensional distortions should have been analyzed a priori, and the fit check presents the opportunity to prove the veracity of these results.

3. Electrical fit check:
   Concomitant with the mechanical fit check is the electrical harness check. Due to various separation systems clocking, harnesses to each payload will have different lengths, which must all be routed within the available spaces, attached appropriately and have adequate strain relief. A bonus will be an end-to-end electrical (continuity, isolation, pin-out) test, if the actual flight harness or identical ground harness is available. In many cases, the end-to-end check may not be possible, due to disparate manufacturing schedules within the SV and LV process. Then incremental electrical checks will have to suffice. But it is highly advisable that each individual segment be exercised so that there is a theoretical end-to-end verification.

4. Procedure dry run:
   Overarching the physical fit check activities is the preparation of procedures for the payload integration and stacking: from the SV lift by the payload representatives to within 3-4” of the

designated PLD port, to the LV's effort to mate all payloads to the PLD and subsequent stacking of each populated PLD. As well, de-stacking procedures must also be prepared for the fit check disassembly and potential future emergency de-manifesting of a payload. The fit check will be performed in coordination with SV and LV's resident Safety Department personnel.

5. Foreign Partner Accommodations:
   Finally, it is expected that as more launch opportunities arise, the possibility of having foreign partners among the SVs (as well as on-board instruments) will increase. This adds another wrinkle in the overall integration effort in that rules for foreign disclosure, Technical Assistance Agreement (TAA) and International Trafficking in Arms Regulations (ITAR) considerations, as well as Communications Security (COMSEC) requirements from the U.S. SVs may apply. Although not specifically described in this write-up, special accommodations will have to be exercised, and the fit check is a perfect opportunity to test such compartmentalization.

3. Assumptions for the Fit Check

Attached in Appendix A is a flow chart of fit check activities. The positions of these tasks are predicated on various assumptions/conclusions stemming from advance discussions with the payload providers, the LV, as well as with the STP customer. The individual tasks are positioned in a roughly chronological manner, in concert with a nominal SV I&T flow as well as catering to the exigencies of both the SV and LV schedules. Listed below are comments and lessons learned workarounds for the fit check:

1. In general, the fit check exercise should be held at least by L-12 months. This will provide adequate time for hardware and process updates as well as reaction to possible de-manifesting or payload exchange maneuvers.
2. At L-12 months, most SVs will be undergoing or initiating their own system level testing. Therefore, demanding a flight article for a fit check may be unrealistic. A mass model (or simulator) and/or a volumetric mock-up may be more appropriate for the fit check purposes; the former to demonstrate adequate weight bearing capabilities and lack of any distortion during installation, the latter to check for clearances and interferences.
    a. The SV Simulator (engineering design unit (EDU) or Simulator or a mass model) details should include:
        i. Correct mass, center of gravity (CG), (also possibly moment of inertia (MOI)) & mechanical ground support equipment (MGSE) interface
        ii. Accurate volumetric considerations (can be built up with Extensions / Protrusions)
        iii. Remove before flight (RBF)/install before flight (IBF) item locations clearly marked for access exercises
        iv. Electrical bracketry / connection mock-ups
    b. In some cases of multiple copies of the same SV on a PLD, having exact same copies of the aforementioned mass model may be cost prohibitive. In this case, copies of the mass models can be mixed in with copies of volumetric models (without accurate mass/CGs, but) with faithful dimensions that may stand in place for spatial and stay-out-zone assessments.
3. It is strongly desired to have each manifested SV have a representative (model) present in their planned location/slot.
4. Separation systems (Flight, EDU or Simulator) must be provided by the SV providers.
5. All mass models should have their separation systems (flight or simulated) installed on the spacer for the fit check to demonstrate accurate stand-off distances.
6. PLDs: ESPA (or ESPA-like) dispenser to be available for integration exercises.
7. Fit check area may not be a clean room but should be environmentally controlled (air conditioning) for personnel comfort. However, in the case of a payload provider bringing their flight article for the fit check, a cleanroom environment (>Class 100k) may have to be instituted.

8. It is mandatory to have overhead crane (and controls) with hopefully similar specifications as in the actual payload processing facility at the launch site.

9. It should be expected that the fit check facility will only provide general access control (no classified/restricted access provision will be in place).

10. When possible, actual SV/LV MGSE (e.g. lifting hardware, integration stand, load cell, hydraset, etc.) will be used for fit check.

11. Draft procedures will be made available at least 1-month prior to the fit check date, and a table top review between SVs and LV be held soon after document delivery but way before the physical fit check for cross checking and coordination. The 1-month standoff period affords time for revisions to the procedures. This dry run can be a special session in an early Ground Operations Working Group (GOWG).

12. LV shall provide their ground support equipment (GSE) platforms/ladders. As well, standard platforms/ladders will be used. During the fit check, those support GSE must be noted in the procedures so that they will be provided during the actual integration.

13. It is desired to use the same (LV and payload I&T) personnel as for the actual launch integration.

14. The LV or launch integrator may utilize paper/plastic gameboard models, or computer simulation at the table top review to assist all parties in planning for staging SVs, GSE, etc., for the actual fit check event, to evaluate potential physical interference, schedule-based conflicts, and facility resource constraints. This can certainly be a GOWG activity. However sole reliance on an 'ERGO-man' computer exercise in lieu of a physical fit check is **highly undesirable and should be strenuously discouraged**.

15. Include grounding straps, grounding points, and alligator clips for actual or simulated hardware electrical grounding to facility grounding bus bars. Personnel wrist-grounding straps with alligator clips may also be employed during the fit check to further simulate actual integration event grounding requirements.

16. Include simulated purge lines/hoses, as-required, by payloads or SVs.

17. Include any required rope-line tethers (tag lines) for SV orientation control during lifting and mounting operations.

4. Explanation of Fit Check Tasks

Appended to this write-up is a notional flow chart. As previously stated, the tasks are arrayed in a rough chronology that is based on a nominal (logical) flow of I&T events. Note that each box in the flow chart has an item number beginning with 1.X through 4.X. This reflects the different events on the flow chart:

1.0 Planning & Procedures
2.0 Fit Check Preparation
3.0 Stacking & SV Mating Operations
4.0 Post Fit Check Activities

As well, there are three colors in the boxes. These refer to activities to be performed by either the payloads (light blue) or Program Office (yellow) or LV (green).

Finally, between each major step, other integration or (SV) parochial activities (such as testing) can be inserted as the individual schedule permits. The purpose of this flow chart is to impart a sense of events flow for a complete fit check exercise.

For simplicity's sake as well as affording better explanation, the tasks are listed hereafter under each category versus the chronological sequence as depicted in the attached flow chart.

1.0 Planning and Procedures

1.1 SV Handling Procedures

This is a document that should be developed by the payloads to guide their routine SV movements during their I&T process. Prior to arriving at the LV facility, each payload should have already formulated its support equipment staging (space/footprint and orientation) and SV handling procedures. *Side comment: Irrespective of the varying levels of readiness, it remains the Program Office's responsibility to insist and instill the 'boy scout' mindset onto both SV and LV counterparts to be as thoroughly prepared for this exercise, to the point of a 'dry run' for the real integration event 12 months hence. Toward that end, a robust IMS and a detailed Giver-Receiver list is paramount.* Any specific instructions to prepare and orient the SV for transport; for installation onto or removal from a SV handling fixture; and for any crane/lift operations should all be included in this document. Note that although mass or volumetric models may be used, this does not excuse the grabbing of protrusions that stand for antennae, feedhorns or external instruments, especially of adjacent SVs. The procedure should note the hands-free and other keep-out zones, and strict adherence of the same should be observed.

1.2 SV Mate and De-mate (Contingency) Procedures

During actual (flight) installation of the payload to the PLD or the stack, the payload crew is responsible for lifting and moving the suspended payload to with 3-4" of the mounting interface on the PLD. At that point, the LV assumes control and is responsible for guiding the payload toward the dispenser mounting location and performing the mate via bolts and the subsequent torqueing of the same. The de-mate procedure is the reverse process but must be listed separately. Although the latter may never be used, it stands as contingency if the need arises due to unforeseen emergency events.

1.3 IPS Stack and De-stack Procedures

Note that the Mate/De-mate activities (above) are different from Stack/De-stack. The former applies to individual SVs, while the latter applies to a wholly populated (with SVs) dispenser ring/tower. On a stack (tower) of multiple payloads, several PLDs may be required. Nominally, each PLD will first be populated (integrated) with the payloads, then each PLD will be sequentially stacked on top of each other to form a complete stack (tower). The LV will develop the sequencing of stacking, the accompanying mating of each stack interface as well as the electrical harness connections. The de-stack procedures are necessary for concluding the fit check, and as contingency during final launch operations.

1.4 Table Top Integration (Technical Interchange Meetings (TIMs)/GOWGs)

Although it is assumed that the SVs and the LV are capable entities with adequate integration experience and expertise, when multiple parties congregate for a collective integration event, it is certain that miscues and confusion would ensue without any prior coordination. This table-top planning meeting purpose is to air out any conflicts or misunderstanding among the group so that the discrepant expectations and routines can be ironed out. Once all documents (procedures) have been received and reviewed (by Program Office, SVs and LV), a tabletop meeting will be held (most probably an early GOWG session) which should entail an actual walk through and possible pantomime of the fit check activities (a la a sand table exercise). This meeting will result in subsequent revisions to all procedures: [1.5] for the payloads, and [1.6], [1.7] for LV. The updated procedures will be applied during the actual fit check, with lessons learned incorporated (redlined) in subsequent revisions.

1.5 Draft SV Handling Procedure

This is the result of the effort delineated in [1.1] above. More specifically, the payloads will set aside a section just for the lifting and integration of the payload to the PLD. This procedure will be utilized during the actual payload lifting and translating exercise during the mechanical fit check. Finally, based on the experience with accommodating neighboring SVs, drop shields or foreign object debris (FOD) blankets and tool tethering should be added to the procedure, if deemed appropriate.

1.6 Draft SV Mate and Demate Procedures

Likewise for the LV, this is the result of step [1.2], and will be used for the integration of the payload to the PLD. Note that this will be used during the mating portion and later demating efforts of the mechanical fit check.

1.7 Draft IPS Stack and Destack Procedures

Like [1.6] above, this is the result of step [1.3] and will be applied during the stacking and (later) destacking exercises in the mechanical fit check.

1.8 Tabletop Integration (GOWG)

After the Post Fit Check Review, another tabletop meeting should be held (probably at the ‘hot wash’ session right after the physical fit check, or at the latest at a follow-on

GOWG). This meeting will result in action items for subsequent (final) revisions to all procedures: [1.9] for the payloads, and [1.10], [1.11] for LV. The updated procedures will be applied during the actual launch campaign integration at the Launch Site Payload Processing Facility (PPF).

1.9 Launch Site SV Handling Procedures

See comments in [1.11] below.

1.10 Launch Site SV Mate and De-mate Procedures

See comments in [1.11] below.

1.11 Launch Site Stacking and De-stacking Procedures

This and the above two documents are the near-final versions of the documents produced by the payloads [1.9] and the LV [1.10] and [1.11] that will be utilized at the actual launch integration. In the past, these documents were the casually redlined versions of the initial drafts. For small payloads with simple attachments, this may be permissible. However, payloads are increasing in size as well as complexity, and some have protruding deployables (antennae, solar arrays, booms). So, it behooves the program office to institute a more formalized process and direction: render this final set as deliverable artifacts for requirements in the SV-LV ICD as well as part of the Missile System Pre-launch Safety Package (MSPSP).

2.0 Fit Check Preparations

2.1 Fabricate Dispensers and Spacers

In past programs, the LV typically builds the PLD and spacers. In addition, LV may send the spacers to each payload for installation to the separation system prior to the payload mass models arriving at LV for fit check.

2.2 Provide Mass Properties

Each SV shall provide their latest SV mass properties (mass, CG (and MOI, if required)) as well as computer-aided design (CAD) models to the Program Office and LV. This may be part of an earlier delivery for the coupled loads analyses (CLA) needs. But the parochial need here is to gain enough information for fit check planning as well as mass model development.

2.3 Install Spacer onto Mass Models

It is expected that all payloads will be receiving spacers (see [2.1] above) from LV, and except for the (potentially) Program Office provided models, the payloads are responsible for installation of the spacers and their separation system onto their mass models.

2.4 Program Office developed Volumetric Mass Models

The Program Office may develop all simulator/mass/volumetric models (if the same cannot be available from the SV providers) to be used for fit check. These items will be available for the fit check. As mentioned earlier, for a flight mass model, the mass, CG, MOIs should be the same as the flight article. The last item is also especially applicable to modal and acoustic testing.

Often, due to the exigencies of the design process, the mass model will not have the same appearance as the actual flight article, especially in the outer appendages such as solar arrays, antennae, telescope covers, etc. For fit check purposes, a volumetric covering and temporary attachments to mimic such protrusions must be installed to highlight potential interference with adjacent articles/SVs and stay-out zones to exercise access requirements.

2.5 SV Provide Mass Models

For the payloads providers that already have their accurate flight mass models, these physical models now need to be delivered to LV.

2.6 Provide Actual Flight SVs

For the payloads that decide to offer their (if incomplete for flight) SVs, they need to populate the missing flight boxes with substitute articles of the same mass and deliver the full up system to LV.

2.7 Pre-Fit Check Table-top Review

Prior to the actual event, a tabletop/paper walk through meeting will be held with all parties to uncover any missing hardware/GSE/procedural steps.

2.8 Provide SV Flight or Simulated Harness

In parallel or soon after the delivery of mass models, the payloads will provide flight or simulation (rope of similar stiffness, diameter and correct length) harnesses to LV.

2.9 Provide LV Flight or Simulated Harness

LV will provide harnesses on their side of the interface for possible mate and routing exercises.

3.0 Stacking and SV Mating Operations

3.1 Payloads Move and Position

Payloaders will sequentially (as planned and mutually decided with LV) lift, move and position their mass models to within approximately 3" of their designated payload port.

3.2 Mechanical/Electrical Fit Check

Both mechanical and electrical fit checks will be led by LV, with close coordination and participation from individual payloads. LV will be solely responsible for the SV installation and stacking activities.

3.3 IPS De-stack

As an aside, if the whole stack is populated by accurate masses, a stack modal test would be a very good opportunity right now. But contractual and schedule exigencies may preclude this event. Regardless, the IPS will be returned to the fit check exercise area and the de-stacking procedure can be exercised ([1.7]).

3.4 SV De-mate

LV will perform de-mate of all mass models, with each cognizant payload representative receiving the hardware and storing into the shipping or storage containers.

4.0 Post Fit Check Activities

4.1 Payload Mass Model Storage

The mass models may be stored at the LV facilities for future flight use, if required. As an example, in the present STP construct, this would be the case where a SV is de-manifested and a mass model is required for flight in its place. The spacers and separation systems will be returned to the payloads for integration onto the flight SVs.

4.2 Flight SV Return

The flight payloads with the dummy boxes will be returned to their respective owners for further SV build up.

4.3 Volumetric Mass Model (VMM) Return

The VMMs will be returned to the payloaders. The spacers and separation systems will also be returned to the payloads for integration onto the flight SVs.

4.4 Post Fit Check Review

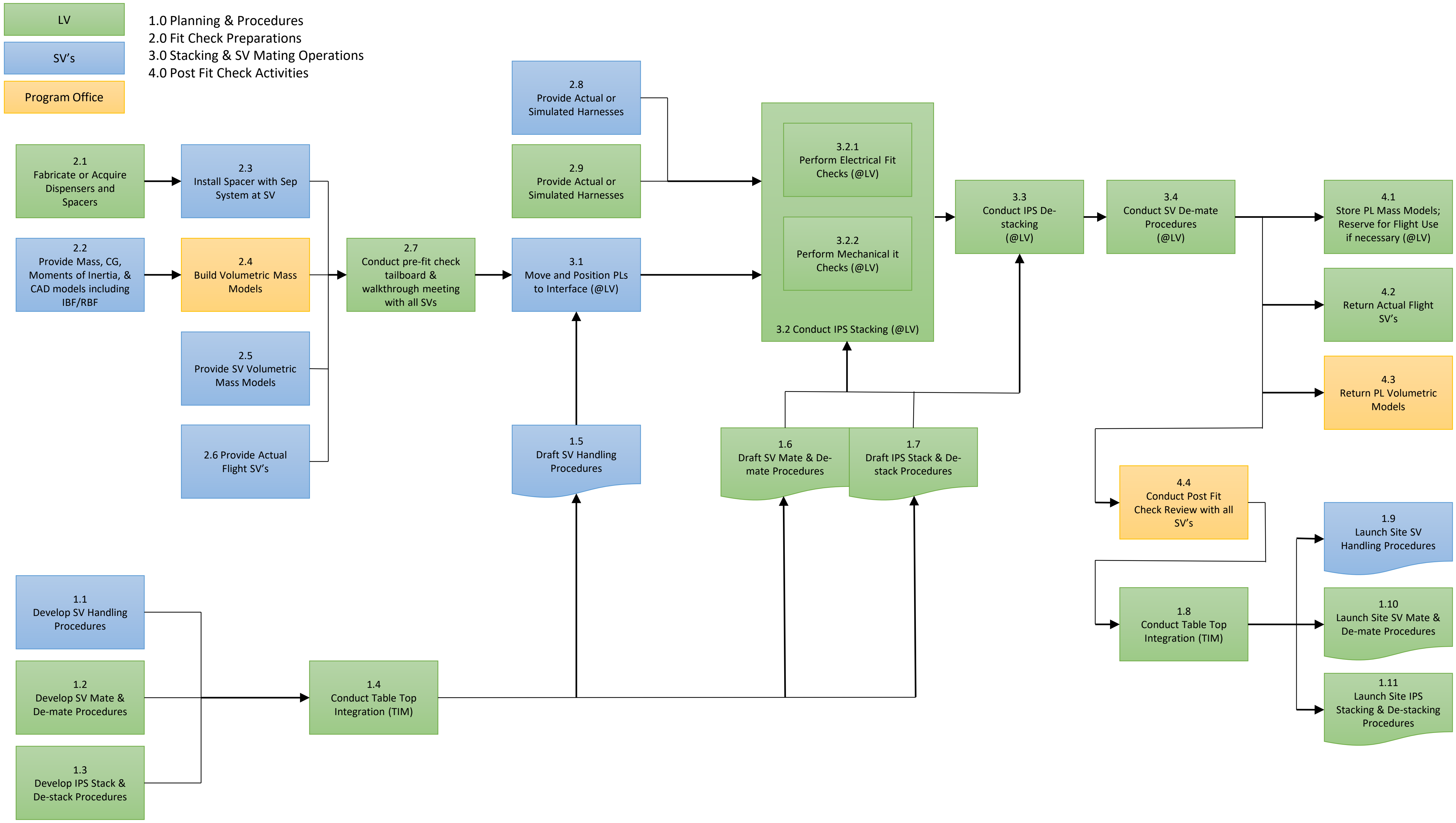
Program Office will convene a post-fit check review to address any issue, coordinate work arounds and incorporate lessons learned for the actual flight integration. Each SV and LV will refine their procedures based on findings from the fit check and this subsequent review. Resulting procedures for both payloads and LV will support the Table Top Integration focused on integration at the Range PPF.

5. Acronym List

CCAFS	Cape Canaveral Air Force Station
CAD	Computer-aided design
CG	Center of gravity
CLA	Coupled loads analysis
COMSEC	Communications Security
EDU	Engineering design unit
EELV	Enhanced Expendable Launch Vehicle
ERGO MAN	Ergonomic man
ESPA	EELV Secondary Payload Adapter
FOD	Foreign object debris
GOWG	Ground Operations Working Group
GSE	Ground support equipment
IBF	Install before flight
IMS	Integrated master schedule
IPS	Integrated payload stack
I&T	Integration and test
ITAR	International Trafficking in Arms Regulations
LV	Launch vehicle
MGSE	Mechanical ground support equipment
MOI	Moment of inertia
MSPSP	Missile System Pre-launch Safety Package
NSS	National Security Space
PLD	Payload dispenser
PPF	Payload Processing Facility (LV's CCAFS facility for SV integration)
RBF	Remove before flight
STP	Space Test Program
SV	Space vehicle
TAA	Technical Assistance Agreement
TIM	Technical Interchange Meeting
U.S.	United States
VMM	Volumetric mass model

Appendix A. Fit Check Flow

Fit Check Flow



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Cognizant Program Manager Approval:

Barbara M. Braun, SYSTEMS DIRECTOR
AGILE SPACE ACQUISITION & IMPLEMENTATION
SPACE INNOVATION DIRECTORATE
DEFENSE SYSTEMS GROUP

Aerospace Corporate Officer Approval:

Martin Whelan, SR VP DEF SYS
DEFENSE SYSTEMS GROUP

Content Concurrence Provided Electronically by:

Arthur A. Menichiello, PROJECT LEADER SR
STRATEGIC INITIATIVES AND SMALL LAUNCH
SPACE INNOVATION DIRECTORATE
DEFENSE SYSTEMS GROUP

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