

Recommended Practice

Space Launch Integration

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American Institute of Aeronautics and Astronautics

Abstract

This document identifies the processes and methodologies of space launch integration and recommends demonstrated practices that can improve the launch integration process. These recommended practices are drawn from both government and commercial sectors. They are identified in four areas: physical and environmental interfaces; pre- and post-launch operations and processes; requirements, verification, analysis, and test; and mission assurance and risk management. In selecting the recommended practices, the following considerations are significant: level of effort, the launch integration process itself, required products and services, project organization, metrics, process improvement, and streamlining. The recommended practices described in this document are based on the evolution of current standard practice as illustrated by ISO International Standards for space systems and other documents.

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Executive Summary

This study was performed under NRO Contract NRO000-98-D-2118, task order 0777, in response to NRO/OSL BAA 99-001, paragraph 1.4, Standards and Best Practices. Its objective was to develop a handbook of recommended practices for Space Launch Integration using a broad-based team of industry, government, and academic experts. The major issue to be resolved was to define how current best practices from all sectors - military, civil, government, and commercial - can be adapted to form a group of standards and best practices to best meet NRO's needs. In accomplishing this objective the following tasks were performed, as specified by the contract:

- (1) Define the processes/elements and methodologies of space launch integration and their relationship to each other and interdependencies. Develop a representative process flow and description for space launch integration, recognizing that space missions have several degrees of complexity
- (2) Identify areas/processes/elements which lend themselves to the application of standards and best practices based on identified best practices of commercial and government integration activities
- (3) Address how an organization would go about implementing the desired standards and best practices, the efforts needed to accomplish the actual development and application of standards, and how they may be leveraged across industry, including recommended methods for streamlining the launch integration process
- (4) Publish the results of this study as an AIAA product utilizing the accredited consensus procedures, "Recommended Practice for Space Launch Integration"

These objectives were pursued in four different areas, each by a separate working group, as follows:

- Physical and Environmental Interfaces
- Pre- and Post- Launch Operations and Processes
- Requirements, Analysis, Verification, and Test
- Mission Assurance and Risk Management

Current practices in the integration of commercial and government payloads are described, and recommended practices identified. In selecting these recommended practices, the following considerations were significant.

- (1) Level of effort. The level of effort required for a launch integration process depends mainly on the following: (a) maturity of the systems involved (e.g., recurring vs nonrecurring missions); (b) complexity of the interfaces; (c) security implications; and (d) risk tolerance.
- (2) The launch integration process itself. The launch integration process begins with assessing the compatibility of spacecraft (SC) system interface requirements relative to launch system capabilities. It also begins with focusing on interface issue resolution to minimize overall cost to the customer, while emphasizing risk mitigation in interface design to enhance mission success. It culminates with the successful delivery of an operational SC to the desired orbit.
- (3) Products and services required. The scope and content of the products developed depend on the complexity of the spacecraft-to-launch vehicle (SC-to-LV) interfaces. The services provided depend on customer requirements. Typical examples of products and services associated with space launch integration are as follows:

Products

- Plans
- Schedules
- Interface requirements documentation
- SC-to-LV interface hardware
- Test procedures
- Technical reports
- Range support documentation
- Range safety documentation
- FAA launch license (where required)

Services

- Conduct and support management reviews
- Chair and support technical working groups
- Conduct selected technical analyses
- Define and verify interface requirements
- Support launch and flight operations
- Provide project security guidance and monitoring
- Set up and staff operations information center during launch operations

(4) Project organization. For highly complex missions, the launch integration organizational structure may include various agencies representing the satellite vehicle contractor, LV contractor, and launch site. In addition, vehicle and support contractors as well as consultants may be involved. This participation will vary depending on the “oversight” and “insight” required by the customer. The optimum project organization depends to a great degree on the nature of the mission, and hence there is no generalized “recommended practice.” Any organization, however, requires the following elements: (a) chain of command; (b) definition of contractor and customer roles and responsibilities; (c) definition of roles, responsibilities, and accountabilities for each functional category; and (d) definition of communication links among all personnel.

(5) Metrics. Definition of appropriate metrics in all four areas of space launch integration is essential to characterize performance, reliability, safety, and mission assurance.

(6) Process improvement and streamlining. Continuous process improvement should be implemented in every program through the use of (a) formal strategies to evaluate “lessons learned” and (b) various analytical methods; e.g., “fishbone” fault-tree analysis, failure modes and effects analyses, probabilistic mission analyses, etc.

Additional background material relevant to current practice that bears on the practices recommended in this document appears in Annexes A, B, C, D, and E.

The recommended practices recognized by this study are summarized as follows:

- (1) Incorporate margins for robustness in both LV and SC designs.

- (2) Design simplification in both SC and LV, while minimizing processing times at the launch site or on the launch pad, increases reliability and reduces cost.
- (3) Begin the space launch integration process as early in the development of SC and LV systems as possible, at least to some degree in the pre-proposal phase. Jointly define roles and responsibilities of SC, LV, range, and all participating organizations as early as possible.
- (4) Select the launch system early in the design of the SC so that design changes downstream can be minimized. Design the SC so that it is compatible with more than one launch system.
- (5) Where possible, fly smaller SC to reduce the risk carried on each launch, allowing launch services to be purchased with minimal mission assurance requirements. Alternatively, spread the risk of a single large spacecraft by using smaller multiple spacecraft launched separately.
- (6) Simplify all types of interfaces between the SC and the LV.
- (7) Include only verifiable interface and performance requirements in the SC Interface Control Document or mission specification. Avoid including scope of work requirements that specify analyses, schedules, plans, contact data requirements list, etc.
- (8) Address all interfaces to the SC, not just those to the LV [Note: This document focuses primarily on the SC/LV interfaces].
- (9) SC design should accommodate off-pad encapsulation, minimizing SC processing at the launch site and minimizing requirements for specialized services and interfaces.
- (10) Conduct effectiveness evaluations of increasing (and decreasing) the levels of oversight and insight during design, manufacture, integration, and pre-launch/post-launch operations.
- (11) Establish manifesting procedures that enhance early conflict resolution.
- (12) Adopt a "data-centric" approach to program management. Consolidate program information into as few databases as possible. Make access to information painless and control information updates via a password system.
- (13) Adopt standardized requirements, physical interfaces, environmental interfaces, and processing procedures as detailed in this study.
- (14) Establish a "most-likely" list of common risk areas and create process assessment practices to minimize risk in each of them. This should be done as early as possible in the program, using a formal risk-management/risk-mitigation process.
- (15) Integrate the mission assurance team into the program throughout the life of the mission. Ensure continuity of personnel on the team, and set up links to ensure that all team members have access to all of the information.
- (16) Create one standard mission assurance process for commercial and government launches, applied consistently, with a common database and common mission assurance metrics.
- (17) Identify a standard set of mission assurance tools (e.g., for space situational awareness) for use in risk mitigation.
- (18) Identify a set of tools for tracking anomalies (and resolving them) through the life of the project, from acquisition and design through post-launch analysis.
- (19) Incentivize SC contractors and launch-service providers in meeting customer requirements, based on the criticality, development risks, etc. associated especially with nonrecurring missions.
- (20) For mature launch systems eliminate the requirement for a full-up Mission Dress Rehearsal.

- (21) Establish a testing practice based on acceptance at the factory door, with subsequent testing only to verify aliveness or “no change.”
- (22) Incorporate a “design-for-test” philosophy from the onset of development, along with factory test-as-you-fly practices.
- (23) Wherever practical employ test processes that combine tests to reduce cost and test time while making small compromises from traditional processes.
- (24) Establish a set of proven techniques for increased automation and remote monitoring in testing, analysis, and operations.
- (25) Adopt existing tools for 3-dimensional modeling to help streamline all phases of the integration process.
- (26) Set up methods to deal with “sunset technology,” i.e., support of software platforms and hardware components that are no longer being manufactured, outmoded standard test equipment, etc.
- (27) Use global positioning system (GPS) receivers or translators aboard LVs to simplify tracking during the launch phase, eliminating the need for tracking radars.
- (28) Establish a mechanism for coordination of rideshare payloads with LV service providers to demonstrate compatibility.
- (29) Develop a next-generation range capacity model that accurately determines launch-range capacity and thereby can establish where funds need to be invested to optimize and increase range capacity.

In summary, mission assurance for commercial SC typically relies on balancing risk, which may be revenue, cost and schedule. For missions with national security or science implications, the risk associated with the loss is entirely different and must be addressed appropriately. Additionally, each program should have a clear understanding of and an established method of “insight” and “oversight”, the mission implications, and a mechanism in place that accommodates implementation of either or both, as appropriate, to achieve the required level of risk mitigation.

The recommended practices developed by this study are based on evolution of current standard practice as described in ISO and other documents, which are referenced and also listed in a bibliography. Prospective areas for future “recommended practice” development will be addressed in follow-on studies as they mature.

Foreword

Spacecraft (SC) systems are developed to satisfy a wide range of specific missions including local and global commercial and government communications, Earth, solar system, and deep space scientific exploration, national defense, and research and experimental systems. SC systems require a launch service to place the SC into an intermediate or final operational earth orbit, or into an interplanetary or other trajectory. A significant effort is required to integrate a SC to a space launch system. This document summarizes the current practices for integration of a SC onto a space launch system and identifies the American Institute of Aeronautics and Astronautics recommended practices for integration.

Although the SC also interfaces with other elements during the launch integration process (e.g., ground systems), this document addresses only its integration with the launch vehicle (LV).

Four specific aspects of space launch integration are covered:

- Physical and Environmental Interfaces
- Pre- and Post- Launch Operations and Processes
- Interface Requirements Definition and Verification
- Mission Assurance and Risk Management

This document has been prepared under Contract NRO000-98-D-2118, Task 0777 in response to NRO Broad Agency Announcement OSL BAA #99-001, dated 31 March 1999, Research Interests 1.4, Standards and Best Practices. The contract specified the following tasks:

- (1) Define the processes/elements and methodologies of space launch integration and their relationship to each other and interdependencies. Develop a representative process flow and description for space launch integration, recognizing that space missions have several degrees of complexity
- (2) Identify areas/processes/elements which lend themselves to the application of standards and best practices based on identified best practices of commercial and government integration activities
- (3) Address how an organization would go about implementing the desired standards and best practices, the efforts needed to accomplish the actual development and application of standards, and how they may be leveraged across industry, including recommended methods for streamlining the launch integration process
- (4) Publish the results of this study as an AIAA product using the accredited consensus procedures, "Recommended Practice for Space Launch Integration"

This AIAA standard was prepared by the AIAA Space Launch Integration Committee on Standards and its four working groups.

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Acronyms

AF	Air Force
AFSCN	Air Force Satellite Control Network
AIB	Accident Investigation Board
ARAR	Accident and Risk Assessment Report
ASP	Area Surveillance Plan
ATE	Automated Test Equipment
ATP	Authorization to Proceed
CAD	Computer-Aided Drafting
CCAM	Collision and Contamination Avoidance Maneuver
CCTV	Closed-Caption Television
CDR	Critical Design Review
CLA	Coupled Loads Analysis
CoS	Committee on Standards
CoSSLI	Committee on Standards for Space Launch Integration
CPRR	Contractor President's Readiness Review
CRR	Contractor Readiness Review
CVCM	Collected Volatile Condensable Material
DCMA	Defense Contract Management Agency
DoD	Department of Defense
EAT	Engineering Analysis Team
EELV	Evolved Expendable Launch Vehicle
EGSE	Electrical Ground Support Equipment
EICD	Electrical Interface Control Document
ELS	Eastern Launch Site
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOC	Evidence of Completion
ERB	Engineering Review Board
FAA	Federal Aviation Administration
FPR	Flight Performance Reserve
FRR	Flight Readiness Review
GIDEP	Government–Industry Data Exchange Program
GOWG	Ground Operations Working Group
GPS	Global Positioning System
GSE	Ground Support Equipment
HAR	Hardware Acceptance Review
HLV	Heavy Launch Vehicle
I&T	Integration & Test
ICD	Interface Control Document
ICWG	Interface Control Working Group
IPT	Integrated Product Team
IRD	Interference Requirements Document

ISO	International Organization for Standardization
IST	Integrated System Test
ITA	Integrated Thermal Analysis
ITP	Integrated Test Procedure
IUS	Inertial Upper Stage
IV&V	Independent Validation & Verification
IVCR	Interface Verification Compliance Report
JMSP	Joint Master Surveillance Plan
LCD	Launch Constraints Document
LDA	Launch Decision Authority
LRR	Launch Readiness Review
LSA	Launch Services Agreement
LSI	Launch Systems Integrator
LSIC	Launch Systems Integration Contractor
LV	Launch Vehicle
LVC	Launch Vehicle Contractor
LVIC	Launch Vehicle Integration Contractor
MA	Mission Assurance
MAB	Mission Assurance Board
MAT	Mission Assurance Team
MGSE	Mechanical Ground Support Equipment
MICD	Mechanical Interface Control Document
MIM	Mission Integration Manager
MIT	Mission Integration Team
MIWG	Mission Integration Working Group
MLV	Medium Launch Vehicle
MOA	Memorandum of Agreement
MP	Mission Peculiar
MPDR	Mission Peculiar Design Review
MPG	Mission Planner's Guide
MRB	Materials Review Board
MRD	Mission Requirements Document
MRR	Mission Readiness Review
MSPSP	Missile System Pre-launch Safety Package
MWG	Management Working Group
N ₂ H ₄	Hydrazine
NASA	National Aeronautics and Space Administration
NRO	National Reconnaissance Office
OOS	Out of Sequence
OSA	Operational Support Agreement
OTS	Off the Shelf
PAF	Payload Attach Fitting
PAIP	Program Assurance Implementation Plan
PDR	Preliminary Design Review

PDSM	Product Delivery System Manual
PLA	Payload Adapter
PLF	Payload Fairing
PM	Program Manager
PMO	Program Management Office
PMR	Program Management Review
PPF	Payload Processing Facility
PPG	Payload Planners Guide
PRR	President's Readiness Review
RAMP	Risk Assessment and Management Plan
RCS	Reaction Control (Sub)System
RF	Radio Frequency
RFI	Radial Frequency Interface
RFP	Request for Proposal
RPO	Range Payload Operations
RR	Readiness Review
SAMP	Single Acquisition and Management Plan
SC	Spacecraft
SDR	System Design Review
SEIT	Systems Engineering and Integration Team
SIB	Safety Investigation Board
SIP	Standard Interface Plane
SOO	Statement of Objective
SOW	Statement of Work
SPO	System Program Office
SRCR	System Requirements Change Request
SRR	Systems Requirements Review
STARS	Space Launch Operations Telemetry Acquisition and Reporting
STIF	System Test and Integration Facility
SVC	Space Vehicle Contractor
T & E	Test & Evaluation
TIM	Technical Interchange Meeting
TML	Total Mass Loss
TRD	Test Requirements Document
TSPR	Total System Performance Responsibility
TWG	Technical Working Group
UPS	Uninterruptible Power Supply
USAF	U.S. Air Force
VTS	Verification Task Sheet

1 Introduction

1.1 General

Critical to establishing the required scope of space launch integration (SLI) for a spacecraft (SC) program is fully understanding the complexity and criticality of the specific SC system and performing a comprehensive assessment of the risks associated with launch. A considered approach should be one that includes:

- An understanding of the consequence of launch failure
- A process to identify and handle risk commensurate with the established risk tolerance

Essential elements of any launch integration effort are clearly defining the roles and responsibilities of the organizations involved and ensuring the contracts and supporting agreements are consistent and in place before beginning the integration effort.

A SC customer or launch service customer must determine the level of insight and/or oversight that will be applied to the space launch integration process. As part of the determination, the customer or sponsoring organization must weigh the value of applying oversight in his efforts to mitigate the risk of a launch failure.

Commercial SC objectives are primarily focused on establishment of a revenue stream when the SC achieves its operational orbit. Commercial SC are based largely on existing, evolving, commercially available SC buses, with payloads designed to achieve specific commercial program objectives. The time frame for the integration and launch of a commercial SC can vary from several months to several years, depending on the maturity of the SC and launch vehicle (LV) systems, and the complexity of the SC-to-launch system interfaces. The space launch integration community for these types of programs is typically comprised of the launch service provider, the SC manufacturer, the SC customer, the launch range operator, and sometimes a launch service integration contractor (LSIC). Commercial SC may be comparatively less expensive and able to be replaceable in the event of a launch or on-orbit failure.

National defense, scientific, and experimental SC, on the other hand, are typically designed to fulfill a specific mission, and generally comprise unique SC bus and payload configurations designed to achieve specific mission objectives of national interest. These SC are typically one-of-a-kind in nature, very expensive, and require a significant span time to replace in the event of a launch failure. Additionally, a launch failure may result in a lost opportunity to achieve a specific mission objective, as in the case of an interplanetary SC, or may result in a reduction in national defense capabilities, as in the case of a national defense SC. SC such as these typically involve complex, unique interface requirements relative to the LV system, and as a result, may require a space launch integration span time of several years. These SC systems typically trend toward increased levels of oversight into the launch integration process, involving numerous organizations. These organizations may include customers, SC contractors, launch system integration contractors, LV contractors, launch service program offices, independent validation and verification contractors, and LV and SC technical advisory contractors. The purpose of these contractor organizations is to mitigate risk and enhance mission success.

In summary, mission assurance for commercial SC typically relies on balancing risk, which may be revenue, with the cost of insurance. For missions with national security or science implications, the risk associated with loss of mission is entirely different and must be addressed appropriately. Additionally, each program should have a clear understanding of and an established method of “insight” and “oversight,” the cost and schedule implications of each, and a mechanism in place that accommodates implementation of either or both, as appropriate, to achieve the required level of risk mitigation.

There are various methods/approaches to accomplish space launch integration. The level of effort required for any launch integration process is dependent on many variables:

- Maturity of the systems involved
- Complexity of the interfaces
- Security implications
- Risk tolerance

Careful consideration should be given to each of these areas and a decision made as to the accommodation of each in the space launch integration process. As an additional consideration, there are various perspectives regarding the best method and approach to launch integration. The perspective will vary with the various organizations involved and their respective roles and responsibilities. Relevant background information on various aspects of the integration process is included herewith in Annexes A, B, C, D, and E.

1.1.1 Mission

The overarching consideration for any program is the SC mission objective. The achievement of this objective establishes the requirement(s) for the SC design and drives the launch integration process. Careful consideration must be given to each element involved in the program, factoring in the perspective of each element and developing a method to accommodate each, as appropriate, for the specific program.

1.1.2 Customer Perspective

The customer's goal during the integration and launch phase of a program is to deliver a functional payload with fully operational satellite bus to an orbit that meets mission objectives. The launch service is of secondary concern to the SC customer. It is natural for each organization, customer/payload designer, upper stage designer, launch service provider, and launch facility operator to consider its own area of interest as having the highest priority. However, the primary objective for all parties involved should be to deliver the SC to the correct orbit, within all environmental constraints, and to maximize the probability that mission objectives will be achieved.

1.1.3 SC Perspective

From the SC perspective, launch is the single most traumatic event in the life of the program. The launch environment generally presents the most severe conditions that the SC will experience. These conditions drive many aspects of the SC design, especially the SC structural design. Launch constraints often present design challenges, which require complicated design solutions to fit within a confined payload fairing (PLF) envelope and provide for post-launch operations. Low-mass design techniques and mass conservation measures may be required to stay within LV performance capabilities.

Recommended Practice: Because of these technical challenges, it is in the best interest of the SC contractor to have early and reliable definition of LV interfaces and available SC accommodations as well as performance capability to the desired orbit.

Recommended Practice: Changing launch requirements will affect SC program costs and schedule, especially when they occur late in the cycle. Hence it is advisable during the early design SC process to make sure it is compatible with more than one type or class of LVs to preclude excessive delays due to the stand-down of one. A spacecraft design that is compatible with several LVs can also be used on different mission applications, which can be very beneficial with regards to both cost and schedule savings.

1.1.4 Launch Systems Integrator Perspective

For security or other specific purposes as described in Section 1, certain programs require the involvement of a launch systems integration contractor (LSIC) to represent the SC contractor in the launch integration process. In these programs, the LSIC becomes the designated interface between the

SC and launch service communities. The LSIC represents the SC side of the SC-to-LV interface and is accountable to its customer to define all interface requirements and certify that they are properly verified. This responsibility includes coordinating the development of integration schedules and plans, specifying SC requirements, performing interface verification, and coordinating integration activities with all participating contractors. Because a separate LSIC does add significant overhead and cost to a program, it should be used only after careful consideration.

If employed, the LSIC is responsible for mission success of the SC-to-LV interface for all phases from pre-launch through orbital insertion and SC separation. The LSIC may co-chair the technical working groups with the launch service provider for the purpose of developing the SC-to-LV interface and certifying completion of the verification tasks for the SC-to-LV interface requirements.

1.1.5 Launch Service Provider Perspective

The launch service provider is responsible for the launch system design, production, and delivery, ensuring that the launch system capabilities accommodate the agreed-upon SC/LV interface requirements. The launch service provider is responsible for the integration and checkout of the launch system components, launch operations, and LV ascent through orbit insertion and subsequent disposal, or return, activities. The launch service provider, in conjunction with the SC contractor and customer, and other launch integration participants as necessary, implements and verifies the SC-to-LV interface requirements.

For missions that use a LSIC, the launch service provider fulfills the role of the launch vehicle integration contractor (LVIC), representing the launch system side of the interface, with the responsibility of certifying that the launch system will successfully place the SC in its desired mission orbit. The LVIC co-chairs the technical working groups with the LSIC for the SC-to-LV interface and conducts the verification tasks for the LV side of the interface. Specifically, the LVIC publishes and maintains the SC-to-LV interface control document (ICD) and plans and conducts verification of launch system side of the SC-to-LV interface requirements. In addition, the LVIC maintains the ICD verification database and closure library, archives all the evidence used for verification closure, and in the absence of a LSIC represents the final approval authority on all verification closures for the ICD.

1.2 Space Launch Integration Process

The success or failure of a mission may be related to the launch integration or it may be attributable to some other aspect of the launch operation. A rigorous, comprehensive launch integration process will not guarantee a successful mission but it will reduce the risk that a SC-to-LV interface anomaly will cause a mission failure. The key is to develop a process that will reduce risks inherent in the launch integration process to an acceptable level. Identifying all the risks and establishing the acceptable level for each risk is much easier said than done. It is especially difficult for complex interfaces and where multiple systems are involved. Another consideration is that, for some missions, cost and schedule considerations are secondary to the need for reducing the risk of failure to the absolute minimum.

Recommended Practice: It is therefore critical that a comprehensive and clearly defined process be established as early as possible, using a formal risk-management/risk-mitigation process, as discussed in the Mission Assurance/Risk Management section of this document. Once the risks are understood, at least at the program level, a determination can be made as to the level of launch integration required to address these risks.

The launch integration process must address other interfaces to the SC; e.g., with transportation systems, processing facilities, launch site facilities, and flight operations centers. The process must incorporate required safety policies and practices into all aspects of the integration process. The responsibility for covering each of these areas can be assigned to one contractor or divided among multiple contractors, depending on the customer requirements, complexity of the interfaces, and contractor agreements.

Recommended Practice: A comprehensive launch integration process begins with assessing the compatibility of SC system interface requirements relative to launch system capabilities and focusing on interface issue resolution to minimize overall cost to the customer, while emphasizing risk mitigation in interface design to enhance mission success. The process culminates with the successful delivery of an operational SC to the desired orbit.

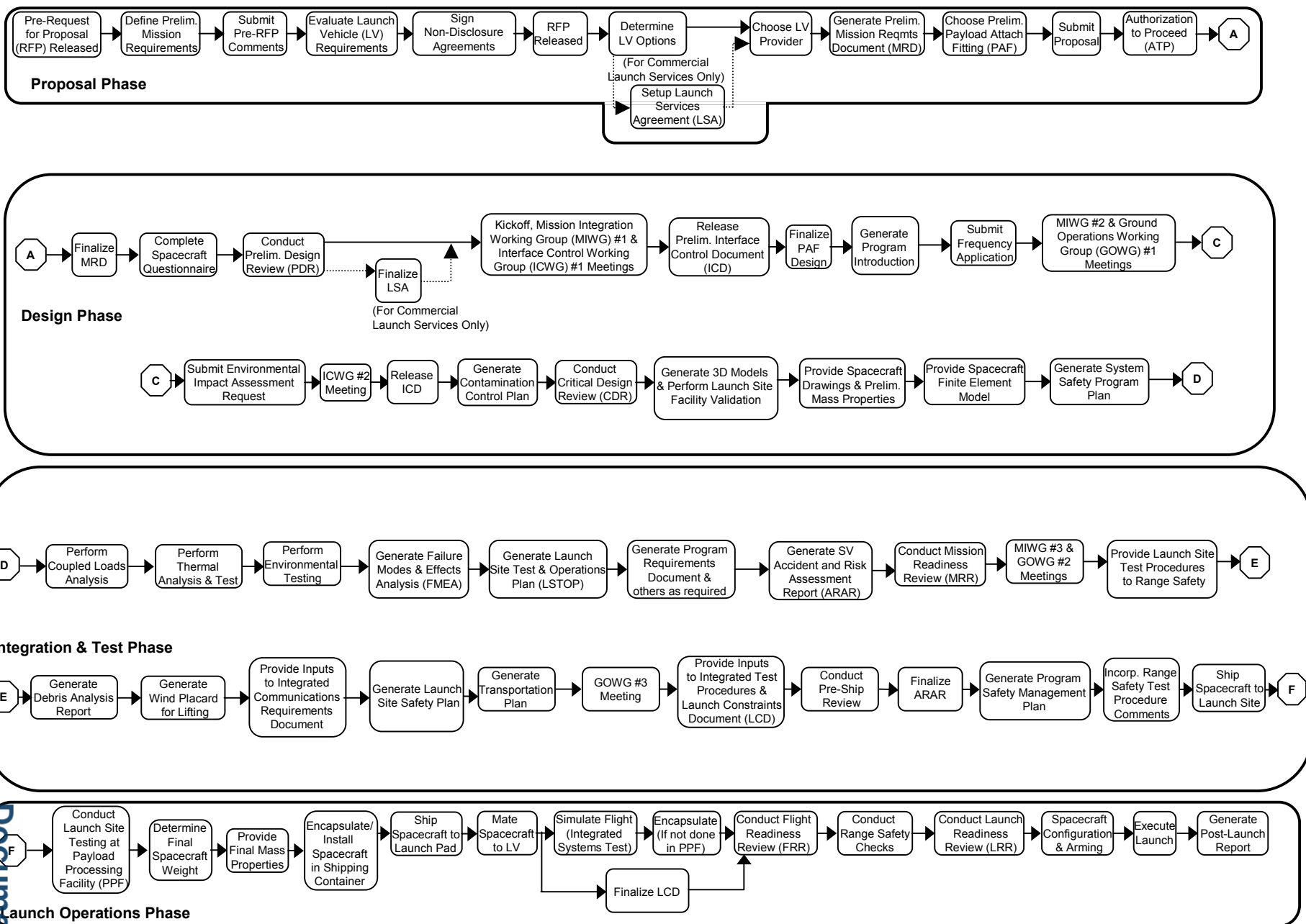
For highly complex missions, the launch integration organizational structure may include various agencies representing the SC contractor, LV contractor, payload contractor(s), and launch site. In addition, vehicle and support contractors as well as consultants may be involved. This participation will vary depending on the “oversight” and “insight” required by the sponsoring organization. For some programs, the customer may want one contractor to provide the total mission service where delivery of an operational SC to the specified orbit is the contractual requirement. Other customers may require a SC contractor, a LV contractor, and a LSIC.

Figure 1 illustrates the basic launch integration process involving a LSIC. This process begins with technical and operational interface requirements that typically flow from the spacecraft vehicle contractor (SVC), through the LSIC (if one is being used), then to the LVIC. Return flow consists of capability assessments, which include updated design information. These assessments go back through the LSIC to the SVC, thus completing a single iteration of the integration process that will eventually lead to the definition of a compatible interface. Formal documentation and control of the agreed interfaces is established in an ICD, as described in Section 5, Requirements and Verification. This process forms an active loop supported by trade studies, analyses, and impact assessments performed, as required, by the various contractors. This loop is closed only when a compatible interface is achieved.

Figure 1 – Basic Launch Integration Process

5

Integration Process: Spacecraft Mission Integration Flow



1.2.1 Space Launch Integration Products and Services

The space launch integration process is executed through the development and provision of specific products and services. The scope and content of the products developed depend on the complexity of the SC-to-LV interfaces. The services provided depend on customer requirements. The following illustrates typical examples of products and services associated with space launch integration.

Products

- Plans
- Schedules
- Interface requirements documentation
- SC-to-LV interface hardware
- Test procedures
- Technical reports
- Range support documentation
- Range safety documentation
- FAA launch license (where required)

Services

- Conduct and support management reviews
- Chair and support technical working groups
- Conduct selected technical analyses
- Define and verify interface requirements
- Support launch and flight operations
- Provide project security guidance and monitoring
- Set up and staff operations information center during launch operations

1.2.2 Initiating the Space Launch Integration Process

The space launch integration process may be seen as a series of major overlapping functions performed over several phases within the launch integration cycle. Each phase may vary in length, depending on the maturity of the SC and launch systems. A typical integration cycle is illustrated in Figure 2.

Recommended Practice: It is important to begin the space launch integration process as early in the development of a SC system as possible. SC/LV integration should start to at least some degree in the pre-proposal phase. For the SC contractor, the most important LV considerations are lift capability, available volume, volume form factor, ascent environment, launch system integration and ground operations effectiveness and efficiency, reliability, availability, and cost.

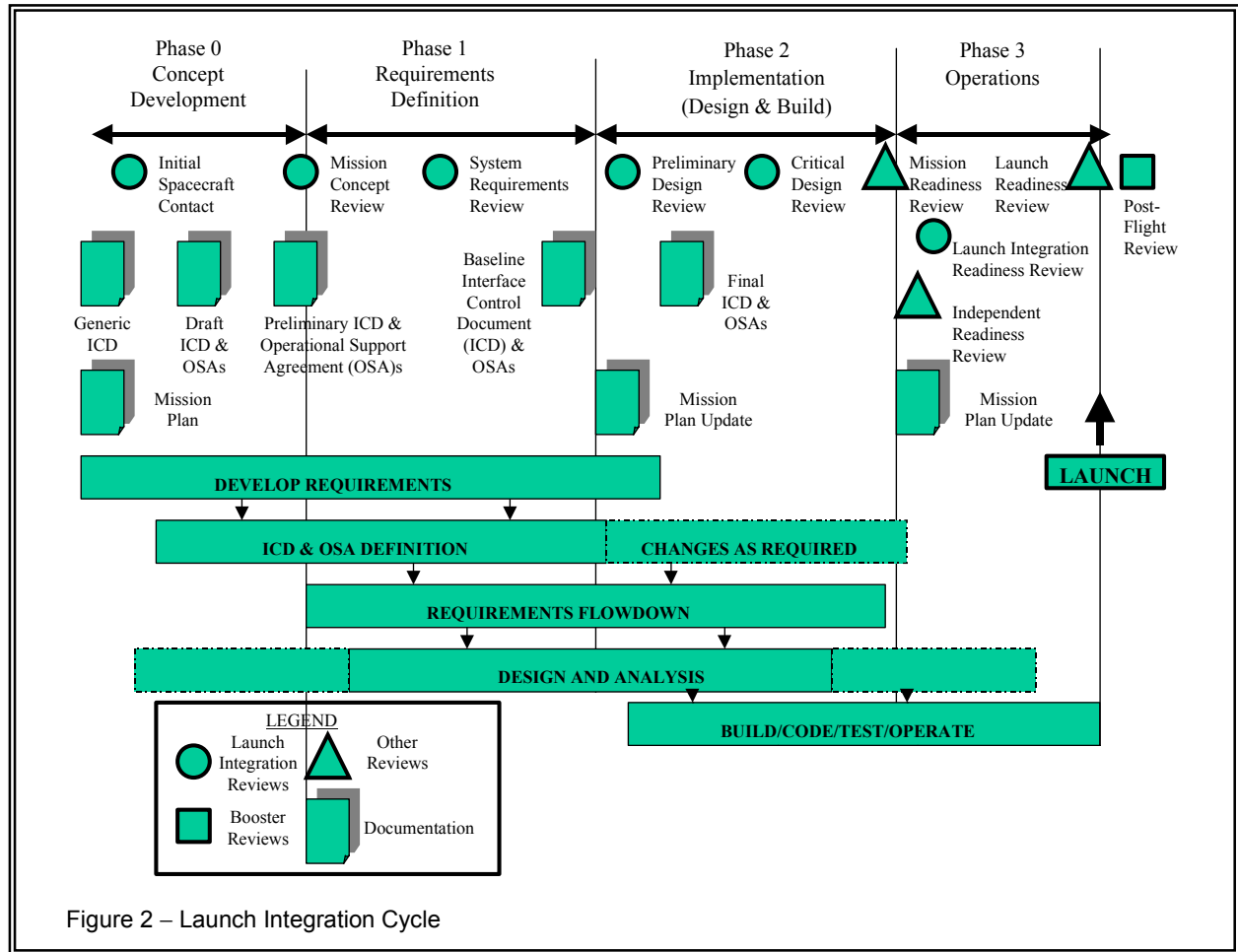


Figure 2 – Launch Integration Cycle

1.2.2.1 LV Selection

To determine the best candidate LV for a mission, all of these issues must be evaluated through the following five-step process.

- (1) Assemble mission requirements and constraints. Some of the elements involved in this analysis include the number of SC per launch, dry weight, overall SC dimensions, mission orbit, timeline, and cost.
- (2) Evaluate and identify acceptable launch systems. This process requires the consideration of the entire SC system weight, which includes the weight of the SC propellant, the weight of the SC adapter and other launch system mission specific hardware requirements. The launch performance capability and associated margins, reliability, availability, launch inclination capability from specified launch sites, and cost are also aspects to be considered.
- (3) Select multiple launch systems for consideration in the design of the SC.
- (4) Determine the SC design envelope and the environmental conditions predicated in the launch system selected. The information considered includes the fairing size and geometry, maximum accelerations and acoustic frequencies and magnitudes, temperature profiles, cleanliness, insertion accuracy, and integration processes.
- (5) Use an iterative approach to navigate through these steps so that all constraints, performance criteria, schedule requirements, and cost issues are satisfied.

Recommended Practice: Select the launch system early in the design of the SC so that design changes downstream can be minimized. It is also prudent to design the SC so that it is compatible with more than one launch system. This allows for greater scheduling and negotiation flexibility. LV contractors are beginning to design launch systems that offer similar capabilities to enhance their ability to attract missions manifested on competing launch systems.

1.2.2.2 SC-to-LV Interface Considerations

If starting at the pre-proposal phase is not an option, start as early as possible to allow for a sufficient amount of time to be allocated to the following activities:

- Resolution of interface issues in an optimal manner, minimizing cost, schedule, and design risks.
- Development of ground processing flows that ensure availability of required facilities, mechanical ground support equipment (MGSE), electrical ground support equipment (EGSE), transportation, and procedures that are compatible with range safety and launch licensing requirements.
- Development of a comprehensive interface verification plan and process.

The evolving SC design must be balanced between maximizing the mission objectives and not exceeding the capabilities of the launch system. Table 1 summarizes typical SC design features that may affect launch system capabilities.

Table 1– SC Design Feature Potential Effects on Launch Systems

Spacecraft Design	Launch System
SC weight	LV performance and handling equipment
SC launch configuration	PLF length, attachment points, and control/stability
Multiple, complicated mechanisms	Multiple loads cycle with possible SC and/or LV modifications
Sensitive components	Contamination, handling, and radio frequency (RF) control
Transport from factory	Special shipping or handling container
Launch processing	Facilities, interfaces, EGSE, MGSE, transportation, etc.
Launch/flight operations and telemetry	Telemetry interface, control facilities, communications, procedures, and training

If the SC mission requirements drive the design to exceed the launch system capabilities, launch system modifications may be required to achieve a compatible SC-to-LV interface. Examples of possible modifications required by such a scenario are listed below. Significant modification of the LV to accommodate SC design increases program risk, cost, and schedule.

Reduce upper stage weight to achieve necessary performance

- Redesign structural elements
- Remove redundant avionics
- Hand pick high-performance components

Modify avionics to achieve the following effects

- Desired reliability
- Required telemetry

Redesign flight or ground hardware to accommodate necessary operations

- Add additional fairing access panels
- Develop special SC cooling ducts
- Modify fairing access panels
- Modify fairing handling MGSE

Enhance LV performance

- Tuning the LV propulsion system
- Use of higher performance nozzles
- Addition of solid rocket motors

1.3 Summary of Recommended Practices

- Establish the scope of space launch integration based on a thorough understanding of the complexity and criticality of the specific program
- Define roles and responsibilities of all participating organizations as early as possible
- Start SC to LV interface considerations at the proposal phase
- Select a primary and backup launch system early in the design of SC and design to more than 1 launch system
- Define the level of insight and/or oversight to be exercised in the integration process, understand the implications of each to the process, and develop contracts and supporting agreements that accommodate each, as appropriate
- Develop a process to identify and handle risks commensurate with mission objectives
- Assess mission risk against maturity and complexity of the systems involved
- A rigorous launch integration process will not guarantee a successful mission but it will reduce risk. It is therefore critical that a process be established as early as possible, using a formal risk management/risk mitigation process.

Basic to any launch integration process is that it must address all interfaces to the SC, not just those to the LV [NOTE: This document addresses only the SC/LV interfaces].

2 Physical Interfaces

Recommended Practice: Margins should generally be added to interface requirements. Margins may be added for items such as battery voltages, current, RF environment, thermal environment, weight, and vibration levels. The mass may include the LV adapter attached to the satellite for the final lift onto the LV. Because of possible last-minute changes of LV configuration, worst cases have to be incorporated at the structure design phase. Margins should be managed at the system level. Margins should not be added by each organization so that the sum results in an excessive margin. It is possible to get to a point where the booster cannot meet the requirements for the SC or vice versa, solely because of redundantly held or excessive margins.

2.1 Mechanical Interfaces

2.1.1 Structural Attach Points

Existing designs reflect legacy configurations, which may not provide the most efficient support for the satellite, but have been carried forward for convenience.

Recommended Practice: Existing attachment and separation systems are the most practical solution for existing LV interfaces in all applications, commercial or non-commercial. New LV interface designs should utilize the largest range of dimensions (bolt hole circles) to distribute satellite loads across the interface. "Wide track" attachment schemes help maintain high first-mode natural bending frequency values for satellite designs, and foster efficient satellite structural design. A systems approach would consider nestling (or otherwise developing loadpaths) of critical structural components (fuel tanks, optical benches) between (inside) the bolt circle.

2.1.2 Consumables Loading Points

Recommended Practice: It is critical that consumable loading (unloading) points be located such that direct access through existing fairing access panels is possible by personnel in SCAPE suits, and with a minimum of platforms above the "floor" level.

Recommended Practice: Consumables fittings should include devices that allow visual confirmation of "closed and locked." Quick disconnects or other designs which minimize the use of tools, and accept flight plugs, are also highly recommended.

Recommended Practice: Although infrequently needed, proper design of the consumable loading point to facilitate unloading in case of a satellite/launch vehicle problem should be given high priority early to minimize integration issues at the launch site. Loading may be performed prior to installation of the fairing, but it is a significant benefit to the satellite, LV and range processes if emergency defueling/unloading (if necessary) can be accomplished quickly and simply without fairing removal. In some instances, unloading consumables in the satellite may be the only reason to remove the fairing, and if this can be avoided by proper engineering of the loading point, corrective maintenance on the LV can be accomplished with greatly reduced on-pad time. This is especially true for LVs which employ only liquid propellants.

2.1.3 Thermal Control Connections

Remove-before-flight thermal control connections may carry conditioned air, conditioned inert gas, or represent a segment of a heat exchanger such as a "cold foot."

Recommended Practice: If these thermal connections are necessary after the fairing is installed, the connection should be designed for full access through an existing fairing door such that bending, stooping or climbing part-way into the fairing access is not necessary for mate/de-mate of the connection. Proper design will permit the use of a non-flight door during the conditioning process, which is replaced simply and quickly with a flight door during final preparations.

Recommended Practice: The location of connectors should consider placement or internal ducting which injects the conditioned medium at the upper section of the fairing, and exhausts at the bottom. Proper interface design will coordinate the conditioned air requirements with the LV upper-stage electronics requirements. Connectors which carry inert media for conditioning should be self-sealing or easily capped at the connection. Cold plates or other physical connections should also be designed with easy access in mind. All of these connections may require mate/demate with the operator in SCAPE suits due to a problem, so all should be “blind mate” and operable with gloves, etc.

2.1.4 Lifting Points and Set-Down Hard Points

Recommended Practice: The lift attach points on the SC should be designed for the particular SC maximum propellant load, plus some margin. The lift attach points should be tested for these higher loads. This step will allow the SC to be assigned to another LV that allows additional propellant to extend its on-orbit life without additional testing.

Recommended Practice: Satellite design should consider the requirement for three sets of handling points. Normally, the LV attach points are used for transportation to the launch site, and a set of transfer points are provided to lift the satellite from one mounting installation (transport container, handling dolly or LV) to another state. Many times this transfer also requires rotation of the satellite from horizontal to vertical, especially for loading consumables. A third set of points provides the capability to move the satellite under anomalous conditions and emergencies.

Recommended Practice: All lift/load points should be accessible without compromising satellite cleanliness; that is, should not require the removal of protective bags or covers. Lifting fixtures should also be compatible with the cleanliness requirements, and not restrict access to consumable loading connections, environmental connections, umbilicals, etc.

2.1.5 Protective Covers

Recommended Practice: The requirement for the use of protective covers is one of the many areas that needs to be taken into account from the beginning when a spacecraft is designed. Protective covers should be designed for removal/installation with the satellite supported by any of the hard points; that is, it should not be necessary to remove lifting fixtures or reposition the satellite to different load points to access the protective covers. The design of final remove-before-flight covers on optics or other items should be designed so that the covers can be removed or installed with the payload fairing in place. Bump covers should be employed with “tell-tales” or other passive instrumentation which will indicate if the satellite has received excessive shock from a bump although the protective cover shows no damage.

Recommended Practice: The following should also be considered in designing protective covers:

- (1) Access requirements for the removal of protective covers for normal operations during transport, on the launch pad, and within the payload fairing.
- (2) Contingency requirements for the installation of covers in case of problems during operations.
- (3) Allowance for personnel dressed in full coverall cleanroom garments
- (4) Appropriate marking of all protective covers and other devices to be removed before flight, as described in ISO 21347. Protective covers and other items removed before flight should undergo bilateral checks and be stored in a controlled container until successful transfer orbit operations are complete. Note, however, that during a spacecraft build cycle there are numerous items that get removed during the course of manufacturing that are not the classic “remove before flight” items described in the ISO document.

2.1.6 Separation and Deployment Sensors and Controls

Recommended Practice: Separation and deployment sensors should be designed for passive verification during the mating (engagement) process. The verification of state should be easily confirmed

without powering the LV or satellite, and should not require the disconnection of any flight connectors in order to determine their state. Passive sensors sometimes employ multiple sets of contacts such that ground verification of the flight switch (or loop-back connection) is possible with a digital meter or EGSE without disturbing the flight circuits, using a separate test connector. Avoid use of non-explosive initiators (wax type) in deployment mechanisms that require the use of continuous power after installation.

2.1.7 Transporters

Recommended Practice: Interface requirements for transporters should include the usable internal volume dimensions for both static and dynamic conditions. The dynamic volume dimensions represent the maximum usable volume within the transporter. The fairing envelope generally defines the usable volume within the transport container and hence its dimensions. Therefore if the SC fits in the container, it should fit in the fairing, unless items are added while the SC is on the launch pad.

Recommended Practice: Maximum exterior dimensions and weight of the transporter should be specified and should not exceed the maximum allowable dimensions or weight limits for the carrier vehicles (aircraft, railroad car, truck, etc.) and facility access doors.

Recommended Practice: Container environmental requirements should be specified. This includes loads, dynamics, thermal (air and wall temperatures), air and container cleanliness (particulate and molecular), and any special purge gas requirements.

2.1.8 Payload Fairing (PLF)

Recommended Practice: The usable interior volume dimensions of the PLF during launch (dynamic envelope) should be specified. This usable volume is the dynamic volume considering deflections during launch, internal insulation blankets, brackets, and other fittings.

Recommended Practice: The usable interior volume dimensions of the PLF before launch are the static envelope. The SC and SC operations during launch should stay within the dynamic envelope. Exceptions may be made if analyses and tests verify that the intrusion does not affect flight operations. Access and clearance requirements for pre-launch operations within the PLF should be considered. Personnel may be wearing full coverall clean-room garments and using tools for these activities.

2.1.9 Natural Frequencies

The satellite with too high a first bending mode has yet to be built, and there is no such thing as too much stiffness. The natural frequency of a loaded column decreases as the load increases, which will lower the first mode of marginal satellites to a critical value. Proper arrangement of major satellite masses and essential structure can result in a satellite with a sufficient first mode and good on-orbit characteristics. Since mass is the most expensive commodity in the aerospace domain, consideration of the launch configuration and first mode can conserve critical structural components later in the development process.

2.1.10 Payload Launch Adapter Interface Specifications

Having the SC manufacturer provide the payload adapter and separation system may increase complexity, require additional analysis on the LV side, and preclude the ability to ensure adherence to shock and vibration levels. The LV provider is typically more experienced with procuring or designing these systems than SC manufacturers.

However, some LV practices (e.g., the Evolved Expendable Launch Vehicle [EELV]) require that the SC manufacturer supply the payload adapter. The payload adapter interfaces with the LV at the standard interface plane (SIP). In this case the LV provider must supply a standard bolt circle at the SIP for payload adapter attachment as defined in the EELV Standard Interface Specification. The rationale for this is that defining a common interface at the SIP affords greater SC manufacturer flexibility in LV provider selection and SC configuration definition.

Recommended Practice: The SC should be designed to use standard payload adapter and separation systems. These are defined in LV user manuals. These adapters are frequently in the hardware pipeline and readily available. The use of new designs may result in launch delays and additional cost for redesign and re-qualification. Using existing designs also allows flexibility to move between launch service providers if the prime vehicle is down for some reason.

Recommended Practice: The payload LV and SC designers should establish an interface control document (ICD) for the payload adapter early in the mission development process that clearly defines roles and responsibilities for the organizations involved with developing this interface. LV providers and SC designers should work closely to define realistic launch load profiles starting from the measured dynamic response from previous flights and estimated dynamics of the new SC. Greater insight into coupled loads analysis also should be afforded SC designers so that they can make better SC design decisions based on accurate launch environment information. High frequency vibration (structure-borne vibrations emanating from the payload attach fitting–payload fairing connection) should also be specified at the payload interface. This information will allow the SC designer to make informed decisions about where vibration-sensitive hardware should be located in proximity to the interface.

2.1.11 Umbilical Connections

Recommended Practice: The use of standard interfaces, connectors, and other hardware is recommended to reduce cost and risk. Designs should be as simple as possible. Greater complexity in services/functions provided by the LV will increase schedule and cost of the integration process. Spare pins and functions should be available for “dry loop” commands, separation detection, etc. as standard.

2.1.12 Separation Devices

Recommended Practice: There should be sufficient clearance for mechanical devices to prevent interference with other elements of the system. Bolt or band release systems can be used. Explosive devices and actuators should not release particles and gases that would compromise the cleanliness of the SC. Low-shock separation systems are an option (these are currently coming to market, and can help reduce SC qualification requirements/costs). The separation electronics can be provided aboard either the SC or the LV.

2.2 Electrical Interfaces

2.2.1 Umbilical Links and Connectors

The electrical interface between the SC and the LV typically includes the umbilical pass throughs for connection of SC to ground support equipment, loop throughs back to the SC and back to LV to provide confirmation of separation.

Recommended Practice: If the SC provides the electronics for the separation event, there should be a signal, (or relay closure) passed across the interface in order to signal the SC that the separation event can occur. The SC should never use a timer to trigger the separation event due to variances that can take place in the LV event timing.

Recommended Practice: The LV should provide the separation electronics. The LV typically has more experience with separation electronics and the electrical interface will be less complex, even when the SC provides the separation system.

2.2.2 Electrical Commands

Recommended Practice: Countdown procedures should state the SC command configuration that is active before launch. Although the command configuration is at the option of the SC designer, it is recommended that the command configuration be active through both the baseband and RF systems. A SC command channel should be active during launch. If there is a problem with the automatic sequencing of deployments and burns, it is possible to recover with commands from the ground.

2.2.3 Ground and Inflight Telemetry

Recommended Practice: Countdown procedures should state the SC telemetry configuration that should be active before launch, and a SC telemetry channel should be available. A SC telemetry channel should be active at separation from the LV. As a backup, the SC should have the capability for the transmitters to be turned on from ground commanding. If there is a problem with the automatic sequencing of deployments and burns, it is possible to recover with commands from the ground.

Recommended Practice: Go/no-go criteria should be agreed on by all parties and published. This can be a sensitive insurance/ownership/penalties area when there are delays or failures.

2.2.4 Power Supply

The typical spacecraft requirement levied on the LV service provider is for uninterruptible power. It may not be operationally feasible to guarantee this. There is always some slight interruption while the system switches to the backup/UPS power system.

Recommended Practice: The spacecraft, facilities, and GSE should be designed to survive this type of interruption without catastrophic result. Power from the local or regional supplier constitutes a single point failure mode and should be considered in design and operational plans. This is applicable to both processing and pad operations.

2.3 RF-Electromagnetic Interfaces

Subjects that were considered in preparing this document but have not been addressed herein include telemetry and command, and field compatibility.

2.4 Servicing Interfaces

Subjects that were considered in preparing this document but have not been addressed herein include ordnance installation, arming, and safing, test and checkout points, facility interfaces (cranes, platforms, elevators, cleanrooms, etc.), and transportation

2.4.1 Access and Inspection Doors and Viewpoints

Recommended Practice: Although typical SC missions do not require allowing room in the fairing for access, if such access *is* required for a specific mission or class of missions, spacecraft design should consider the available payload fairing dimensions and volume to allow access of suited personnel for contingency operations. Such operations typically require personnel to wear full coverall clean-room garments. If the spacecraft fills all available space within the fairing, then access is limited. If the spacecraft has a problem and entry is required, activities such as propellant offload and box removal and replacement may not be possible. It is necessary to consider locations of access doors and the usable volume of the payload fairing in the flight configuration with any internal hardware installed, such as insulation blankets and brackets.

Recommended Practice: SC design should consider ability to remotely operate the SC during long periods of unattended, stand-by condition. There may be long periods between last SC access and launch. This time may be up to 24 hours.

Recommended Practice: The SC design should be compatible with either vertical or horizontal processing and fueling. A problem may occur if the SC is designed for only horizontal processing. There may be a need for propellant offload while on stand in a vertical configuration. Always consider designing the SC for the ability to offload propellants in the encapsulated/vertical configuration.

Consider allowing for fairing removal on the pad. Vertical vs horizontal processing can become a complex problem, too long to discuss here.

2.4.2 Fluid Interfaces (Propellants, Cryogenics, Gas Purges, Coolants)

The cleanliness of fluid systems can be specified using ISO 14952:2002. ISO 14952:2002 has six parts. 14952-1:2002 contains the definitions. 14952-2:2002 defines standard cleanliness levels for fluid systems. 14952-3:2002 describes the analytical procedures and test methods used for the determination of nonvolatile residues and particulate contamination of fluid systems. 14952-4, -5, and -6:2002 describe rough cleaning, drying, and precision cleaning processes.

Recommended Practice: Verify the cleanliness of air conditioning ducts, tubing, and hoses before connecting them to the payload.

2.5 Fluid Requirements

Recommended Practice: Fluids should be specified using standard specifications for composition. ISO 14951:1999 has 13 parts specifying the composition of fluids, gases and liquids. ISO 15859:2002 has 13 parts describing the sampling and test methods to be used as well as the compositions of the fluids. Compositions and purities not included in the specifications may be obtained from specialty providers or by the use of additional filtering at the point of use.

Recommended Practice: SC/LV design should allow using the least stringent specification for fluids. The issue is availability. If the planned source is contaminated, alternative sources may be available, but they may not meet the desired specification for the content of water and other contaminants. These contingencies should be considered in the design and operational plans.

Recommended Practice: Because fluids are susceptible to contamination during handling and transport, composition and purity may, at the option of the integration contractor, be verified at the point of use. Possible contaminants include water, particles, oil, and grease.

Recommended Practice: SC/LV design should allow using the least stringent specification for propellants. The issue is availability. If a source is contaminated, alternative foreign sources may be available, but they currently do not meet the standard U.S. specification for water/contaminate content.

The following ISO standards are new, and existing documentation may reference current U.S. national standards. Some existing standards are included, following the ISO references, for information.

2.5.1 Oxygen

ISO 14951-1:1999 and 15859-1:2002 specify gaseous and liquid oxygen grades used for purging, pressurization, crew breathing, fuel cells, and propulsion. Mil-Prf-25508F and Mil-Prf-27110G are still active for use in documents.

2.5.2 Hydrogen

ISO 14951-2:1999 and 15859-2:2002 specify gaseous and liquid hydrogen grades used as fuels. Mil-Prf-27201C is still active for use in documents.

2.5.3 Nitrogen

ISO 14951-3:1999 and 15859-3:2002 specify gaseous and liquid nitrogen used for purging, pressurization, cooling, and crew breathing. Mil-Prf-27401D is still active for use in documents.

2.5.4 Helium

ISO 14951-4:1999 and 15859-4:2002 specify gaseous and liquid helium used for purging and cooling. Mil-Prf-27407B is still active for use in documents.

2.5.5 Nitrogen Tetroxide

ISO 14951-5:1999 and 15859-4:2002 specify five grades of nitrogen tetroxide (NTO or N_2O_4) used as propellants. Mil-Prf-26539E is still active for use in documents.

2.5.6 Monomethylhydrazine

ISO 14951-6:1999 and 15859-6:2002 specify two grades of monomethylhydrazine (MMH) used as propellants. Mil-Prf-27404 is still active for use in documents.

2.5.7 Hydrazine

ISO 14951-7:1999 and 15859-7:2002 specify three grades of hydrazine used as propellants. Mil-Prf-26536E is still active for use in documents.

2.5.8 Unsymmetrical Dimethyl Hydrazine (UDMH)

Mil-Prf-25604E is still active for use in documents.

2.5.9 Aerozine 50-50

Mil-Prf-27402C is still active for use in documents.

2.5.10 Kerosene

ISO 14951-8:1999 and 15859-8:2002 specify kerosene used as a propellant. Mil-P-25576C is still active for use in documents.

2.5.11 Argon

ISO 14951-9:1999 and 15859-9:2002 specify gaseous and liquid argon used for purging and cooling. Mil-Prf-27415A is still active for use in documents.

2.5.12 Water

ISO 14951-10:1999 and 15859-10:2002 specify two grades of water, high purity and potable (drinking).

2.5.13 Ammonia

ISO 14951-11:1999 and 15859-11:2002 specify ammonia used as a coolant. Fed-Spec-O-A-445B is still active for use in documents.

2.5.14 Breathing Air

ISO 14951-13:1999 and 15859-13:2002 specify breathing air from compressed and liquid sources.

2.6 Interface Catalog

Subjects that were considered in preparing this document but have not been addressed herein include variations from catalog specifications, compatibility of space vehicle with multiple LVs, and compatibility of LV with multiple space vehicles

2.7 Pathfinder

The Pathfinder was considered in preparing this document but has not been addressed.

2.8 Upper Stages

Upper stages were considered in preparing this document but have not been addressed.

3 Environmental Interfaces (Ground and Flight)

Although this document covers only the SC interfaces with the LV, the launch integration process must also address other environmental interfaces to the SC; e.g., with transportation systems, processing facilities, launch site facilities, and flight operations centers.

3.1 Mechanical/Physical Environment

Recommended Practice: General commercial practice is that backup LV dynamics personnel work with the SC manufacturer to ensure that the SC bus testing levels accommodate backup LV levels even if the SC is not able to fly on the primary LV. This practice is recommended because it ensures that if the prime LV is not available, it is possible to accommodate the SC without requiring re-testing. This allows for more customer flexibility and schedule assurance.

3.1.1 Pressures

Static pressure time histories should be defined per ISO 14303:2001, section 8.3. In addition, pressure decay rate time histories provide useful data.

3.1.2 Ground and Flight Loads (Including Wind Loading and Acceleration)

Recommended Practice: Quasi-static flight limit load factors should be defined per ISO 14303:2001, section 8.1.1, for preliminary spacecraft design. Additional useful information can be provided by breaking out the load factors into steady state and oscillatory dynamic components. The spacecraft first lateral and axial mode frequencies for which the load factors are applicable should be defined. Higher fidelity loads for final design should be defined through Coupled Loads Analyses (CLA) performed by integrating launch vehicle and spacecraft dynamic models.

3.1.3 Shock

Recommended Practice: Shock should be defined per ISO 14303:2001, section 8.1.7. A transmissibility (Q) of 10 should be used in all shock spectra calculations for consistency.

3.1.4 Vibration

Recommended Practice: Sinusoidal vibration at the spacecraft interface should be defined per ISO 14303:2001, sections 8.1.2 and 8.1.3. The transient response environment at a spacecraft to launch vehicle interface is characterized by the combination of coupled dynamic response analysis (CLA) and equivalent sinusoidal vibration. Consequently, notching of the sinusoidal vibration in the 0 to 50 Hz range may be allowed to reduce component responses below design levels, while demonstrating margin over CLA values. Notching of the sinusoidal vibration input in the 50-100 Hz range should not be done without technical discussion with the launch vehicle contractor.

Random vibration at the spacecraft interface may be defined per ISO 14303:2001, section 8.1.5. However, the random vibration that a spacecraft experiences is primarily due to the acoustic noise field, with a very small portion being mechanically transmitted from the engines. The acoustically excited random vibration environment tends to be the design driver for components and small structure supports. The high frequency vibration level will vary from one location to another depending on physical properties of each area of the spacecraft. Because the vibration level at the payload interface depends on the adjacent structure above and below the interface, the exact interface level depends on the structural characteristics of the lower portion of the spacecraft, the particular payload adapter, and how the acoustic field is influenced by the particular spacecraft.

An acoustic test of the spacecraft will more accurately simulate the high-frequency environment that it will undergo in flight than will a random vibration test. If the spacecraft is mounted to a test fixture that has structural characteristics similar to the PLA, then vibration levels at the interface will be similar to flight levels. It is not recommended to attach the spacecraft to a rigid fixture during the acoustic test because

the interface vibration will be zero at the launch vehicle interface attach point, but at some distance away from the interface the vibration levels will be similar to flight levels.

3.1.5 Acoustic

The flight level acoustic spectrum should be defined per ISO 14303:2001, section 8.1.6. Although the ISO standard allows either octave or one-third octave band definition, the normal U.S. practice is to use one-third octave bands for better definition of acoustic peaks. Levels should represent the maximum expected environment based on a 95% probability and 50% confidence.

3.1.6 Seismic

Recommended Practice: Seismic events should be considered in the design of the SC, aerospace ground equipment, and facilities. Each element of the flight and ground systems should, as a minimum, be designed to survive expected seismic events to the extent that loss of life can be prevented. The level of expected seismic events and required safety measures should be provided by the range.

3.2 Controlled Environment

3.2.1 Thermal

Thermal environments should be defined per ISO 14303:2001, Spacecraft to Launch Vehicle Interfaces Document, Section 8.2. Annex D, Figure D-7 of ISO 14303:2001 shows a typical temperature time history.

3.2.1.1 Temperatures

Temperatures were considered in preparing this document but have not been addressed.

3.2.1.2 Aerothermal Heating

During launch and ascent, aerothermal heating may increase the temperatures of exposed surfaces of the LV, including the payload fairing. The increased temperatures can add to the heat load on the SC as well as increase the outgassing from volatile materials. Increased outgassing can increase contamination of the SC.

Recommended Practice: Design/materials/testing of SC should allow testing for margin so that, if analyses indicate a slight overshoot of the expected temperature levels, then there is not a major "showstopper."

3.2.2 Humidity

Humidity requirements should be specified as relative humidity, dew point, or both depending on the requirements of the components, subsystems, and system. Special requirements may be imposed for some operations depending on system requirements.

3.3 Environment (Uncontrolled)

Subjects that were considered in preparing this document but have not been addressed herein include precipitation and winds.

3.3.1 Humidity

The humidity in the environment external to the controlled facilities can have a large impact on operations within the facilities. A high dew point generally requires that moisture be removed from the air to maintain the interior relative humidity (RH) at an acceptable level. A low dew point in the external, uncontrolled environment can result in a relative humidity in the controlled environment that is too low unless moisture is added to the conditioned air. A low RH in a facility can be a safety and equipment hazard because of

the greater probability for electrostatic discharge, increased potential for the deposition of particulate contaminants, and personnel discomfort.

3.3.2 Lightning

Recommended Practice: SC test configuration should include some means of surge protection. While existing pad and processing facilities have lightning protection systems, they are not adequate for a direct or proximity hit. Operational constraints should also be clearly defined and communicated to the crew. Lightning warning systems and personnel are currently in place at Cape Canaveral and should be used as a source of weather and lightning information for off-pad processing as well. This can easily be arranged upon request.

3.4 Contamination and Cleanliness Control

Contamination and cleanliness control programs are used to reduce the risk of failure or excessive degradation in performance resulting from particulate and molecular contaminants. The usual practice is to have a contamination control plan that covers all phases of the system from design through the end of mission life. An example is described in ASTM E 1548. Analyses are frequently performed to relate specific operations to system performance degradation. The levels of detail and complexity of the plan and analyses depend on the requirements of the system and the mission. A cost-effective approach is to tailor the plan and analyses to the minimum necessary to meet performance requirements.

3.4.1 Facilities and Ground Support Equipment

Cleanliness requirements for facilities and ground support equipment (GSE) can include both airborne and surface deposition of particulate and molecular contaminants. This includes all equipment used in the vicinity of contamination-sensitive flight hardware.

Recommended Practice: The maximum limits for airborne molecular and particulate contaminants should be specified based on SC requirements. Each facility and each operation within the facility could have unique requirements to meet the required surface cleanliness levels of the system.

Recommended Practice: Do not impose strict contamination control measures at the launch base unless required. Contamination control measures beyond the established baseline may result in significant cost increases.

Water from leaks and rain, particles, debris, and molecular contaminants may enter a cleanroom in the event of severe weather conditions, equipment failure, or human error.

Recommended Practice: It is good practice to provide protection for sensitive hardware or the total SC. This arrangement has to be made explosion proof if the GSE is to be used in the same facility as the SC after the SC is fueled. It is desirable to put windows in cleanroom walls and opaque clean enclosures. Alternatively, fixed or mobile pan/tilt/zoom/auto-focus close-caption television (CCTV) cameras can be placed in the processing areas with monitors in administrative and/or technical support areas. These practices allow visitors to observe operations without entering the cleanroom and causing additional contamination. Roll-up shades can be added to the windows or the CCTV cameras disconnected for security, if necessary. It is desirable to have the electrical GSE outside the cleanroom, where possible, with feed throughs for cable connections. This arrangement has to be made explosion-proof if fueling is carried out in the same hall. Materials used in facilities and GSE should be selected for low outgassing and low particle generation as described in ISO 15388 (to be published in 2002).

Recommended Practice: Surface cleanliness requirements should be specified as described in IEST-Std-CC1246D. Requirements for airborne particle concentrations (class of air) in cleanrooms and other facilities, air conditioning air, and purge air should be specified as described in ISO 14644-1:1999. Because ISO 14644-1:1999 is new, and Fed-Std-209E is still being used, consider specifying the Class of air using the definitions in both documents until such time as the ISO 14644-1:1999 is in general use.