FALCON USER'S GUIDE

Version 8 – March 2025

TABLE OF CONTENTS

ACRONYMS

ACS .... attitude control system
AFSPCMAN .... Air Force Space Command Manual
AWG .... American wire gauge
BPSK .... binary phase shift keying
CG .... center of gravity
C3 .... characteristic energy (escape energy)
CAD .... computer-aided design
CCSFS .... Cape Canaveral Space Force Station
CLA .... coupled loads analysis
CRS .... Commercial Resupply Services
DSSS .... direct-sequence spread spectrum
ECS .... environmental control system
EELV .... evolved expendable launch vehicle
EGSE .... electrical ground support equipment
ESPA .... EELV secondary payload adapter
FAA .... Federal Aviation Administration
FM .... frequency modulation
GN_2 .... gaseous nitrogen
GNSS .... Global Navigation Satellite System
GPS .... Global Positioning System
GSE .... ground support equipment
GSO .... geosynchronous orbit
GTO .... geosynchronous transfer orbit
HEO .... highly elliptical orbit
HITL .... hardware-in-the-loop
HTP .... high test peroxide
HVAC .... heating, ventilation, and air conditioning
ICD .... interface control document
IP .... internet protocol
IRIG .... inter-range instrumentation group
ISS .... International Space Station
LAX .... Los Angeles International Airport

LEO	low-Earth orbit
LOX	liquid oxygen
LSA	launch services agreement
LV	launch vehicle
LVLH	local vertical/local horizontal
M1D	Merlin 1D engine
Max Q	maximum dynamic pressure
MDP	maximum design pressure
MECO	main engine cut-off
MEOP	maximum expected operating pressure
MMH	monomethylhydrazine
MPE	maximum predicted environment
MVac	Merlin Vacuum
NASA	National Aeronautics and Space Administration
NTO	nitrogen tetroxide
OASPL	overall sound pressure level
PAF	Payload attach fitting
PCM	pulse code modulation
PLA	payload adapter
PPF	payload processing facility
PSK	phase shift keying
Q	dynamic pressure
RBF	remove before flight
RF	radio frequency
RP-1	rocket propellant-1 (rocket-grade kerosene)
SBA	Santa Barbara Airport
SC	spacecraft
SCAPE	self-contained atmospheric protective ensemble
SECO	second-engine cut-off
SES	second-engine start
SLC	Space Launch Complex
SpaceX	Space Exploration Technologies Corp.
SPL	sound pressure level

SRS .... shock response spectrum

SSO .... sun-synchronous orbit

TAC .... transport air conditioning

TE .... transporter-erector

TEA-TEB .... triethylaluminum-triethylborane

U.S. .... United States

VSFB .... Vandenberg Space Force Base

List of Figures

LIST OF TABLES

CHANGE LOG

Version	Date	Update
1	October 2015	Original Release
2	May 2016	Updated Release
3	January 2019	Updated Release
4	April 2020	Updated Release
5	August 2020	Updated Release
6	August 2021	Updated Release
7	September 2021	Updated Release
8	March 2025	Updated Release. Major updates listed as follows: • Section 3.3 Launch Windows • Section 3.6 Multiple Payloads & Constellation • Section 4 Interfaces • Section 5 Environments • Section 6 Payload Design Requirements • Section 7 Verification • Appendix A: PAF Mechanical Interfaces • Appendix B: Payload Mechanical, Electrical, and Purge Standard Interfaces • Appendix C: Constellation Payload Mechanical Interfaces and Keep-in Volumes • Appendix D: Cryogenic Fluid Standard Interface • Appendix E: Payload CAD Model Requirements • Appendix F: Payload Dynamic Model Requirements • Appendix G: Payload Thermal Model Requirements • Appendix H: Delivery Format of Separation State Vectors • Appendix I: Test Schedule for Constellations

1 INTRODUCTION

1.1 USER'S GUIDE PURPOSE

The Falcon User's Guide is a planning document provided for customers of SpaceX (Space Exploration Technologies Corp.). This document is applicable to the Falcon vehicle configurations with a 5.2 m (17-ft) diameter fairing and the related launch service (Section 2).

This user's guide is intended for pre-contract mission planning and for understanding SpaceX's standard services. The user's guide is not intended for detailed design use. Data for detailed design purposes will be exchanged directly between a SpaceX customer and a SpaceX mission manager.

SpaceX reserves the right to update this user's guide as required. Future revisions are assumed to always be in process as SpaceX gathers additional data and works to improve its launch vehicle design.

1.2 COMPANY DESCRIPTION

SpaceX offers a family of launch vehicles that improves launch reliability and increases access to space. The company was founded on the philosophy that simplicity, reliability, and cost effectiveness are closely connected. We approach all elements of launch services with a focus on simplicity to both increase reliability and lower cost. The SpaceX corporate structure is flat and business processes are lean, resulting in fast decision-making and product delivery. SpaceX products are designed to require low-infrastructure facilities with little overhead, while vehicle design teams are co-located with production and quality assurance staff to tighten the critical feedback loop. The result is highly reliable and producible launch vehicles with quality embedded throughout the process.

Established in 2002 by Elon Musk, SpaceX has developed and flown the Falcon 1 light-lift launch vehicle, the Falcon 9 medium-lift launch vehicle, the Falcon Heavy heavy-lift launch vehicle, and Dragon, which is the first commercially produced spacecraft to visit the International Space Station and the first commercially produced spacecraft to carry people to and from low-Earth orbit (LEO).

SpaceX has built a launch manifest that includes a broad array of commercial, government, and international customers. In 2008, NASA selected the SpaceX Falcon 9 launch vehicle and Dragon spacecraft for the International Space Station Cargo Resupply Services contract. NASA has also awarded SpaceX contracts to develop the capability to transport astronauts to space as well as to launch scientific satellites. SpaceX's first crewed test flight with Dragon launched in May 2020, carrying NASA astronauts Douglas Hurley and Robert Behnken to the International Space Station and safely returning them to Earth two months later. NASA has certified the Falcon 9 / Dragon system for human spaceflight, and SpaceX is providing operational missions to the International Space Station under the Commercial Crew Program, as well as providing the capability to launch commercial astronauts to space. In addition, SpaceX serves the National Security community and is on contract with the U.S. Space Force for multiple missions on the Falcon family of launch vehicles.

SpaceX has state-of-the-art production, testing, launch, and operations facilities. SpaceX design and manufacturing facilities are conveniently located near the Los Angeles International Airport. This location allows the company to leverage southern California's rich aerospace talent pool. The company also operates cutting-edge propulsion and structural test facilities in central Texas, along with launch sites in Florida and California, and a commercial orbital launch site in development in south Texas. See Figure 1-1 for all SpaceX sites.

Figure 1-1: SpaceX Offices and Sites

1.3 FALCON PROGRAM OVERVIEW

Drawing on a history of prior launch vehicle and engine programs, SpaceX privately developed the Falcon family of launch vehicles. Component developments include first and second stage engines, cryogenic tank structures, avionics, guidance and control software, and ground support equipment.

With the Falcon 9 and Falcon Heavy launch vehicles, SpaceX is able to offer a full spectrum of medium- and heavy-lift launch capabilities to its customers (Figure 1-2), as well as small and micro satellite launch capabilities via its Rideshare Program. SpaceX currently operates Falcon launch facilities at Cape Canaveral Space Force Station (CCSFS), Kennedy Space Center (KSC), and Vandenberg Space Force Base (VSFB) and can deliver payloads to a wide range of inclinations and altitudes, from low-Earth orbit (LEO) to geosynchronous transfer orbit (GTO) to escape trajectories for interplanetary missions.

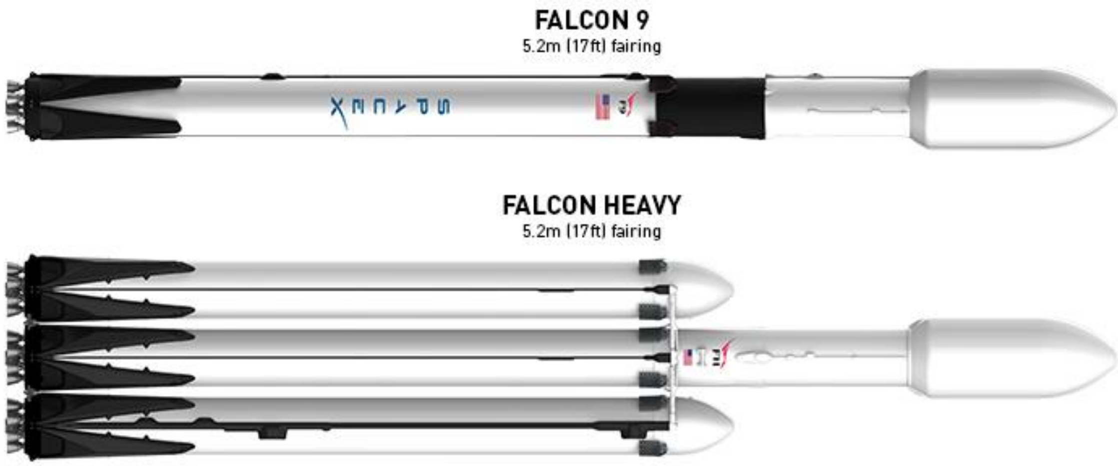


Figure 1-2: SpaceX vehicles are designed for high cross-platform commonality

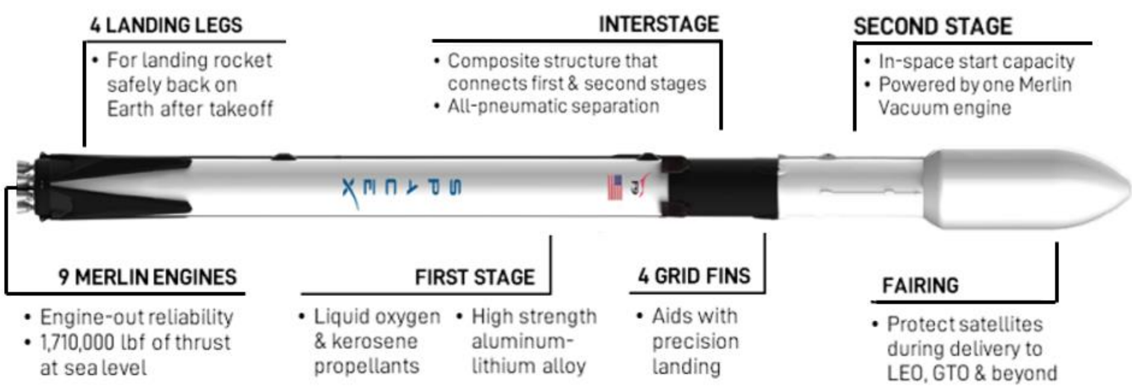


Figure 1-3: Falcon 9 Architecture

The Falcon family has conducted successful flights to the International Space Station (ISS), LEO, medium-Earth orbit (MEO), highly elliptical orbit (HEO), GTO, and Earth-escape trajectories. As of the end of 2024, SpaceX has completed over 430 Falcon launches, making it the most flown U.S. launch vehicle currently in operation.

Reusability is an integral part of the Falcon program. SpaceX pioneered reusability with the first re-flight of an orbital class rocket in 2017. As of February 2025, SpaceX has re-flown Falcon first stage boosters more than 384 times with a 100% success rate. Since 2018, SpaceX had more missions launching with a flight-proven first stage booster than a first flight booster. SpaceX also started re-flying fairings in late 2019, and as of February 2025 has re-flown fairing halves on 307 missions with a 100% success rate. By re-flying boosters and fairings, SpaceX increases reliability and improves its designs and procedures by servicing and inspecting hardware as well as incorporating lessons that can only be learned from flight.

1.4 FALCON LAUNCH VEHICLE SAFETY

The Falcon launch vehicles were designed from the beginning to meet NASA human-rated safety margins. We continue to push the limits of rocket technology as we design the safest crew transportation system ever flown while simultaneously advancing toward fully reusable launch vehicles. Our emphasis on safety has led to advancements such as increased structural factors of safety, greater redundancy, and rigorous fault mitigation. Because SpaceX produces one Falcon core vehicle, satellite customers benefit from the high design standards required to safely transport crew. The major safety features are listed in more detail in Table 1-1.

Table 1-1: Key Safety Features of Falcon Launch Vehicles

Design/Operations Feature	Safety Benefit
Designed to NASA human-rating margins and safety requirements	Improves reliability for payloads without crew through increased factors of safety, redundancy, and fault mitigation
Horizontal manufacturing, processing, and integration	Reduces work at height during numerous manufacturing, processing, and integration procedures, and eliminates many overhead operations
All-liquid propulsion architecture: fuel and oxidizer are stored separately on the ground and in the vehicle. Propellant is not loaded into the vehicle until the vehicle is erected for launch	Significantly improves safety by eliminating hazardous ground handling operations required for systems that use solid propellant cores or boosters
Rocket-grade kerosene and liquid oxygen as primary propellants	Reduces health hazards to processing, integration, and recovery personnel compared to systems that use high toxicity primary propellants
Non-explosive, pneumatic release and separation systems for stage separation and standard payload fairing separation	Zero-debris separation systems significantly reduce orbital debris signature, can be repeatedly tested during the manufacturing process, and eliminate hazardous pyrotechnic devices
Regular hardware-in-the-loop (HITL) software testing	Complete verification of entire mission profile prior to flight

1.5 FALCON RELIABILITY

A study[1] by The Aerospace Corporation found that 91% of known launch vehicle failures in the previous two decades can be attributed to three causes: engine, avionics, and stage separation failures. With this in mind, SpaceX incorporated key engine, avionics, and staging reliability features for high reliability at the architectural level of Falcon launch vehicles. Significant contributors to reliability include:

1.5.1 ENGINES

Engine failure modes are minimized by eliminating separate subsystems where appropriate. For example, the first stage thrust vector control system pulls from the high-pressure rocket-grade kerosene system, rather than using a separate hydraulic fluid and pressurization system. Using fuel as the hydraulic fluid eliminates potential failures associated with a separate hydraulic system and with the depletion of hydraulic fluid.

The high-volume engine production required to fly 10 Merlin engines (Falcon 9) or 28 engines (Falcon Heavy) on every launch results in high product quality and repeatability through process control and continuous production. Flying several engines on each mission also quickly builds substantial engineering data and flight heritage.

During Falcon launch operations, the first stage is held on the ground after engine ignition while automated monitors confirm nominal engine operation. An autonomous safe shutdown is performed if any off-nominal condition is detected. Hold-on-pad operations, enabled by the launch vehicle's all-liquid propulsion architecture and autonomous countdown sequence, significantly reduce risks associated with engine start-up failures and underperformance.

By employing multiple first stage engines, SpaceX offers the world's first evolved expendable launch vehicle (EELV)-class system with engine-out capability through much of first-stage flight. System-level vehicle management software controls the shutdown of engines in response to off-nominal engine indications; this has been demonstrated in flight, with 100% primary mission success. Although the likelihood of catastrophic engine failure is low, and failing engines are

[1] Chang, I-Shih. "Space Launch Vehicle Reliability," *Aerospace Corporation Publication (2001).*

designed to be shut down prior to a catastrophic failure, each engine is housed within its own metal bay to isolate it from neighboring engines.

The second stage Merlin Vacuum engine uses a fixed, non-deploying expansion nozzle, eliminating potential failure modes in nozzle extension.

1.5.2 AVIONICS

Falcon launch vehicle avionics, and guidance, navigation, and control systems use a fault-tolerant architecture that provides full vehicle single-fault tolerance and uses modern computing and networking technology to improve performance and reliability. Fault tolerance is achieved either by isolating compartments within avionics boxes or by using triplicated units of specific components. Both the first and second stages host their own multiple redundant lithium-ion batteries to minimize the complexity of the electrical interface.

1.5.3 STAGING ARCHITECTURE AND DESIGN

The two stage Falcon 9 architecture was selected to minimize the number of stage separation events, eliminating potential failure modes associated with third and fourth stage separations, as well as potential engine deployment and ignition failure modes in the third and fourth stages. Falcon Heavy uses the same stage architecture as Falcon 9 with the addition of two separating side cores.

The Falcon second stage and Falcon Heavy side booster restraint, release, and separation systems use pneumatic devices that provide low-shock release and positive force separation over a comparatively long stroke. The pneumatic system allows for acceptance and functional testing of the actual flight hardware, which is not possible with a traditional explosives-based separation system.

For each Falcon launch vehicle, SpaceX performs an exhaustive series of tests from the component to the vehicle system level. The test program includes component-level flight acceptance and workmanship testing, structures load and proof testing, flight system and propulsion subsystem-level testing, and full first and second stage testing up to full system testing (including first and second stage static fire testing). In addition to testing environmental extremes (plus margin), flight critical and workmanship sensitive hardware are tested to account for off-nominal conditions. For example, stage separation tests are performed for off-nominal cases with respect to geometrical misalignment, anomalous timing, and sequencing.

The Falcon first stage is designed to survive atmospheric entry and to be recovered, handling both the rigors of the ascent portion of the mission and the loads of the recovery portion. Stage recoverability also provides a unique opportunity to examine recovered hardware and assess design and material selection to continually improve Falcon 9 and Falcon Heavy.

1.5 PRICING

The standard price for Falcon 9 and Falcon Heavy launch services can be found at
https://www.spacex.com/media/Capabilities&Services.pdf. Pricing includes Range services, standard payload integration, and third-party liability insurance. Please see Section 9.3 for a complete description of standard services. Nonstandard services are also available.

2 VEHICLES

Descriptions and performance information in this user's guide are for the Falcon 9 and Falcon Heavy fairing configuration; please contact SpaceX for information about Dragon launch capabilities. Table 2-1 provides additional details on Falcon 9 and Falcon Heavy dimensions and design characteristics.

2.1 FALCON VEHICLE OVERVIEW

Falcon 9 (Figure 2-1) is a two-stage launch vehicle powered by liquid oxygen (LOX) and rocket-grade kerosene (RP-1). The vehicle is designed, built, and operated by SpaceX. Falcon 9 can be flown with a fairing or with a SpaceX Dragon spacecraft. All first and second stage vehicle systems are the same in the two configurations; only the payload interface to the second stage changes between the fairing and Dragon configurations.

Falcon 9 was updated in the summer of 2015 to a Full Thrust configuration from its previous v1.1 configuration (flown from 2013 – summer 2015). Falcon 9 underwent further updates and first flew its Full Thrust Block 5 configuration in spring 2018. The Falcon 9 Block 5 architecture focused on improving performance, reliability, and life of the vehicle, as well as ensuring the vehicle's ability to meet critical government human spaceflight and non-human spaceflight mission requirements. Engine performance on both stages was improved, releasing additional thrust capability. Thermal protection shielding was modified to support rapid recovery and refurbishment. Avionics designs, thrust structures, and other components were upgraded for commonality, reliability, and performance.

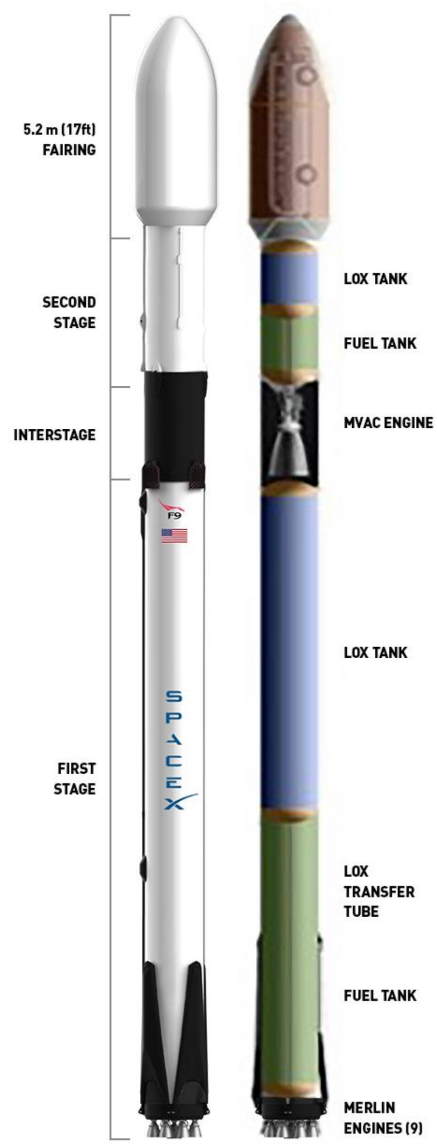


Figure 2-1: Falcon 9 Overview

2.2 FALCON HEAVY VEHICLE OVERVIEW

Falcon Heavy (Figure 2-2) is a two-stage, heavy-lift launch vehicle powered by LOX and RP-1.

Falcon Heavy builds on the proven, highly reliable design of Falcon 9. Falcon Heavy's first stage comprises three Falcon 9 first stages with enhancements provided to strengthen the cores. Furthermore, Falcon Heavy utilizes the same second stage and same payload fairing as flown on Falcon 9, fully benefiting from the flight heritage provided by Falcon 9 flights. This commonality has also minimized infrastructure unique to the vehicle. SpaceX first launched the Falcon Heavy vehicle in February of 2018.

Figure 2-2: A Falcon Heavy launch from KSC on April 11, 2019

The first stage comprises three Falcon 9 first stages: a center core and two side boosters; each booster and the core has nine Merlin 1D (M1D) engines. Each of the 27 first stage engines produces 845 kN (190,000 lbf) of thrust at sea level, for a total of 22,819 kN (5,130,000 lbf) of thrust at liftoff. The two side boosters are connected to the center core at the base engine mount and at the forward end of the LOX tank on the center core.

With nine engines in each first stage booster, Falcon Heavy has propulsion redundancy – unlike any other heavy-lift launch system. The launch vehicle monitors each engine individually during ascent and can, if necessary, preemptively command shutdown of off-nominal engines, provided the minimum injection success criteria are achievable with the remaining engines. This engine-out reliability provides propulsion redundancy throughout first-stage ascent – a feature unique to Falcon launch vehicles.

2.3 STRUCTURE AND PROPULSION

The first stage propellant tank walls of the Falcon vehicles are made from an aluminum lithium alloy. Tanks are manufactured using friction stir welding, the highest strength and most reliable welding technique available. A common dome separates the LOX and RP-1 tanks, and a double-wall transfer tube carries LOX through the center of the RP-1 tank to the engine section. Four grid fins near the top of the first stage along with four deployable legs at the base are nominally flown to support recovery operations.

Nine SpaceX M1D engines power the Falcon 9 first stage with up to 845 kN (190,000 lbf) thrust per engine at sea level, for a total thrust of 7,605 kN (1,710,000 lbf) at liftoff, which has the highest thrust-to-weight ratio of any boost engine ever made. The liquid-propelled Merlin engine powers the Falcon propulsion system. The engine features a reliable turbopump design with a single shaft for the liquid oxygen pump, the fuel pump, and the turbine. The engine uses a gas generator cycle instead of the more complex staged combustion cycle. The regeneratively cooled nozzle and thrust chamber use a milled copper alloy liner that provides large heat flux margins. A pintle injector provides inherent combustion stability. The first stage M1D engines are configured in a circular pattern, with eight engines surrounding a center engine.

Twenty-seven SpaceX Merlin engines power the Falcon Heavy first stage boosters and core for a total thrust of 22,819 kN (5,130,000 lbf) at liftoff. The figure below shows the nomenclature for the center core and side boosters (center, plus y-axis, and minus y-axis.) Structurally, the plus y-axis and minus y-axis boosters are identical. The center core consists of thicker tank walls and carries the booster separation system. The z-axis points to zenith when the vehicle is horizontal.

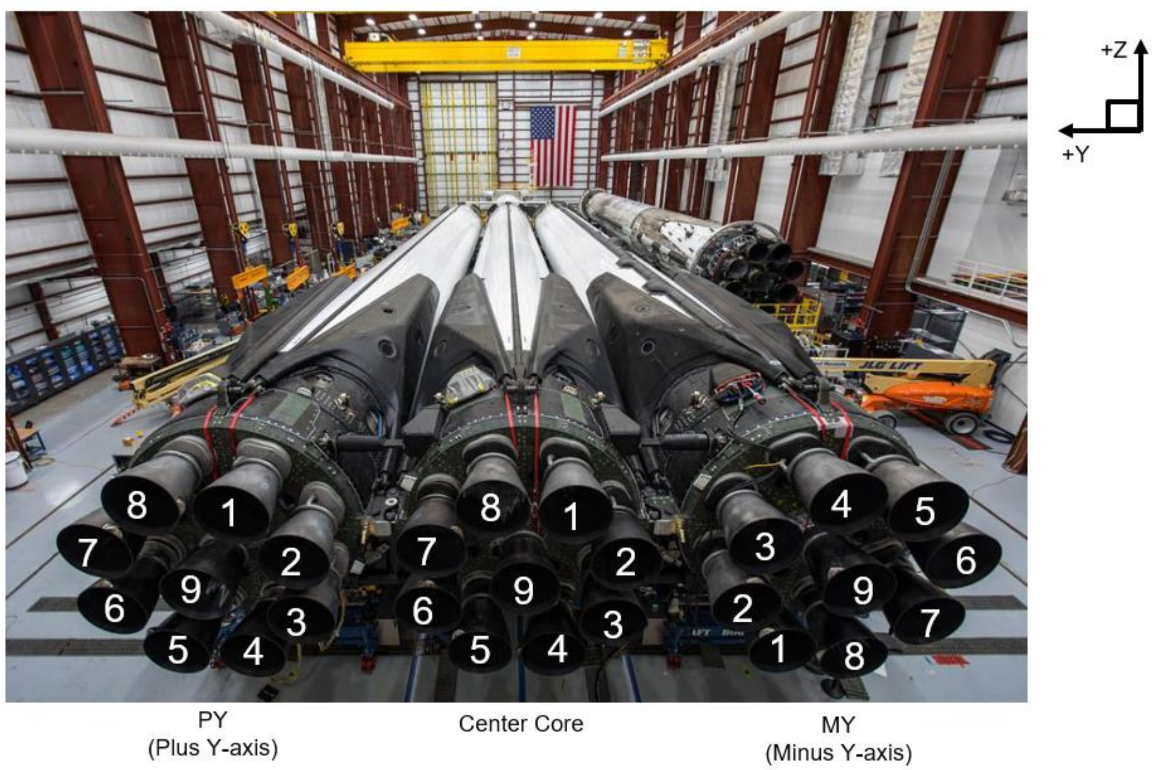


Figure 2-3: Falcon Heavy First Stage Engine Layout

After engine start, Falcon vehicles are held down until all vehicle systems are verified as functioning normally before release for liftoff.

The Falcon vehicles' interstage, which connects the first and second stages, is a composite structure consisting of an aluminum honeycomb core surrounded by carbon fiber face sheet plies. The interstage is fixed to the forward end of the first stage tank. The stage separation system is located at the forward end of the interstage and interfaces to the second stage.

The second stage tank for Falcon vehicles is a shorter version of the first stage tank and uses most of the same materials, construction, tooling, and manufacturing techniques as the first stage tanks. A single Merlin Vacuum (MVac) engine powers the second stage, using a fixed 165:1 expansion nozzle. For added reliability of restart, the engine contains dual redundant triethylaluminum-triethylborane (TEA-TEB) pyrophoric igniters. In addition, the second stage contains a cold nitrogen gas (GN_2) attitude control system (ACS) for pointing and roll control. The GN_2 ACS is more reliable and produces less contamination than a propellant-based reaction control system.

Table 2-1: Falcon Dimensions and Characteristics

Characteristic	First Stage	Second Stage
Structure		
Height	70 m (229.6 ft) including both stages, interstage, and standard fairing; 75.2 m (246.7 ft) with extended fairing.	
Diameter	3.66 m (12 ft)	3.66 m (12 ft)
Type	LOX tank – monocoque Fuel tank – skin and stringer	LOX tank – monocoque Fuel tanks – skin and stringer
Material	Aluminum lithium skin; aluminum domes	
Propulsion		
Engine type	Liquid, gas generator	Liquid, gas generator
Engine designation	M1D	MVac
Engine designer	SpaceX	SpaceX
Engine manufacturer	SpaceX	SpaceX
Number of engines	9	1
Propellant	Liquid oxygen/kerosene (RP-1)	Liquid oxygen/kerosene (RP-1)
Thrust (stage total)	7,686 kN (sea level) (1,710,000 lbf)	981 kN (Vacuum) (220,500 lbf)
Propellant feed system	Turbopump	Turbopump
Throttle capability	Yes (190,000 lbf to 108,300 lbf sea level)	Yes (220,500 lbf to 140,679 lbf)
Restart capability	Yes	Yes
Tank pressurization	Heated helium	Heated helium
Ascent attitude control		
Pitch, yaw	Gimbaled engines	Gimbaled engine/nitrogen gas thrusters
Roll	Gimbaled engines	Nitrogen gas thrusters
Coast attitude control	Nitrogen gas thrusters (recovery only)	Nitrogen gas thrusters
Operations		
Shutdown process	Commanded shutdown	Commanded shutdown
Stage separation system	Pneumatically actuated separation mechanism	N/A

2.4 RETENTION, RELEASE, AND SEPARATION SYSTEMS

The first and second stages are mated by mechanical latches at three points between the top of the interstage and the base of the second stage fuel tank. After the first stage engines shut down, a high-pressure helium circuit is used to release the latches via redundant actuators. The helium system also preloads four pneumatic pushers, which provide a positive force for stage separation after latch release. This includes a redundant center pusher to further decrease the probability of re-contact between the stages following separation.

The two halves of the standard fairing are fastened by mechanical latches along the fairing vertical seam. To deploy the fairing, a high-pressure helium circuit releases the latches, and four pneumatic pushers facilitate positive-force deployment of the two halves. The use of all-pneumatic separation systems provides a benign shock environment, allows acceptance and preflight testing of the actual separation system hardware, and minimizes debris created during separation.

The two halves of the extended fairing are fastened by a bolted frangible seam joint. To deploy the fairing, redundant detonators initiate a detonation cord contained inside an expanding tube assembly. The detonation causes the expanding tube to expand outwards and break the structural seam between the two fairings in a controlled and contained manner. Four pneumatic pushers facilitate positive-force deployment of the two halves. The use of a non-bolted clamshell interface between the payload fairing and the rest of the vehicle provides significant shock attenuation of the separation event, maintaining environments for the payload well within nominal payload requirements.

For Falcon Heavy, the fundamental purpose of the side boosters is to apply axial force to the center core during ascent and increase the impulse delivered to the second stage before stage separation. The timing of the shutdown for the Falcon Heavy side boosters can be tailored for each mission to ensure that the proper impulse is delivered. Each side booster is structurally connected to the center core at forward and aft locations. Two pneumatic pusher separation mechanisms connect the forward ends of each side booster to the center core, fastening the top of the LOX tank in the center core to the side boosters. They maintain the connection during ascent and then actively jettison the side boosters following side booster shutdown. Two identical pusher separation mechanisms connect the aft ends of each side booster to the center core and are used to laterally force the base of the side booster from the center core following shutdown of side boosters.

2.5 AVIONICS AND GUIDANCE, NAVIGATION, AND CONTROL

Falcon avionics feature a flight-proven, three-string, fault-tolerant architecture that has been designed to human-rating requirements. Avionics include flight computers, Global Positioning System (GPS) receivers, inertial measurement units, SpaceX designed and manufactured controllers for vehicle control (propulsion, valve, pressurization, separation, and payload interfaces), a network backbone, S-band transmitters, and a C-band transponder for Range Safety tracking. The S-band transmitters are used to transmit telemetry and video to the ground, from both the first and second stages, even after stage separation.

Our launch vehicles are equipped with an autonomous flight termination system (AFTS) to limit the potential damage caused by a launch vehicle malfunction. The system terminates the flight of the vehicle automatically if mission rules are violated. The use of an AFTS requires fewer Range assets to support launch operations, resulting in fewer Range constraints and increased launch opportunities.

3 PERFORMANCE

3.1 AVAILABLE INJECTION ORBITS

SpaceX launch services are offered at its Cape Canaveral Space Force Station, Kennedy Space Center, and Vandenberg Space Force Base launch sites. Together, Cape Canaveral Space Force Station and Kennedy Space Center are referred to herein as the Eastern Range. Vandenberg Space Force Base is referred to herein as the Western Range (Section 8).

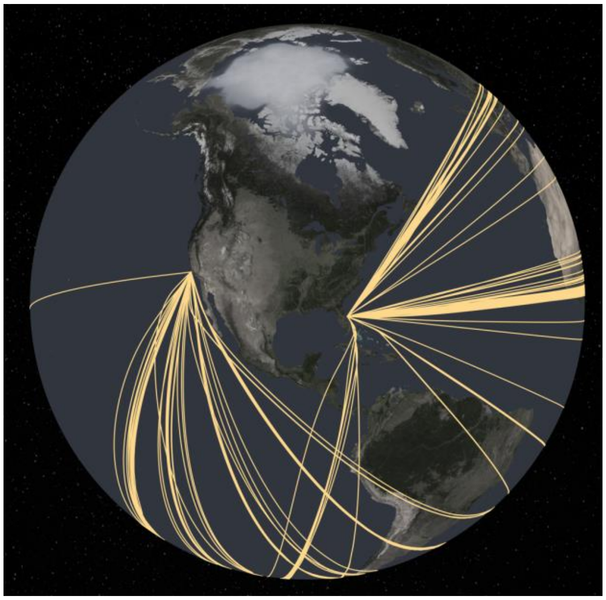


Figure 3-1: Ground tracks/orbits of previous Falcon 9/Falcon Heavy launches

Table 3-1 describes the typical injection orbits available from our operational launch sites. (As other launch sites are activated, this user's guide will be updated.)

Table 3-1: Falcon 9 and Falcon Heavy Launch Services

Insertion Orbit	Inclination Range	Vehicle	Launch Site(s)
LEO	28.5 – 55 deg	Falcon 9 or Falcon Heavy	Eastern Range
LEO	55 – 65 deg*	Falcon 9 or Falcon Heavy (Eastern Range only)	Eastern or Western Range
LEO	65 – 85 deg	Falcon 9	Western Range
LEO / Retrograde	105+ deg	Falcon 9	Western Range
LEO Polar / SSO	85 – 105 deg*	Falcon 9	Western or Eastern Range
GTO	Up to 28.5 deg	Falcon 9 or Falcon Heavy	Eastern Range
GSO	Up to 28.5 deg	Falcon Heavy	Eastern Range
Earth escape	N/A	Falcon 9 or Falcon Heavy	Western or Eastern Range

*Subject to mission-specific performance considerations. Falcon Heavy is only available from the Eastern Range

Launch services to a range of low-Earth orbits are available, including services to low-inclination orbits through high-inclination and sun-synchronous orbits (SSO). Falcon vehicles can provide either two-burn or direct-inject launch services: two-burn mission profiles optimize vehicle performance, while direct-inject mission profiles offer reduced mission duration and require only a single start of the second stage engine. LEO missions to a 55 deg inclination or lower are typically flown from the Eastern Range. LEO missions can also be flown from the Eastern Range to inclinations between 55 and 65 deg, but doing so has some performance cost due to the need to perform a "dog leg" maneuver. LEO missions to higher inclinations are baselined to be flown from Vandenberg Space Force Base, but may also be flown from the Eastern Range in specific cases and at SpaceX's discretion, particularly for SSO orbits for which SpaceX has developed the ability to fly Polar missions from the Eastern Range (contact SpaceX for more information). Launch services to inclinations lower than 28.5 deg are available from the Eastern Range, but they incur a performance penalty.

Launch services to a range of GTOs and other high-altitude orbits are available, including standard GTO, sub-GTO for heavy payloads, and supersynchronous injection. A perigee altitude of 185 km (100 nmi) is baselined for GTO; higher perigee values may be provided subject to SpaceX approval, and may incur a performance penalty. SpaceX may also impose restrictions on certain combinations of perigee and apogee to enable a controlled deorbiting of the second stage after satellite separation. Currently, all GTO missions are flown from the Eastern Range.

Launch services directly into geosynchronous orbit (GSO) are available from Kennedy Space Center via Falcon Heavy. The satellite is placed into a circular orbit directly above or below GSO to allow it to phase into its correct orbital position.

Launch services to a range of Earth-escape orbits are available. Customers may also utilize a customer-supplied kick-stage to achieve higher escape energy (C3) performance, based on mission requirements. Earth-escape missions are typically flown from the Eastern Range.

Additional information regarding the Falcon launch vehicle family's world-leading mission design flexibility is available upon request.

3.2 MASS-TO-ORBIT CAPABILITY

Mass-to-orbit capabilities for the Falcon 9 and Falcon Heavy fairing configuration are available upon request.

3.3 LAUNCH WINDOWS

Falcon launch vehicles can launch any day of the year, at any time of day, subject to environmental limitations and constraints as well as Range availability and readiness. Launch window times and durations are developed specifically for each mission.

In order to maximize launch availability, SpaceX requires its customers to remove constraints that may restrict launch windows to no less than a daily four-hour window as far as possible and to avoid selecting launch windows that result in a high statistical probability of violation (POV) for launch weather constraints as defined in the tables below for launch from the Eastern and Western Ranges, respectively.

For missions that require a near-instantaneous launch window, customer constraints shall not limit SpaceX to less than a 15-second daily launch window to provide SpaceX the flexibility to shift the liftoff time by a few seconds based on the final conjunction assessment results performed by the Combined Space Operations Center (CSpOC) prior to launch.

Table 3-2: Weather Violation Risk for Eastern and Western Ranges

Weather Violation Percent (%) Risk for Cape Canaveral Falcon Launches

UTC Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
0	7.1	8.0	6.8	8.6	11.1	19.4	16.1	15.4	15.1	6.8	5.2	5.6	10.4
1	6.2	7.0	5.8	6.4	10.5	13.0	10.5	8.4	12.6	6.1	4.1	5.6	8.0
2	6.9	7.3	5.9	5.9	8.5	10.3	9.2	6.7	11.8	5.6	4.5	5.6	7.4
3	7.1	6.5	5.9	5.3	5.8	10.9	7.8	6.9	10.4	5.9	5.7	6.1	7.0
4	6.9	6.9	5.4	4.6	4.0	8.5	6.6	5.2	8.9	5.5	5.1	5.8	6.1
5	6.4	6.6	5.3	5.2	3.6	7.4	6.2	4.9	8.0	5.0	5.5	5.4	5.8
6	6.8	7.1	5.9	5.3	3.2	6.1	5.0	3.6	6.6	4.7	4.6	5.5	5.4
7	6.6	5.7	5.3	5.7	3.4	5.8	4.3	3.3	6.8	5.0	3.9	5.1	5.1
8	5.8	6.3	5.4	4.8	4.1	5.4	3.8	2.9	6.1	6.2	3.7	5.6	5.0
9	6.2	7.0	4.9	4.3	3.6	6.7	4.7	5.3	6.3	5.5	3.9	5.4	5.3
10	7.3	7.5	5.4	5.3	4.3	8.1	4.8	4.8	8.2	6.8	5.0	5.9	6.1
11	6.6	6.9	5.1	4.5	3.8	7.3	5.4	5.9	7.0	5.9	5.1	5.8	5.8
12	7.4	6.2	5.0	3.8	3.9	7.2	7.3	7.1	7.9	5.6	5.2	5.0	5.9
13	7.1	6.3	5.6	4.2	5.0	8.0	5.4	5.4	7.7	5.5	5.1	5.4	5.9
14	7.2	6.1	5.0	4.4	4.5	7.0	5.6	6.4	7.3	4.8	4.5	6.2	5.7
15	7.2	6.2	4.9	4.7	4.0	6.9	6.1	7.4	8.0	5.9	4.3	5.5	5.9
16	8.3	6.4	4.7	5.1	6.0	9.2	7.1	8.8	8.3	5.2	5.0	6.2	6.7
17	8.7	6.7	5.4	5.3	8.7	13.7	15.9	11.7	9.7	5.4	4.8	6.1	8.5
18	7.9	8.1	6.0	6.9	9.7	20.2	22.1	17.0	10.3	4.8	4.8	6.5	10.4
19	7.6	8.2	6.2	8.5	11.3	25.7	25.5	23.6	14.8	5.2	5.1	6.5	12.3
20	7.7	8.9	5.9	9.0	12.0	29.9	30.9	26.3	19.0	6.0	5.4	6.9	14.0
21	7.8	7.3	6.0	9.8	10.1	25.6	32.0	28.1	21.7	6.4	5.3	7.2	13.9
22	8.0	8.3	6.2	9.3	11.4	25.3	29.2	25.4	21.3	5.9	5.3	6.9	13.5
23	8.4	7.3	7.9	10.2	12.0	24.4	24.9	22.3	17.9	6.9	5.4	6.8	12.9
Avg.	7.2	7.0	5.7	6.1	6.8	13.0	12.4	10.9	10.9	5.7	4.8	5.9	8.0

SLC-4 | UTC Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
0	6.1	7.8	5.3	4.5	2.4	0.4	1.3	0.5	1.1	2.2	3.9	8.2	3.6
1	6.2	7.9	4.8	4.5	1.7	0.4	1.1	0.4	0.8	1.7	4.2	7.9	3.5
2	6.7	7.8	4.6	4.0	1.9	0.4	0.7	0.3	1.4	1.8	3.8	6.9	3.4
3	6.1	7.9	4.9	3.8	1.5	0.2	1.3	0.6	0.9	1.5	2.8	6.1	3.1
4	6.4	7.8	5.0	3.8	1.6	0.2	0.8	0.7	0.9	1.2	2.8	6.0	3.1
5	6.8	8.0	5.7	4.1	1.6	0.3	0.8	0.4	1.1	1.0	3.4	5.7	3.2
6	7.2	8.9	5.8	3.9	1.6	0.4	0.7	0.5	0.8	1.5	4.2	6.2	3.5
7	7.2	9.0	5.6	3.5	1.6	0.4	0.7	0.7	0.9	1.4	4.0	5.7	3.4
8	7.7	8.8	6.1	3.3	1.9	0.4	0.7	0.6	0.8	1.7	4.3	5.5	3.5
9	7.8	9.8	5.5	3.2	2.2	0.3	0.9	0.8	0.9	1.5	3.8	6.7	3.6
10	7.5	7.7	5.5	3.8	1.5	0.4	2.0	0.7	1.1	2.3	3.7	5.3	3.4
11	8.5	8.7	5.0	3.9	1.9	0.9	1.9	0.4	0.8	2.0	4.1	6.1	3.7
12	9.7	9.0	5.3	3.7	2.4	1.1	1.7	0.7	1.1	2.0	3.3	6.9	3.9
13	8.2	9.4	4.9	3.8	2.6	0.8	1.3	0.6	1.0	2.1	3.7	6.4	3.7
14	8.5	9.7	5.4	3.3	1.5	1.0	1.6	0.8	1.2	1.8	3.3	6.4	3.7
15	8.6	9.4	4.4	3.6	1.7	0.8	1.3	0.9	1.0	2.0	3.4	6.4	3.6
16	8.3	10.3	4.4	3.3	1.6	0.8	1.0	0.7	0.9	2.1	4.0	7.0	3.7
17	8.1	9.8	4.7	3.9	1.4	0.5	0.9	1.0	0.7	1.8	3.0	7.1	3.6
18	8.3	8.8	3.8	3.1	1.6	0.7	1.1	0.5	1.1	2.0	3.7	7.7	3.5
19	8.2	9.1	4.6	3.4	1.4	0.7	1.3	0.9	1.1	2.0	3.2	7.2	3.6
20	8.2	9.1	5.5	3.9	1.7	0.5	1.1	1.1	1.4	2.3	3.2	8.3	3.9
21	7.5	9.8	6.1	4.2	1.7	0.7	0.8	1.0	1.2	2.3	3.4	7.7	3.9
22	6.9	8.5	5.4	4.4	1.9	0.8	0.7	0.8	1.3	2.3	3.6	7.5	3.7
23	7.0	9.0	6.1	4.9	2.0	1.2	1.6	0.8	0.7	2.0	4.0	6.9	3.8
Avg.	7.6	8.8	5.2	3.8	1.8	0.6	1.1	0.7	1.0	1.8	3.6	6.7	5.3

3.4 FLIGHT ATTITUDE

Falcon 9 and Falcon Heavy can provide payload pointing and roll control during long-duration coast phases for sun avoidance and thermal control. If requested, the Falcon second stage will point the X-axis of the launch vehicle to a customer-specified attitude and perform a passive thermal control roll of up to ± 1.5 deg/sec around the launch vehicle X-axis, held to a local vertical/local horizontal (LVLH) roll attitude accuracy of ± 5 deg.

3.5 SEPARATION ATTITUDE AND ACCURACY

Falcon launch vehicles offer 3-axis attitude control or spin-stabilized separation as a standard service. For inertial separation, the vehicle will point the second stage and payload to the desired LVLH attitude and minimize attitude rates. For spin-stabilized separation, the Falcon launch vehicle will point the second stage and payload to the desired LVLH attitude and initiate a spin about the launch vehicle X-axis at a customer-specified rate dependent upon payload mass properties.

SpaceX does not implement multiple trajectories for various dates/times and does not provide sun-referenced or inertially referenced attitudes during ascent or for payload separation.

Standard pre-separation attitude and rate accuracies are developed as a mission-specific standard service. More information about separation attitude and rate accuracy is available from SpaceX upon request.

3.6 MULTIPLE PAYLOADS & CONSTELLATIONS

Falcon 9 and Falcon Heavy can launch multiple satellites on a single mission. As a liquid-propellant launch vehicle with restart capability, Falcon launch vehicles also provide flexibility to deploy each satellite into a different orbit, performance allowing. SpaceX also offers dedicated rideshare missions via its Smallsat Rideshare Program.

Falcon launch vehicles can accommodate a broad range of dispenser systems including multi-payload systems and mission-unique adapters. SpaceX can develop and provide such adapters and dispensers if desired, as a nonstandard service, or can integrate third-party systems. Please contact SpaceX with your mission-unique requirements.

See Section 4.1.6 for standard constellation arrangements and interfaces using SpaceX hardware.

3.6.1 SECONDARY PAYLOADS

SpaceX typically reserves the right to manifest secondary payloads aboard Falcon missions on a non-interference basis. Secondary payloads may be manifested on a variety of secondary payload adapters including a SpaceX-developed Rideshare Dispenser Ring, a SpaceX-developed Surfboard, or other mission-unique secondary deployment structures.

Please contact SpaceX or refer to the Rideshare Payload User's Guide or Cake Topper Payload User's Guide for information regarding flight opportunities, interface requirements and pricing for secondary payloads.

3.6.2 CENTER OF GRAVITY SHIFT

For multiple payload deployments that require different insertion orbits or burns as part of a single launch, the maximum CG shift Δ (above the PAF) that is allowed between orbits or burns is 5 cm RSS lateral (launch vehicle CSYS).

- *Customer-provided dispenser*: Customers must meet this requirement (verification by analysis is acceptable)
- *SpaceX-provided dispenser*: SpaceX will work with the customer to meet this requirement through stack CG analysis (SpaceX does not intend to supply any mass simulators to help meet the requirement).

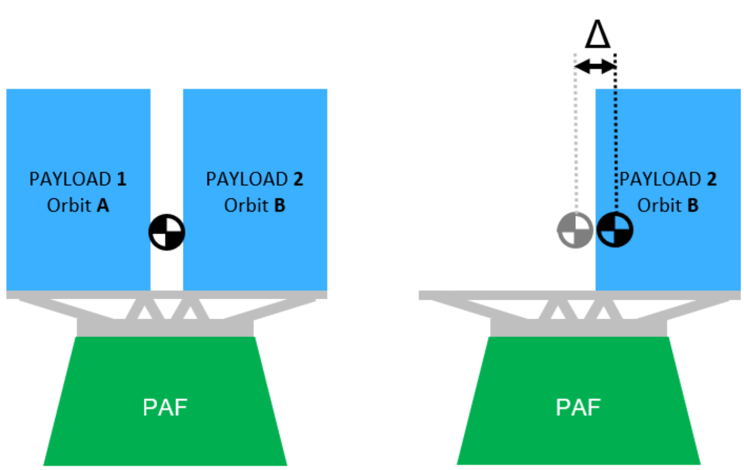


Figure 3-2: Example of CG Shift Between Two Payloads Deployed at Different Orbits

4 INTERFACES

4.1 MECHANICAL INTERFACES

4.1.1 LAUNCH VEHICLE COORDINATE FRAME

The launch vehicle uses a right-hand X-Y-Z coordinate frame, indicated with the subscript "LV," centered 440.69 cm (173.5 in.) aft of the first stage radial engine gimbal, with $+X_{LV}$ aligned with the vehicle long axis and $+Z_{LV}$ opposite the TE strongback as shown in Figure 4-1. X_{LV} is the roll axis, Y_{LV} is the pitch axis, and Z_{LV} is the yaw axis.

Figure 4-1: Launch Vehicle Coordinate Frame

4.1.2 PAYLOAD COORDINATE FRAME

The origin of the payload coordinate system is fixed at the center of the separation plane. The payload should use a right-hand X-Y-Z coordinate system (indicated with a subscript "PL").

For forwarded mounted payloads, it is preferred that the payload coordinate system is aligned with launch vehicle axes: payload axial direction $+X_{PL}$ aligned with launch vehicle $+X_{LV}$ (in the direction of deployment), and $+Z_{PL}$ aligned with the launch vehicle $+Z_{LV}$ direction. Customers should provide all data and deliverables in this Payload Coordinate Frame.

For side mounted payloads, it is preferred that the payload coordinate, indicated with a subscript "PL", is defined such that $+X_{PL}$ aligned with the payload axial direction and $+Z_{PL}$ aligned with the launch vehicle $+X_{LV}$ direction as shown in Figure 4-2. Customers should provide all data and deliverables in this Payload Coordinate Frame.

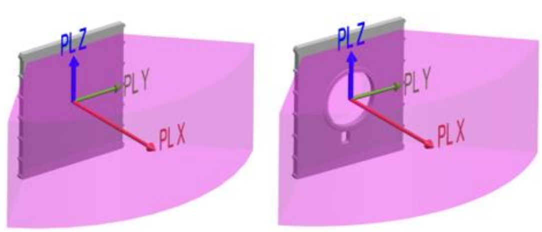


Figure 4-2: Side Mounted Payload Coordinate Frame

4.1.3 PAYLOAD FAIRINGS AND KEEP-IN VOLUMES

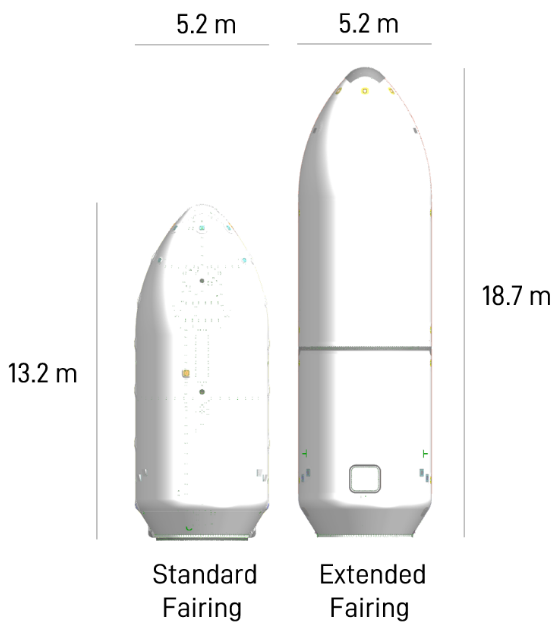


Figure 4-3: Standard and Extended Fairing

The standard SpaceX Falcon fairing is 5.2 m (17.2 ft) in outer diameter and 13.2 m (43.5 ft) high overall. The payload static envelope for the recoverable standard fairing with acoustic blankets installed is available for download on spacex.com. Other keep-in volumes are available upon request.

The payload static envelope, or keep-in volume, indicates the volume that the spacecraft is allowed to occupy under static conditions and accounts for payload dynamic deflections relative to the fairing, without intrusion by the fairing due to its dynamic motions. Dynamic deflections are verified via coupled loads analysis (CLA). The geometry of each PAF allows for payload hardware to protrude below the base of the payload static envelope; this is included in the published keep-in volumes. Any payload adapters required (e.g., to achieve a 937-mm or 1,194-mm or 1,666-mm (36.89 in. or 47.01 or 65.59 in.) interface) must also fit within the keep-in volumes.

SpaceX can also provide an extended fairing as a nonstandard service. The extended fairing has the same diameter as the standard faring (5.2 m, 17.2 ft) and an overall height of 18.7 m (61.25 ft). The payload static envelope for the extended fairing is available upon request. Most of the standard and nonstandard services provided for the standard fairing are available for the extended fairing as well. Please contact SpaceX for more details.

The standard fairing includes one access door in the cylindrical portion; SpaceX can also provide a fairing with up to eight access doors as a nonstandard service. The payload fairing doors are all in fixed positions and circular, with a 610-mm (24-in.) diameter size.

All processing requiring access to the payload must be completed prior to fairing encapsulation, including standard remove/install-before-flight items. Post-encapsulation access via the fairing door(s) for remove/install-before-flight items that cannot be accomplished prior to encapsulation can be provided as a nonstandard service. In the event of a payload anomaly requiring customer access to the payload, the standard concept of operations for Falcon vehicles is to return the launch vehicle to the hangar and remove the fairing. Access doors are not designed for emergency access into the payload fairing after encapsulation or once the launch vehicle is on the pad.

A single internal fairing RF antenna system can be provided as a nonstandard service for use during payload antenna testing while on the launch pad, using common command and telemetry frequencies. For missions using an internal fairing RF antenna, SpaceX utilizes fixed RF antennae locations on the fairing and will work to clock the payload accordingly. Contact SpaceX for further information on multiple RF antennae systems or nonstandard frequencies. Internal fairing RF antenna systems are not available for use during flight.

SpaceX can also provide a break wire signal to inform the spacecraft when the fairing is jettisoned, as a nonstandard service, to be used for enabling spacecraft transmitter activation on a non-interference basis.

4.1.4 INTERFACE SELECTION GUIDE

Customers should select and plan for the following interfaces, masses, and keep in volumes. Masses should be used as an initial guide. Further limitations may exist from mission-specific analyses.

Table 4-1: Guide on PAF Selection and Payload and Adapter Mass Overall Limitations

	Single Payload	Multi Payload/Constellations
Circular PAF, 1,575 mm *Section 4.1.5.1*	Total Mass: up to 10,885 kg, see Section 4.2.1 for CG limitations Keep-In Volume: • *Standard Fairing, Recoverable, with Blankets – available on spacex.com* • *Standard Fairing, Recoverable, without Blankets – contact SpaceX* • *Standard Fairing, Expendable – contact SpaceX*	
Circular PAF, 2,624 mm Section *4.1.5.2*	Total Mass: up to 19,050 kg, see Section 4.2.1 for CG limitations Keep-In Volume: • *Standard Fairing, Recoverable, with Blankets – available on spacex.com* • *Standard Fairing, Recoverable, without Blankets – contact SpaceX* • *Standard Fairing, Expendable – contact SpaceX*	
Circular PAF, 3,117 mm *Section 4.1.5.3*	Total Mass*: Contact SpaceX* Keep-In Volume*:* • *Standard Fairing – contact SpaceX* • *Extended Fairing – contact SpaceX*	N/A
Strut PAF, 3,117-mm *Sections 4.1.5.4*	Total Mass: up to 26,500 kg, see Section 4.2.1 for CG limitations Keep-In Volume*:* • *Extended Fairing only – contact SpaceX*	N/A
Square PAF *Section 4.1.5.5*	Total Mass: up to 10,885 kg, see Section 4.2.1 for CG limitations Keep-In Volume: • *Standard Fairing, Recoverable, with Blankets – available on spacex.com* • *Standard Fairing, Recoverable, without Blankets – contact SpaceX* • *Standard Fairing, Expendable – contact SpaceX*	Total Mass: • *Customer-Provided Dispenser:* up to 10,885 kg, see Section 4.2.1 for CG limitations • *SpaceX-Provided Dispenser*: up to 170 kg to 850 kg per payload, depending on Tiers, see Section 4.1.6 and 4.2.2 for limitations Keep-In Volume: • *Customer-Provided Dispenser*: see options for "Single Payload" on left • *SpaceX-Provided Dispenser:* See Section 4.1.6.

4.1.5 PAYLOAD ATTACH FITTINGS

4.1.5.1 1,575-MM PAF

The standard mechanical interface between SpaceX-provided Falcon launch vehicle hardware and customer-provided hardware is a 1,575-mm (62.01 in.) diameter bolted interface, at the forward end of the launch vehicle PAF (Figure 4-4). This interface is designed to conform to the EELV 1,575-mm (62.01 in.) diameter medium-payload-class mechanical interface defined in the EELV Standard Interface Specification Rev. C June 2017, and is defined in Appendix A. The forward end of the 1,575-mm PAF includes a close-out plate between the payload and the upper stage of the launch vehicle. SpaceX prefers the use of standard PLA interfaces for this PAF, which are offered as a standard service (see Section 4.1.7). Specifications for standard 937-mm or 1,194-mm or 1,666 mm payload interfaces are detailed in Appendix A. As a nonstandard service, SpaceX can procure a variety of other payload adapters for this interface.

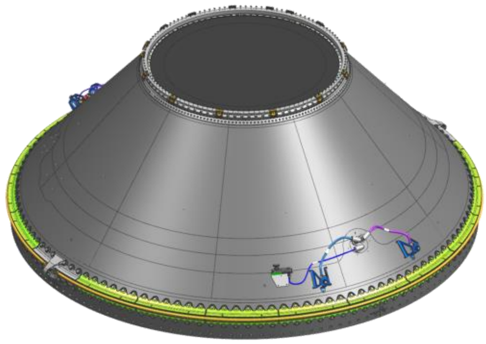


Figure 4-4: 1,575-mm Payload Attach Fitting

4.1.5.2 2,624-MM PAF

SpaceX offers a PAF with a 2,624-mm (103.307 in.) bolted interface (Figure 4-5) for payloads exceeding the 1,575 mm PAF capability. Interface specifications are detailed in Appendix A. The forward end of the 2,624-mm PAF also includes a close-out plate between the payload and the upper stage of the launch vehicle. SpaceX can provide a structural riser as a nonstandard service to raise the height of the payload interface plane above the keep-out volume. Please contact SpaceX for details. SpaceX can procure a variety of payload adapters for this interface, see Section 4.1.7.

Figure 4-5: 2,624-mm Payload Attach Fitting

4.1.5.3 3,117-MM PAF

SpaceX offers a PAF with a 3,117-mm (122.717 in.) bolted interface (Figure 4-6) for heavy to ultra-heavy payloads. Please contact SpaceX for interface specifications and mass-CG limitations. The forward end of the 3,117-mm PAF also includes a close-out plate between the payload and the upper stage of the launch vehicle. SpaceX can procure a 3,100-mm payload adapter as an optional service.

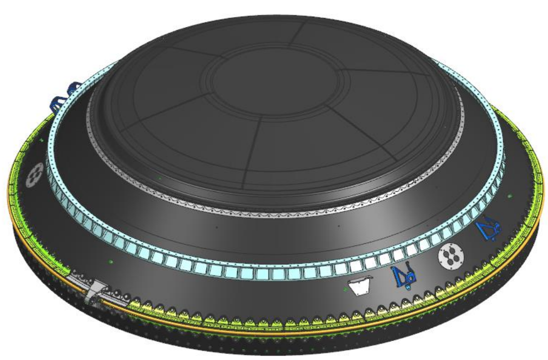


Figure 4-6: 3,117-mm Payload Attach Fitting

4.1.5.4 STRUT PAF INTERFACE

SpaceX offers a 3,117-mm (122.717 in.) payload interface for payloads requiring additional capability (Figure 4-7), using a strut architecture. The forward end of the PAF also includes a close-out plate between the payload and the launch vehicle. Contact SpaceX for interface specifications. The 3,117-mm strut PAF can be used only with an extended fairing.

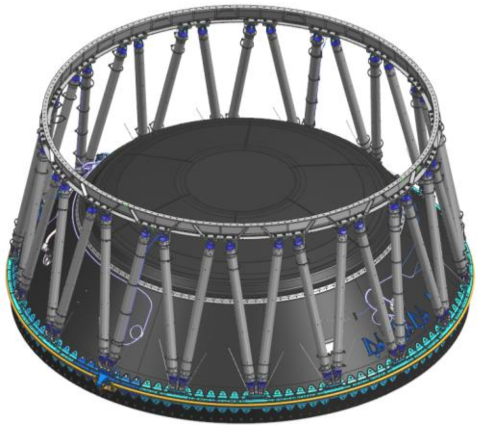


Figure 4-7: 3,117-mm Strut PAF

4.1.5.5 SQUARE PAF

SpaceX offers a square PAF option for a single or multiple manifested payload/constellation dedicated launch (Figure 4-8). See Section 4.1.6 for more details on constellations using square PAF. The square PAF has 96 holes for a 5/16" fastener, arranged in a cube configuration of 24 fastener holes per side (refer to Appendix A). The forward end of the square PAF also includes a close-out filter between the payload and the upper stage of the launch vehicle.

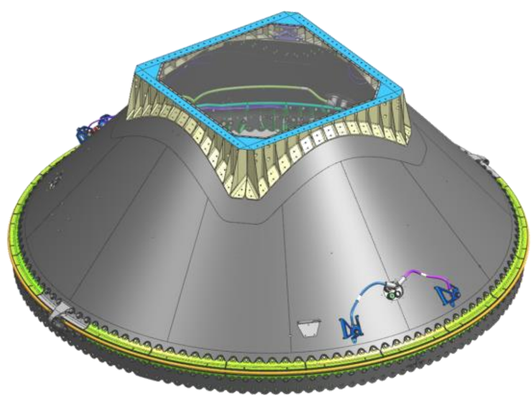


Figure 4-8: Square PAF

4.1.6 CONSTELLATION INTERFACE AND CONFIGURATION OPTIONS

With the Square PAF configuration, SpaceX can offer a dedicated, multi-payload mission using standard rideshare hardware developed for SpaceX's Rideshare Program. Please contact SpaceX or refer to the Rideshare Payload User's Guide for information regarding interface requirements, environments, and verification for side-mounted payloads. SpaceX can develop and provide such adapters and dispensers if desired, as a nonstandard service, or can integrate third-party systems.

SpaceX can accommodate up to 21 payloads (with a cube arrangement) or up to 41 payloads (with an octagon arrangement), as shown in Table 4-3 and Figure 4-9. Arrangements are shown as illustration only, and SpaceX could accommodate other arrangements. Each individual payload volume may only contain one payload confined to the available keep-in volume as defined in the following sections. Electrical connectivity may be limited depending on electrical requirement. Please reach out to SpaceX for further information.

Table 4-2: Constellation Standard Configuration

	Cube Arrangement	Octagon Arrangement
Maximum Number of Tiers	5 + 1 Forward Mounted Payload	5 + 1 Forward Mounted Payload
Maximum Number of Payloads	20 + 1 Forward Mounted Payload	40 + 1 Forward Mounted Payload

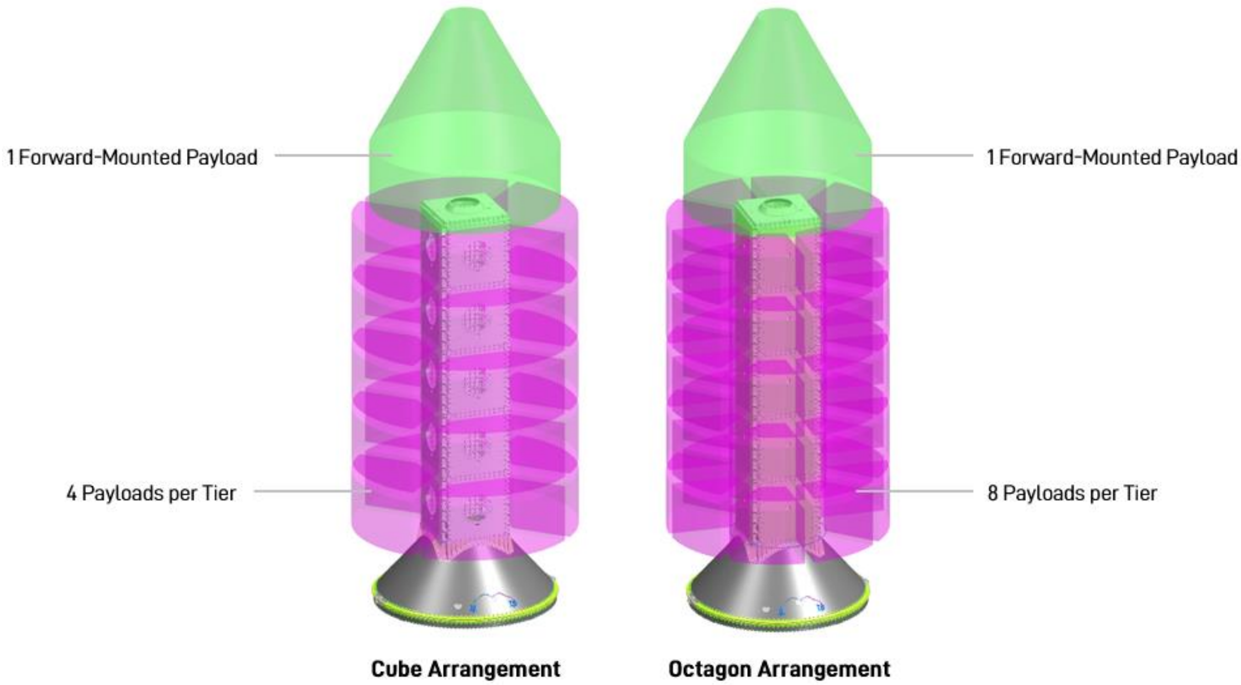


Figure 4-9: Example Constellation Arrangements in a Cube Configuration and Octagon Configuration

Table 4-3 provides a guide on the maximum payload mass per constellation configuration. Additional limitations exist on center of gravity for each payload per Section 4.2.2, and may be additionally limited by CLA analysis results. This guide assumes a forward mounted payload is present (all available payload interfaces are populated), and the forward mounted payload is identical to side mounted payloads. SpaceX may accommodate a heavier forward mounted payload, please contact SpaceX or consult the Cake Topper User Guide.

Table 4-3: Maximum Payload Mass per Constellation Configuration[1]

Number of Tiers	Cube Arrangement		Octagon Arrangement	
	Total Payload Max Mass	Per Payload Max Mass (Identical Payloads)	Total Payload Max Mass	Per Payload Max Mass (Identical Payloads)
1 Tier	4,250 kg	850 kg	7,650 kg	850 kg
2 Tiers	7,650 kg	850 kg	9,945 kg	585 kg
3 Tiers	9,750 kg	750 kg	9,500 kg	380 kg
4 Tiers	9,350 kg	550 kg	9,075 kg	275 kg
5 Tiers	6,930 kg	330 kg	6,970 kg	170 kg

IMPORTANT: Payloads flying with any of the configurations above will need to meet acoustic MPE levels for Falcon 9 without blankets (Section 5.3.4.2). Otherwise, additional restrictions may apply to the keep-in volumes defined in the next section.

4.1.6.1 CUBE ARRANGEMENT

Customers choosing a cube constellation arrangement configuration may choose between the following interfaces:

- 15" standard diameter circular interface
- 24" standard diameter circular interface
- 4-point interface

For payloads with a 24" diameter interface, there is an allowable 177.8 mm intrusion through the SpaceX-provided mechanical interface. Cube arrangement keep-in volumes are shown in Figure 4-10. Detailed volume dimensions and fastener interfaces can be found in Appendix C and the Rideshare Payload User's Guide. Refer to "XL Plate" and "XL Plate with Intrusion" interfaces. Payload adapters and separation systems must also fit within the keep-in volumes.

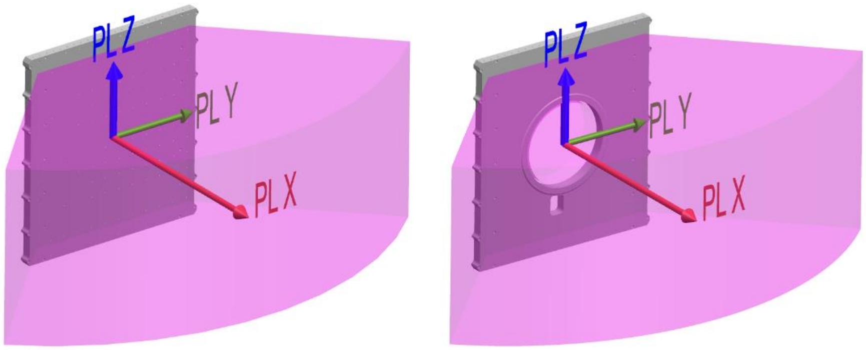


Figure 4-10: Cube Arrangement Keep-In Volumes

4.1.6.2 OCTAGON ARRANGEMENT

Customers choosing an octagon arrangement may choose between the following interfaces:

- 15" standard diameter circular interface
- 4-point interface (limited to 16" wide footprint; height may vary between 16" and 40" in 4" increments)

The octagon arrangement keep-in volumes are shown in Figure 4-11 (two volumes shown). Detailed volume dimensions and fastener interfaces can be found in Appendix C and the Rideshare Payload User's Guide. Refer to "Half XL Plate" interfaces. Payload adapters and separation systems must also fit within the keep-in volumes.

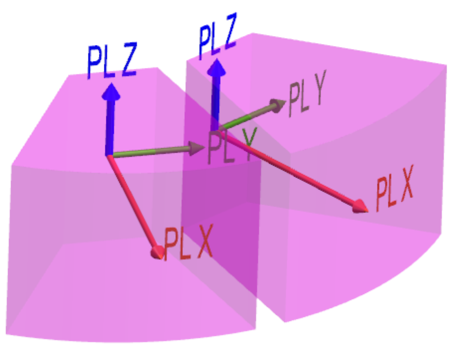


Figure 4-11: Octagon Arrangement Keep-In Volumes (2 Shown)

4.1.6.3 OTHER PAYLOAD ARRANGEMENTS

SpaceX may supply other multi-payload and constellation arrangements outside of these published options. Please contact SpaceX for more information.

4.1.7 PAYLOAD ADAPTERS AND SEPARATION SYSTEMS

SpaceX has extensive experience procuring payload adapter and separation systems for a variety of payloads.

4.1.7.1 STANDARD SERVICE

For customers with 937-mm (36.89 in.) or 1,194-mm (47.01 in.) or 1,666-mm (65.59 in.) clampband interface, SpaceX will either provide and integrate a payload adapter and clampband separation system or will integrate an adapter and separation system chosen and provided by the customer with the launch vehicle, as a standard service.

SpaceX prefers the use of standard PLA interfaces. Specifications for standard 937-mm or 1,194-mm or 1,666-mm interfaces are detailed in Appendix B: Payload Mechanical, Electrical and Purge Standard Interfaces.

4.1.7.2 NONSTANDARD SERVICE

For customers with alternative interface requirements, SpaceX can procure almost any industry-standard adapter system as a nonstandard service. SpaceX has experience integrating numerous commercially available and internally developed adapters and separation systems. Falcon 9 and Falcon Heavy are compatible with adapter and separation system products offered by industry-leading providers.

4.2 MASS – CG LIMITATIONS

4.2.1 PAF MASS-CG LIMITATIONS

Payloads should comply with the mass and CG properties limitations given in Figure 4-12 (for the 1,575-mm PAF, square PAF, and 2,624-mm PAF), and Figure 4-13 (for the 3,117-mm strut PAF). Payloads exceeding these limits may be accommodated as a mission-unique service. Payload mass properties should be assessed for all items forward of the PAF 1,575-mm, 2,624-mm, or 3,117-mm bolted interfaces, including any mission-unique payload adapters and separation systems. Mass properties capabilities may be further constrained by mission-unique payload adapters, dispensers, separation systems, or CLA results.

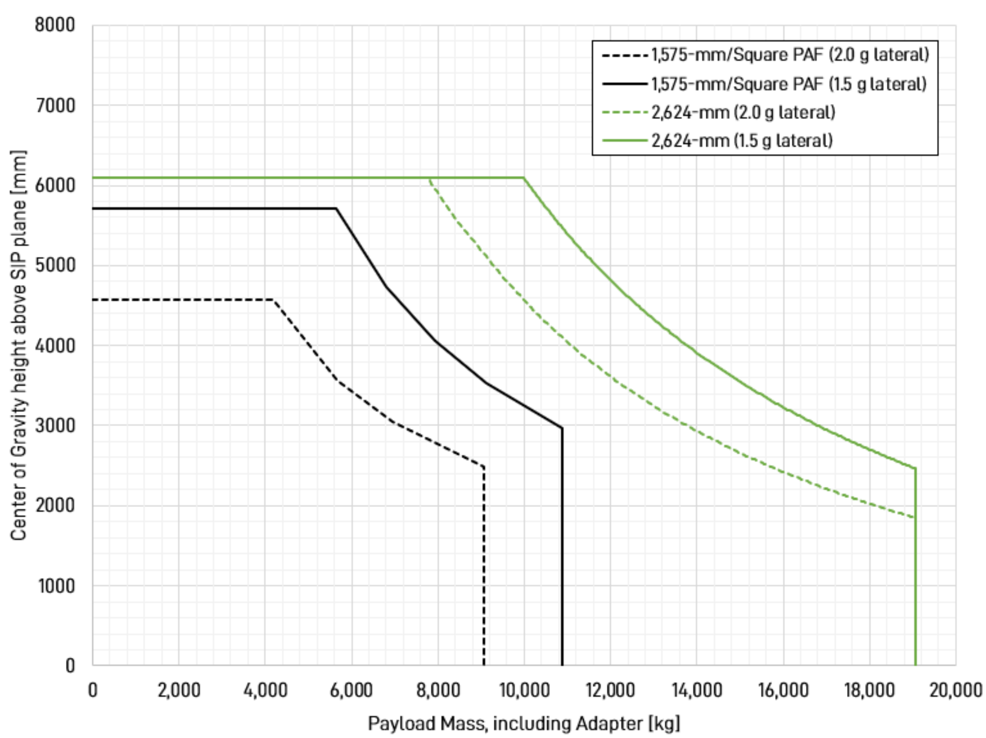


Figure 4-12: Allowable Mass and Center of Gravity above SIP for 1,575 mm, 2,624-mm, and Square PAF

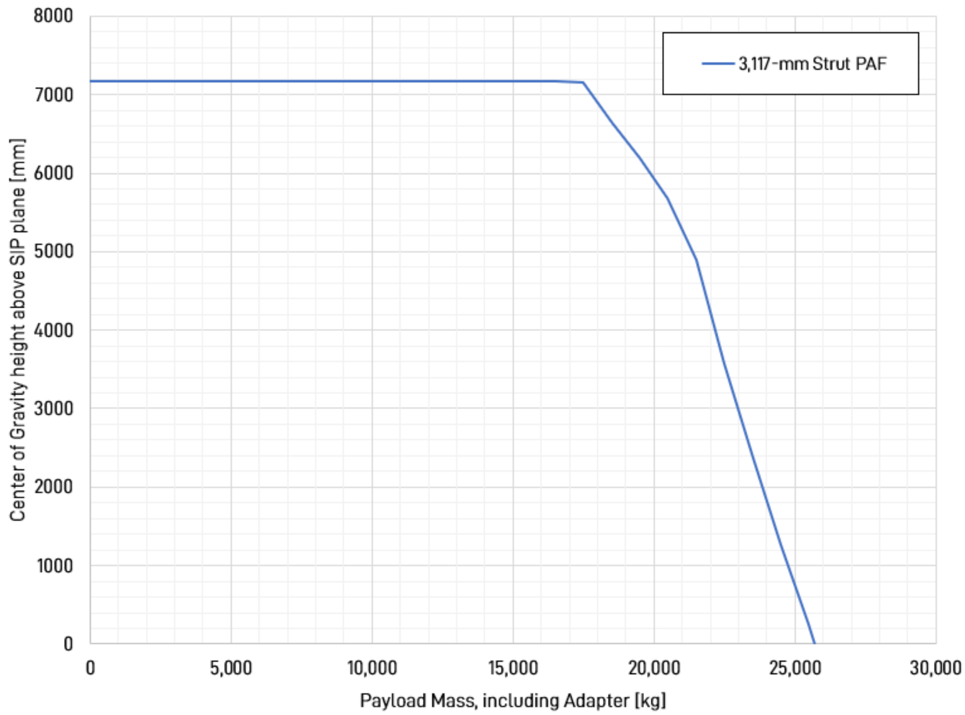


Figure 4-13: Allowable Mass Center of Gravity Height above SIP for the 3,117-mm Strut PAF

4.2.2 MASS-CG LIMITATIONS FOR CONSTELLATION PAYLOADS

For payloads with a 15" or 24" diameter mechanical interface, the mass and X_{PL} CG limitations are defined in Figure 4-14.

Note: CG limitation is relative to the launch vehicle interface, *inclusive of separation systems*. Typical separation system height for a side mounted payload is 50-55 mm.

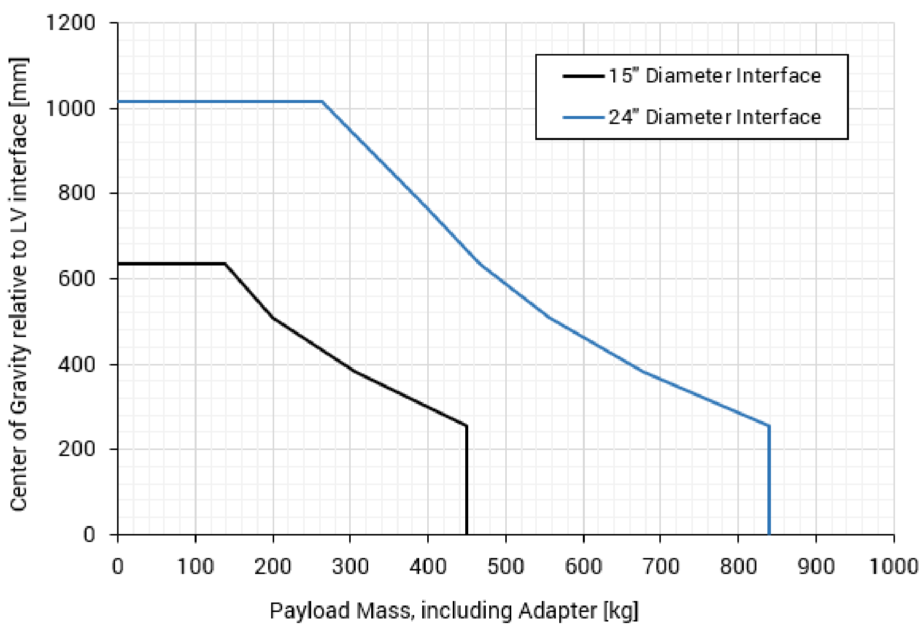


Figure 4-14: Mass and Center of Gravity Limitations for Constellation Payloads

For payloads with a 4-point interface, the mass and CG limitations are defined in Figure 4-15. Customers must select the mass and CG curve that matches the shorter edge of their 4-point interface, as measured from foot to foot.

Note: CG limitation is relative to the launch vehicle interface, *inclusive of separation systems*. Typical separation system height for a side mounted payload is 50-55 mm.

Examples:

- For a 16" x 24" 4-point interface, mass and CG must be within the 'Short edge 16" or greater' capability curve.
- For a 28" x 28" 4-point interface, mass and CG must be within the 'Short edge 24" or greater' capability curve.

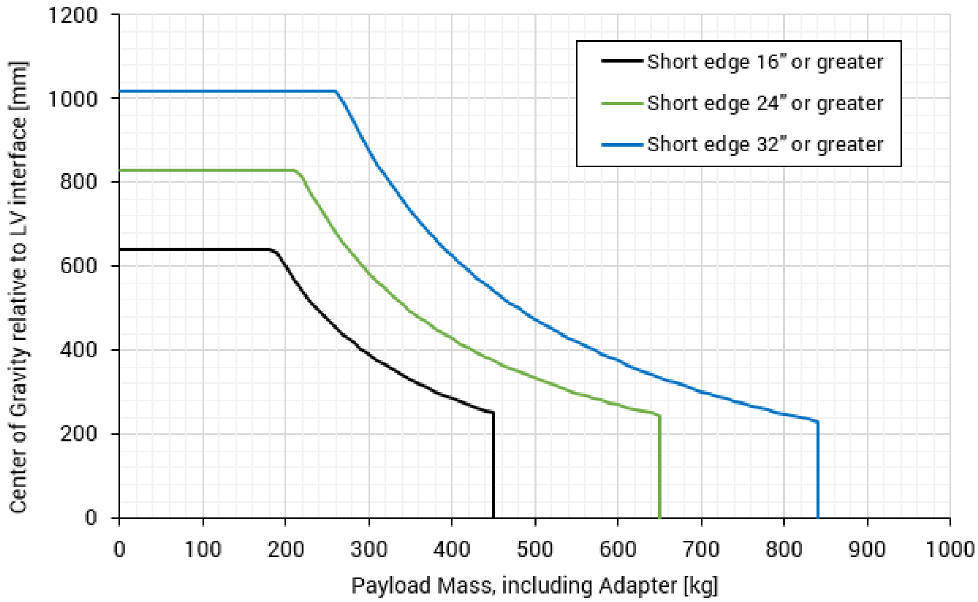


Figure 4-15: Payload Mass and Center of Gravity Limitations for 4-Point Interfaces

SpaceX requires that customers verify the mass properties of their system through measurement before shipping it to the launch site. SpaceX may request insight into relevant analyses and testing performed for satellite qualification, acceptance, and interface verification. Falcon vehicles may be able to accommodate payloads with characteristics outside the limitations indicated in this section. Please contact SpaceX with your mission-unique requirements.

4.3 PAYLOAD FLUID INTERFACES

4.3.1 GN2 PURGE

SpaceX can offer a purge interface as a nonstandard service. Specifications are provided in Table 4-4 and Appendix B: Payload Mechanical, Electrical and Purge Standard Interfaces.

Table 4-4: GN2 Purge Interface Offering

Purge Requirements	Specification
GN2 Purge Gas Purity	MIL-PRF-27401G, Type 1, Grade B
Purge Line/Fitting Cleanliness	IEST-STD-CC1246 level 100R1
GN2 Purge Pressure	0 – 3.45 barg (0 – 50 psig)
GN2 Purge Flow Rate	5 – 50 SLPM

4.3.2 CRYOGENIC PROPELLANT LOADING

SpaceX can offer LOX and LCH_4 cryogenic propellant loading as a nonstandard service at LC-39A. Specifications are provided below and in Appendix D. Please contact SpaceX for further information.

- SpaceX provides four (4) cryogenic propellent loading lines, including one (1) LOX fill line, one (1) LOX drain line, one (1) LCH4 fill line, and one (1) LCH4 drain line.
- SpaceX provides four (4) QDs to serve as the interface between the payload-side cryogenic lines and the LV-side cryogenic lines. SpaceX will provide and manage both payload side and LV side of the QD lines.
- The customer shall use flex hoses with a ¾" outer diameter to mate to the SpaceX QDs per specifications in Appendix D: Cryogenic Propellant Interface. Flex hoses and flex hose fittings are provided by the customer.
- Payload must be compatible with a 1,575 mm payload adapter. Specifications are defined in relation to the payload to LV interface plane (1,575-mm adapter passive ring interface).
- Commodity specifications are shown in Table 4-5.
- During cryogenic loading operations, only one commodity will be filled at a time. SpaceX must be able to control the payload-side fill/drain valves as part of the cryogenic loading operation.
- Cryogenic loading operations will be jointly developed between the customer and SpaceX.

Verification: Customers must demonstrate that the payload passes successful integrated leak checks. See Section 7.5.3.

Table 4-5: Cryogenic Loading Commodity Specifications

	Oxygen (LOX)	Methane (CH4)
Specification	MIL PRF 25508 Grade A (99.6%)	Highest purity product available, with agreement from customer
Flowrate	Max. 45.4 L/min (12 GPM)	Max. 75.7 L/min (20 GPM)
Pressure (Liquid fill)	Max. 6.89 bar (100 psia)	Max. 6.89 bar (100 psia)
Pressure (Ullage)	Max. 6.89 bar (100 psia)	Max. 6.89 bar (100 psia)
Propellant Ground Interface Temperature	Min. -190°C (-310°F)	Min. -168°C (-270°F)
Filtration	139 μm abs.	139 μm abs.

4.4 ELECTRICAL INTERFACES

Falcon vehicles provide electrical connectivity between the payload and customer-provided electrical ground support equipment prior to launch, as well as in-flight separation device commanding and separation monitoring. Table 4-6 summarizes the standard electrical offering for payloads:

Table 4-6: Electrical Interface Summary

Signal Type	Standard Offering
Ground-side Umbilical	Up to 2x 61-Pin Connectors
Separation Command	Up to 81x Redundant Signals
LV-side Breakwire Channels	Up to 160x Channels

Additional capability, including interleaved telemetry, discrete payload commanding, switch closure functions, and additional payload separation commands are available as a nonstandard service and can be defined as part of payload-specific ICD as part of the mission development process.

4.4.1 SEPARATION COMMANDS

Deployment channels are offered in pairs of primary and secondary commands. One primary and one secondary command are used for each actuation. Customer-procured separation devices must be approved by SpaceX.

All customer-procured deployment/separation devices directly interfacing with launch vehicle electrical systems must have sufficient reliability to ensure safe deployment. The preferred method of achieving reliability is two independent actuators on separate circuits. Either of these actuators must be capable of independently initiating payload separation, effectively removing a single point of failure to launch vehicle separation. Exceptions to this method are discouraged but can be considered on a case-by-case basis at SpaceX's sole discretion.

All deployments from the launch vehicle will be commanded by SpaceX. The use of customer-provided sequencers for commanding more than one deployment from the launch vehicle within the payload is prohibited.

The deployment device timing delay from receipt of the launch vehicle deployment signal to physical release of the payload is required to be characterized as <2 seconds ± 0.5 second uncertainty.

Each deployment command sent by the launch vehicle can be configured in one of two ways:

1. Constant-Current Pulse: Used for low-resistance loads, this mode of operation provides up to 6 A of constant current. Specifics of the pulse duration and current setting will be defined as part of the payload-specific ICD.

2. Bus-Voltage Pulse: Used for high-resistance or motor-driven loads, this mode of operation will provide an unregulated voltage signal with a bus voltage of 24-36 V with a maximum current draw of 6 A. Specifics of the voltage provided to the separation device and pulse duration will be defined as part of the payload-specific ICD.

The specific configuration of the deployment commands will be determined by SpaceX through analysis and testing of each separation device. A test unit of each type of new separation device must be provided by the customer to SpaceX for this testing.

4.4.2 BREAKWIRE CHANNELS

Breakwire channels are used to determine separation status of the payload constituents from the launch vehicle. Breakwires are organized into two categories, "PL-side breakwires," which are used by the launch vehicle to detect separation, and "LV-side breakwires," which are used by the payload to detect separation. This is illustrated in Figure 4-16.

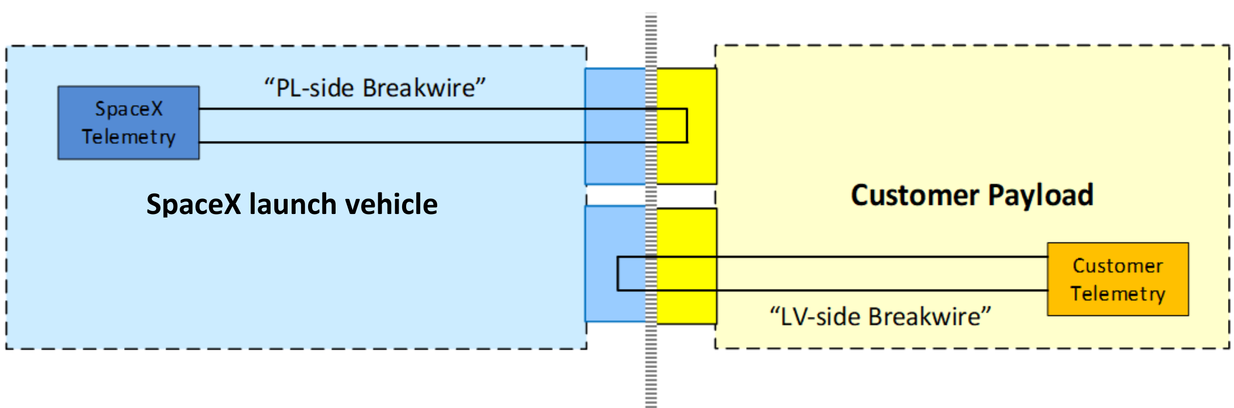


Figure 4-16: Illustration of Breakwire Channel Categories

A minimum of one (1) PL-side breakwire is recommended to be used for each deployment from the launch vehicle, SpaceX will evaluate exceptions on a case-by-case basis. There are no restrictions from SpaceX on the number of LV-side breakwires requested by the customer.

PL-side breakwire channels must transition from a low resistance state to a high resistance state, or vice-versa. Table 4-7 defines the required properties of each state.

Table 4-7: PL-Side Breakwire Resistance Requirements

PL-Side Breakwire State	Resistance Requirement
Low-resistance state	<200 Ω
High-resistance state	>8 kΩ

It is acceptable for either loopback circuits or separation switches to be used for PL-side and LV-side breakwires. The final properties of the PL-side breakwire circuit(s), including the expected transition during deployment, will be defined as part of the payload-specific ICD.

The Falcon vehicle provides up to 8 PL-side breakwire channels. Customer may request any number of LV-side breakwire loops at a separation connector.

4.4.3 ELECTRICAL UMBILICAL CONNECTORS

As a standard service, Falcon launch vehicles provide up to two in-flight disconnect electrical interface points located at the payload separation plane. See Appendix B: Payload Mechanical, Electrical and Purge Standard Interfaces for umbilical locations. MIL-C-81703 connectors are strongly recommended to encourage schedule compatibility. A list of examples of in-flight disconnect connectors is shown below in Table 4-8. Falcon is compatible with many connectors outside of this list. Please contact SpaceX if you have questions regarding the use of a specific connector.

Table 4-8: Example In-Flight Disconnect Connectors

Part Number (Payload-side)	Part Number (LV-side)	Number of Electrical Contacts
DBAS-70-61-0SN	DBAS-79-61-0PN	61
DBAS-70-61-0SY	DBAS-79-61-0PY	61

All customer electrical interfaces, including EGSE interfaces, will be defined as part of the payload-specific ICD.

4.4.4 FLIGHT HARNESS DESIGN

Flight harnesses are nominally designed and built by SpaceX up to the payload interface at the separation plane. Other interface locations are possible. The interface location and build responsibility of the harnesses will be defined as part of the payload-specific ICD.

4.4.5 UMBILICAL CONNECTIVITY DURING PAYLOAD PROCESSING AND ON LAUNCH PAD

The Falcon 9 and Falcon Heavy systems accommodate electrical connectivity between customer EGSE and the payload during most processing and integration activities. Table 4-9 summarizes the availability of interfaces during standard processing and integration activities. Customers may connect directly between their EGSE and their payload during payload processing operations. Electrical interfaces will not be available during SpaceX adapter mate, encapsulation, launch vehicle integration, and rollout operations. However, between these steps the customer will be able to interface with its payload. Customers may supply separate EGSE for payload processing facility (PPF) and pad operations or may relocate EGSE from the PPF to the pad.

Table 4-9: Payload Electrical Interface Connectivity

Phase	Interface Connection
In PPF (payload processing)	Customer cables directly to payload
In PPF (adapter mate and encapsulation)	None – SpaceX connects the payload to the flight adapter harness; SpaceX will provide payload to PAF connection cables
In PPF (encapsulated)	Customer cables to PPF junction box or equivalent interface
Transport to hangar	None – mobile
In hangar (pre-integration)	Customer cables to hangar junction box
In hangar (launch vehicle integration)	None – SpaceX connects the flight adapter harness to the second stage flight harness
In hangar (on transporter-erector)	Customer cables to hangar junction box (J-box)
Rollout	None – mobile
On pad (horizontal and vertical)	Customer cables (provided by customer) to pad junction box (J-box)
Flight	None – separation indication only

Pad EGSE provided by the customer will be housed in an instrument bay beneath the launch pad deck (Section 8.1). Payload EGSE is connected to a SpaceX-provided junction box. If utilizing hangar and pad EGSE connections, customers must provide 6.1-m (20-ft) cables to connect the payload EGSE to the junction box.

The junction box ("J-box") is connected to the launch vehicle transporter-erector via a ground harness. A harness then runs along the length of the transporter-erector and connects to the second stage T-0 quick disconnect. The flight side of the second stage quick disconnect mates to up to four dedicated payload electrical harnesses that are provided by SpaceX as part of the second stage. The payload harnesses are routed along the exterior of the second stage propellant tanks, underneath raceway covers that provide protection during ground and flight operations. At the top of the second stage, the harnesses are routed through the PAF (Section 4.1.5) and to the spacecraft separation plane.

The total cable lengths between the payload racks/EGSE and the spacecraft separation plane are listed in Table 4-10 and shown in Figure 4-17.

Table 4-10: Maximum Expected Cable Lengths Between Payload Racks/EGSE and Separation Plane

Launch Site	PPF	Hangar	Launch Pad
VSFB (SLC-4)	30.5 m (100 ft)	208.5 m (684 ft)	171.9 m (564 ft)
CCSFS (SLC-40)	18.3 m (60 ft)	197.8 m (649 ft)	171.9 m (564 ft)
KSC (LC-39A)	18.3 m (60 ft)	181.1 m (594 ft)	196.3 m (644 ft)

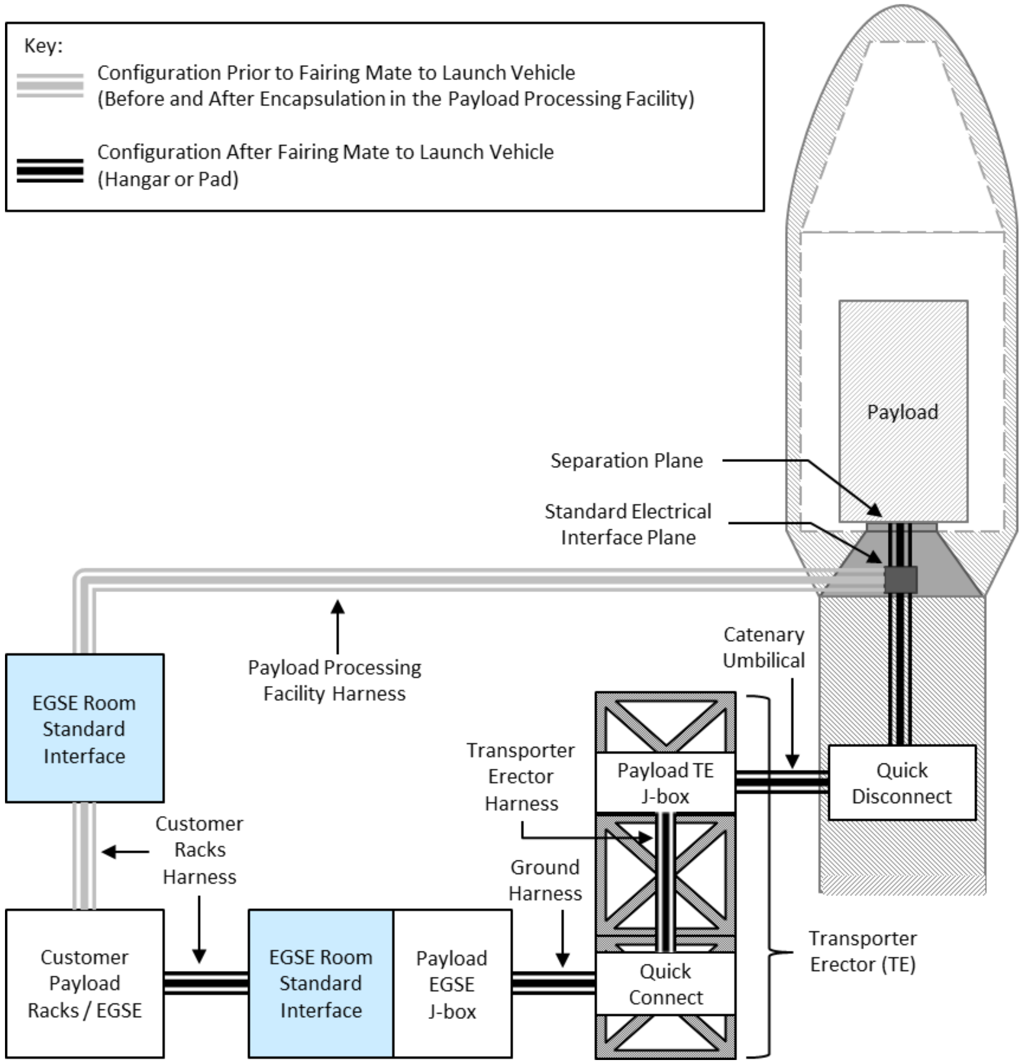


Figure 4-17: On-Pad Electrical Interfaces

The lowest available round-trip resistance from EGSE to the standard electrical interface plane is 1 Ω. SpaceX ground systems maintain a minimum of 1 MΩ of isolation resistance between conductors. Table 4-11 defines the typical distribution of EGSE signal properties offered as a standard service. Contact SpaceX for mission-specific EGSE signal configurations.

Table 4-11: EGSE Electrical Properties

Signal Properties	Number of Available Conductors
1 Ω one-way resistance	24
2 Ω one-way resistance	12
3 Ω one-way resistance	60
4 Ω one-way resistance	60
13 Ω one-way resistance	20
100 Ω controlled characteristic impedance	48

4.4.6 TIMING SERVICES

SpaceX can supply inter-range instrumentation group IRIG-B000 or IRIG-B120 time from its GPS clocks to customer EGSE at the PPF and/or the launch pad. A launch countdown clock can also be supplied in the IRIG CS-5246 format. These timing services are provided as a standard service; other options are available as nonstandard services.

4.5 INTERFACE COMPATIBILITY VERIFICATION REQUIREMENTS

SpaceX requires that customers verify the compatibility of their systems with the Falcon mechanical, electrical, and fluid interfaces before shipment to the launch site. As a standard service, SpaceX will support a payload adapter mechanical fit check, including electrical connector location compatibility, at a facility of the customer's choosing. This interface compatibility verification does not include a separation shock test. Second unit and later flights of similar systems may be subject to reduced pre-ship verification requirements. Nonstandard verification approaches can be developed on a mission-unique basis.

5 ENVIRONMENTS

Falcon 9 and Falcon Heavy have been designed to provide as benign a payload environment as possible via the use of all-liquid propulsion, a single staging event, deeply throttleable engines, and pneumatic separation systems. The environments presented below reflect mission levels for Falcon 9 and Falcon Heavy and are based on the use of the standard fairing; please contact SpaceX for information on payload environments for missions requiring the extended fairing. Mission-specific analyses will be performed and documented in an interface control document for each mission.

5.1 TRANSPORTATION ENVIRONMENTS

Transportation will be accomplished by two-wheeled vehicles: a payload transporter from the PPF to the hangar and the launch vehicle transporter-erector from the hangar to the launch pad. The maximum predicted environments experienced by the payload during transportation are provided in Table 5-1. It is expected that transportation environments will be enveloped by the flight environments in Section 5.3 for most payloads.

Table 5-1: Quasi-Static Load Factors for Transportation

Transportation Method	LV Longitudinal Acceleration (g)[1]	LV RSS Lateral Acceleration (g)[1]
PPF to Hangar using payload Transporter	-0.5 / +1.5 g	1.0 g
Hangar to Pad Rollout using Transporter Erector	-1.0 / +1.5 g	1.5 g

[1] Limits are inclusive of both static and dynamic loads, including gravity.

5.2 TEMPERATURE, HUMIDITY, AND CLEANLINESS

The standard service temperature, humidity, and cleanliness environments during various processing phases are provided in Table 5-2. Values in the table are selectable where explicitly stated. Conditioned air will be disconnected for a short duration during rollout to the pad. Spacecraft environmental temperatures will be maintained above the dew point of the supply air at all times (*Note:* prior to rollout to pad, ECS air may need to be briefly preconditioned to 30°C (86°F) to ensure dew point is not reached). A nitrogen purge is available as a non-standard service, see Section 4.3.1. The PAF and fairing surface are cleaned to Visibly Clean-Highly Sensitive, achieving a residue level between R2E-1 and R1 and a particulate level between 500 and 750 per IEST-STD-CC1246E. SpaceX can accommodate environments outside the standard service. Please contact SpaceX for details.

Table 5-2: Temperature and Cleanliness Environments

Phase	Control System	Approx. Duration	Temp. (°C [°F])	Humidity (%)	Cleanliness (class)
Spacecraft processing	Facility HVAC	3 weeks	15 – 25 [59 – 77]	30 – 65	100,000 (Class 8)
Propellant conditioning	Facility HVAC	3 days	15 – 25 [59 – 77]	30 – 65	100,000 (Class 8)
Spacecraft propellant loading	Facility HVAC	Mission unique	15 – 25 [59 – 77]	30 – 65	100,000 (Class 8)
Transport from PPF to Hangar	Trailer TAC	<12 hours	15 – 30 [59 – 86]	0 – 65	10,000 (Class 7 supply air cleanliness)
Encapsulated in hangar	Ducted supply from hangar ECS	1 week	15 – 25 [59 – 77]	30 – 65	10,000 (Class 7 supply air cleanliness)
Encapsulated rollout to pad without ECS	None	<1 hour	N/A	N/A	10,000 (Class 7 supply air cleanliness)
Encapsulated rollout to pad with ECS	Trailer TAC	<4 hours	15 – 30 [59 – 86]	0 – 65	10,000 (Class 7 supply air cleanliness)
Encapsulated on pad (vertical or horizontal)	Pad ECS	<1 day	Selectable 15.6 – 30 [60 – 86]	0 – 65	10,000 (Class 7 supply air cleanliness)

5.3 FLIGHT ENVIRONMENTS

The maximum predicted environments the payload will experience from liftoff through separation are described in the sections below. Falcon vehicles may be able to accommodate payloads with characteristics outside the limitations indicated in these sections and may also be able to provide environments lower than those indicated in these sections. Please contact SpaceX with your mission-unique requirements.

5.3.1 NATURAL FREQUENCY

SpaceX recommends that the payload's primary lateral frequency be above 10 Hz, the primary axial frequency be above 25 Hz, and all secondary structure minimum resonant frequencies be above 35 Hz to minimize coupling with launch vehicle dynamics. Payloads with primary frequencies below the recommended levels can be accommodated but may result in mission-specific loads that exceed the quasi-static load factors described in Section 5.3.2 and the sine vibration environment described in Section 5.3.3. Contact SpaceX for more details.

5.3.2 QUASI-STATIC LOADS

During flight, the payload will experience a range of axial and lateral accelerations. Axial acceleration is driven by vehicle thrust and drag profiles; lateral acceleration is primarily driven by wind gusts, engine gimbal maneuvers, first stage engine shutdown, and other short-duration events. Both the first and second stage engines may be throttled to help maintain launch vehicle and payload steady state acceleration limits.

Figure 5-1 and Table 5-3 provide the quasi-static load factors envelope for the following mass classes:

- *Heavy-class payloads* - total payload mass greater than 1,800 kg (Falcon 9 and Falcon Heavy)
- *Medium-class payloads* - total payload mass between 1,000 kg and 1,800 kg (Falcon 9 only)
- *Light-class payloads* - total payload mass lower than 1,000 kg (Falcon 9 only)

Please contact SpaceX for more information on Falcon Heavy payloads under 1,800 kg.

Provided loads are maximum flight loads (limit level) and do not contain a qualification factor, refer to Section 7 on test factors and verification. The quasi-static load factors are intended for a single payload mission; multi-payload missions should coordinate directly with SpaceX.[2] A positive axial value indicates a compressive net-CG acceleration, while a negative value indicates tension.

Loads are applicable for payloads with and without isolators below the spacecraft interface.

Actual payload loads, accelerations, and deflections are a function of both the launch vehicle and payload structural dynamic properties and can be accurately determined via CLA. Please consult with SpaceX for applicability based on spacecraft modal frequencies and CG height.

---

[2] For forward-facing payloads (Cake Toppers) on a dedicated mission with SpaceX-supplied dispensers, please refer to the Cake Topper's User Guide for enveloping limit levels. For side-mounted payloads on a dedicated mission with SpaceX-supplied dispensers, please refer to the Rideshare User's Guide for enveloping limit levels.

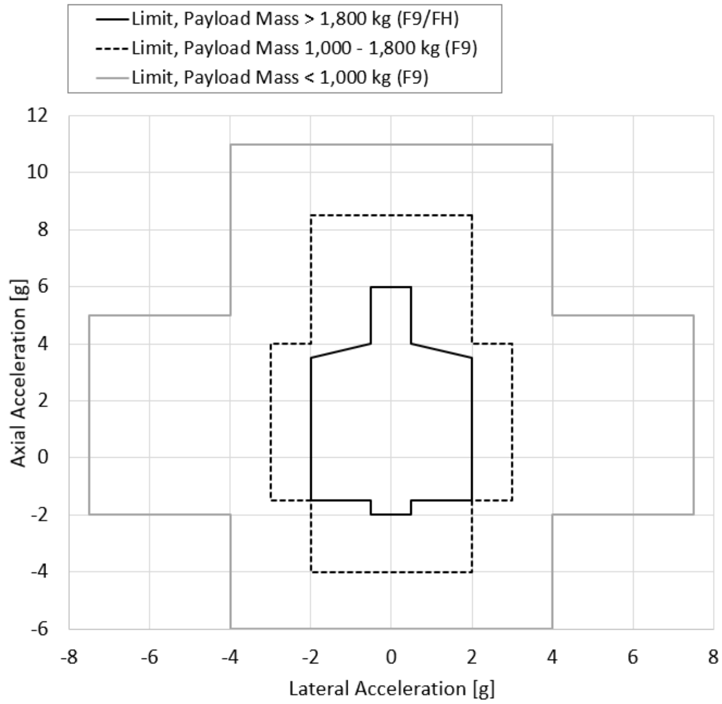


Figure 5-1: Falcon 9 and Falcon Heavy Flight Limit Load Factors

Table 5-3: Falcon 9 and Falcon Heavy Flight Limit Load Factors

>1,800 kg (F9/FH)		1000 – 1800 kg (F9)		<1,000 kg (F9)	
Axial [g]	Lateral [g]	Axial [g]	Lateral [g]	Axial [g]	Lateral [g]
6.0	0.5	8.5	2.0	11.0	4.0
4.0	0.5	4.0	2.0	5.0	4.0
3.5	2.0	4.0	3.0	5.0	7.5
-1.5	2.0	-1.5	3.0	-2.0	7.5
-1.5	0.5	-1.5	2.0	-2.0	4.0
-2.0	0.5	-4.0	2.0	-6.0	4.0
-2.0	-0.5	-4.0	-2.0	-6.0	-4.0
-1.5	-0.5	-1.5	-2.0	-2.0	-4.0
-1.5	-2.0	-1.5	-3.0	-2.0	-7.5
3.5	-2.0	4.0	-3.0	5.0	-7.5
4.0	-0.5	4.0	-2.0	5.0	-4.0
6.0	-0.5	8.5	-2.0	11.0	-4.0
6.0	0.5	8.5	2.0	11.0	4.0

5.3.3 SINE VIBRATION

The maximum predicted sinusoidal vibration environments are shown in Figure 5-2 and Table 5-4 for:

- *Heavy-class payloads* - total payload mass greater than 1,800 kg (Falcon 9 and Falcon Heavy)
- *Medium-/light-class payloads* - total payload mass lower than 1,800 kg (Falcon 9 only)

These environments represent the vibration levels at the top of the PAF for Q=20 through Q=50, and envelop all stages of flight. Please contact SpaceX for more information on Falcon Heavy payloads under 1,800 kg.

<u>IMPORTANT</u>: If the payload has any isolation systems below the spacecraft interface, these levels do not apply. Reference Section 6.3 and contact SpaceX for further details.

The sine vibration environments are intended for a single payload mission; multi-payload missions should coordinate directly with SpaceX.[3]

Provided loads are maximum flight loads (limit level) and do not contain a qualification factor; refer to Section 7 for test factors and verification. The results of CLA may be used to modify these levels, if necessary, to reflect the levels at the payload interface.

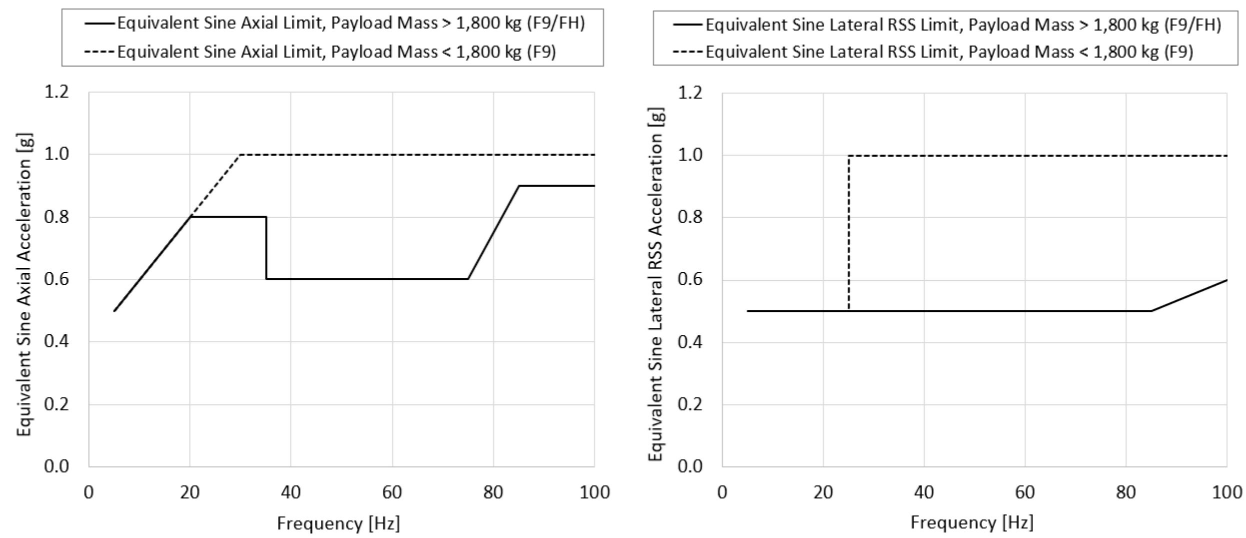


Figure 5-2: Maximum Limit Level Axial and Lateral RSS Equivalent Sine Environment for Falcon 9 and Falcon Heavy

Table 5-4: Maximum Limit Level Axial and Lateral RSS Equivalent Sine Environment for Falcon 9 and Falcon Heavy

Maximum limit level axial sine environment				Maximum limit level lateral RSS sine environment			
>1,800 kg (F9/FH)		<1,800 kg (F9)		>1,800 kg (F9/FH)		<1,800 kg (F9)	
Frequency [Hz]	Eq. sine axial [g]	Frequency [Hz]	Eq. sine axial [g]	Frequency [Hz]	Eq. sine lateral [g]	Frequency [Hz]	Eq. sine lateral [g]
5	0.5	5	0.5	5	0.5	5	0.5
20	0.8	30	1.0	85	0.5	25	0.5
35	0.8	100	1.0	100	0.6	25	1.0
35	0.6					100	1.0
75	0.6						
85	0.9						
100	0.9						

5.3.4 ACOUSTICS

During flight, the payload will be subjected to a varying acoustic environment, with levels highest near liftoff and during transonic flight, due to aerodynamic excitation. The acoustic environment, defined as the spatial average and derived at a P95/50 level, is shown with full-octave and third-octave definitions. Predicted acoustic levels for a specific mission will depend on the use of acoustic blankets and the payload's size and volume, with smaller payloads generally having lower acoustic levels based on their lower fill fraction of the fairings volume. Margin for qualification testing or for payloads larger than 60% fairing volume fill is not included in the MPE. Levels are shown for both Western Range and Eastern Range launch sites.

[3] For forward facing payloads (Cake Toppers) on a dedicated mission with SpaceX-supplied dispensers, please refer to the Cake Topper's User Guide for enveloping limit levels. For side-mounted payloads on a dedicated mission with SpaceX-supplied dispensers, please refer to the Rideshare User's Guide for enveloping limit levels.

5.3.4.1 FALCON 9, STANDARD FAIRING, WITH ACOUSTIC BLANKETS

Figure 5-3 and Table 5-5 show the acoustic MPE levels for Falcon 9 standard fairing with acoustic blankets.

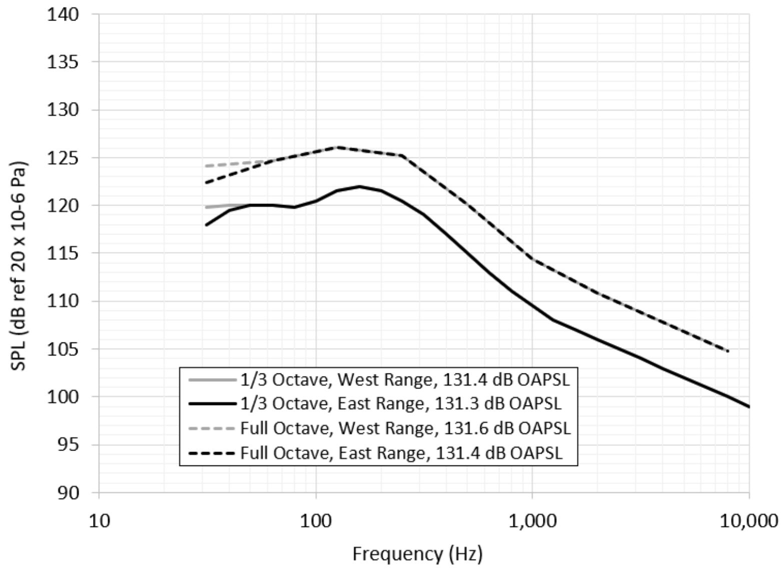


Figure 5-3: Falcon 9 Acoustic MPE (P95/50), with Acoustic Blankets, 60% Fill-Factor, Western and Eastern Range

Table 5-5: Falcon 9 Acoustic MPE (P95/50), with Acoustic Blankets, 60% Fill-Factor, Western and Eastern Range

Frequency (Hz)	Acoustic MPE, WITH blankets, WEST Range, 60% Fill-Factor (1/3 Octave)	Acoustic MPE, WITH blankets EAST Range, 60% Fill-Factor (1/3 Octave)
31.5	119.8	118.0
40	120.0	119.5
50	120.0	120.0
63	120.0	120.0
80	119.8	119.8
100	120.5	120.5
125	121.5	121.5
160	122.0	122.0
200	121.5	121.5
250	120.5	120.5
315	119.0	119.0
400	117.0	117.0
500	115.0	115.0
630	113.0	113.0
800	111.0	111.0
1000	109.5	109.5
1250	108.0	108.0
1600	107.0	107.0
2000	106.0	106.0
2500	105.0	105.0
3150	104.0	104.0
4000	103.0	103.0
5000	102.0	102.0
6300	101.0	101.0
8000	100.0	100.0
10000	99.0	99.0
OASPL (dB)	131.4	131.3

Frequency	Acoustic MPE, WITH blankets, WEST Range, 60% Fill-Factor (Full Octave)	Acoustic MPE, WITH blankets EAST Range, 60% Fill-Factor (Full Octave)
31.5	124.1	122.4
63	124.7	124.7
125	126.1	126.1
250	125.2	125.2
500	120.1	120.1
1000	114.4	114.4
2000	110.8	110.8
4000	107.8	107.8
8000	104.8	104.8
OASPL (dB)	131.6	131.4

5.3.4.2 FALCON 9, STANDARD FAIRING, WITHOUT ACOUSTIC BLANKETS

Figure 5-4 and Table 5-6 show the acoustic MPE levels for Falcon 9 standard fairing without acoustic blankets.

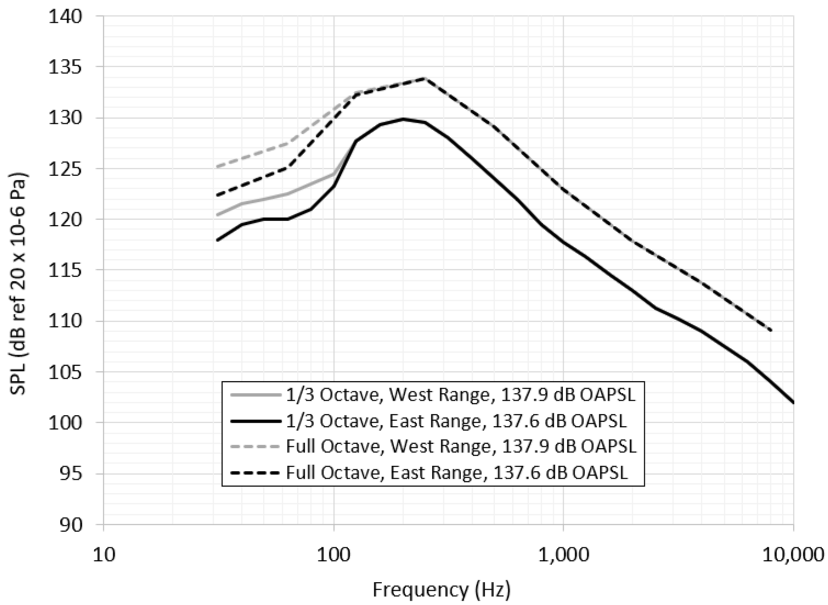


Figure 5-4: Falcon 9 Acoustic MPE (P95/50), without Acoustic Blankets, 60% Fill-Factor, Western and Eastern Range

Table 5-6: Falcon 9 Acoustic MPE (P95/50), without Acoustic Blankets, 60% Fill-Factor, Western and Eastern Range

Frequency (Hz)	Acoustic MPE, NO blankets, WEST Range, 60% Fill-Factor (1/3 Octave)	Acoustic MPE, NO blankets EAST Range, 60% Fill-Factor (1/3 Octave)
31.5	120.5	118.0
40	121.5	119.5
50	122.0	120.0
63	122.5	120.0
80	123.5	121.0
100	124.5	123.3
125	127.7	127.7
160	129.3	129.3
200	129.8	129.8
250	129.5	129.5
315	128.0	128.0
400	126.0	126.0
500	124.0	124.0
630	122.0	122.0
800	119.5	119.5
1000	117.8	117.8
1250	116.4	116.4
1600	114.5	114.5
2000	113.0	113.0
2500	111.3	111.3
3150	110.2	110.2
4000	109.0	109.0
5000	107.5	107.5
6300	106.0	106.0
8000	104.0	104.0
10000	102.0	102.0
OASPL (dB)	137.9	137.6

Frequency	Acoustic MPE, NO blankets, WEST Range, 60% Fill-Factor (Full Octave)	Acoustic MPE, NO blankets EAST Range, 60% Fill-Factor (Full Octave)
31.5	125.2	122.4
63	127.5	125.1
125	132.4	132.2
250	133.9	133.9
500	129.1	129.1
1000	122.9	122.9
2000	117.9	117.9
4000	113.8	113.8
8000	109.1	109.1
OASPL (dB)	137.9	137.6

5.3.4.3 FALCON HEAVY, STANDARD FAIRING

Figure 5-5 and Table 5-7 provide the acoustic MPE levels for Falcon Heavy standard fairing with acoustic blankets. These levels are applicable to launches from the Eastern Range (LC-39A).

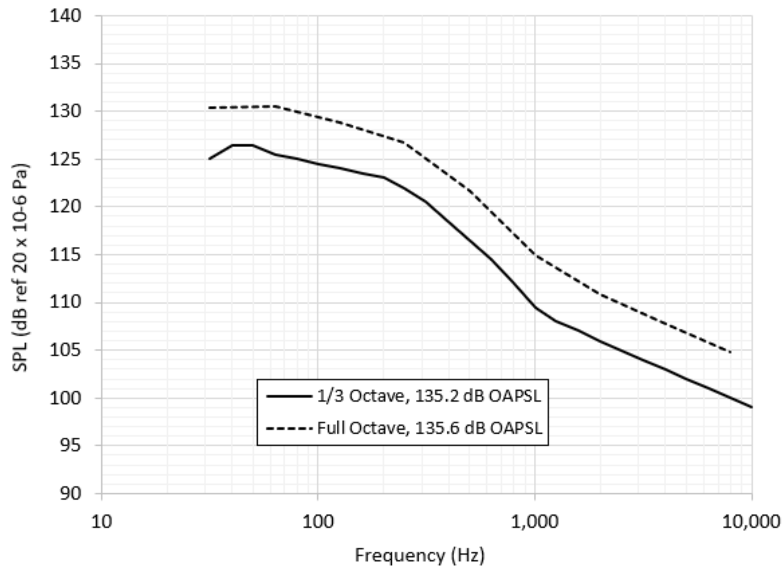


Figure 5-5: Falcon Heavy Acoustic MPE (P95/50), 60% Fill-Factor, Eastern Range

Table 5-7: Falcon Heavy Acoustic MPE (P95/50), 60% Fill-Factor, Eastern Range

Frequency (Hz)	Acoustic MPE (P95/50), 60% Fill-Factor (1/3 Octave)
31.5	125.0
40	126.5
50	126.5
63	125.5
80	125.0
100	124.5
125	124.0
160	123.5
200	123.0
250	122.0
315	120.5
400	118.5
500	116.5
630	114.5
800	112.0
1000	109.5
1250	108.0
1600	107.0
2000	106.0
2500	105.0
3150	104.0
4000	103.0
5000	102.0
6300	101.0
8000	100.0
10000	99.0
OASPL (dB)	135.2

Frequency	Acoustic MPE (P95/50), 60% Fill-Factor (Full Octave)
31.5	130.3
63	130.5
125	128.8
250	126.7
500	121.6
1000	114.9
2000	110.8
4000	107.8
8000	104.8
OASPL (dB)	135.6

5.3.4.4 EXTENDED FAIRING

Please contact SpaceX for Extended Fairing acoustic levels.

5.3.5 SHOCK

Five events during flight result in shock loads:

1. Release of the launch vehicle hold-down at liftoff
2. Side booster separation (Falcon Heavy only)
3. Stage separation
4. Fairing separation (Figure 5-6)
5. Spacecraft separation (Figure 5-6)

The first three shock events are negligible for the payload, relative to fairing separation and spacecraft separation, because of the large distance and number of joints over which the shock loads will travel and dissipate.

Table 5-8 shows the launch-vehicle-induced shock MPE for Standard and Extended Fairing at the spacecraft separation plane. LV-induced shock is driven by fairing separation.

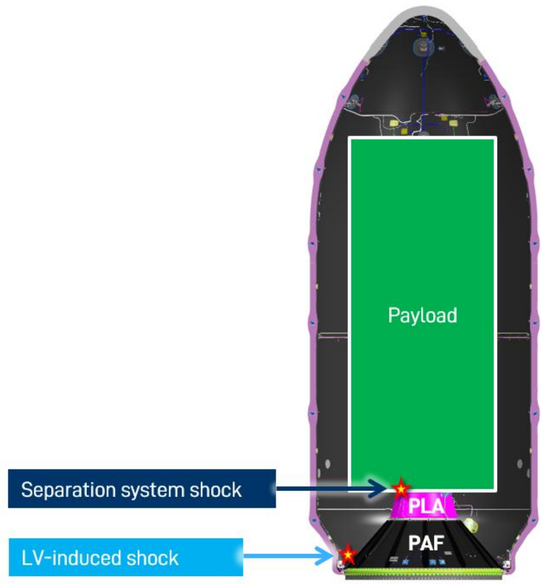


Figure 5-6: Shock Sources

Spacecraft separation system shock is typically enveloping of LV-induced shock. Table 5-9 shows the separation shock at the spacecraft separation plane for 937-mm or 1,194-mm or 1,666 mm (36.89 in. or 47.01 in. or 65.59 in.) clampband separation systems, derived at an average level. Some separation systems may have shock characteristics that vary and differ from the stated average. Contact SpaceX or the separation system manufacturer for more details. Actual shock environments experienced by the payload at the top of the mission-unique payload adapter will be determined following selection of a specific payload adapter and separation system.

Table 5-8: LV-Induced Shock at the Spacecraft Separation Plane (P95/50 MPE)

Frequency (Hz)	Standard Fairing SRS (g)	Extended Fairing SRS (g)
100	30	30
500	300	500
10,000	300	500

Table 5-9: Separation System-Induced Shock at the Spacecraft Separation Plane (Average)

Frequency (Hz)	SRS (g)
100	30
1,000	1,000
10,000	1,000

5.3.6 RANDOM VIBRATION

The maximum predicted random vibration environment at the top of the PAF is shown in Figure 5-7 and Table 5-10. This environment is derived from flight data measured at the top of the PAF and does not account for any additional attenuation as the vibration traverses the mission-specific payload adapter or spacecraft interface. The smoothline is an envelope of all flight events (liftoff, Stage 1 ascent, and Stage 2 burns) and is derived at a P95/50 statistical level.

The random vibration environment can be broken into three frequency bands as shown in Figure 5-7 and listed below:

1. Low Frequency (20 – 100 Hz): Excitations driven by global vehicle motion and modes. CLA and sine vibration envelop this region
2. Mid Frequency (100 Hz – 600 Hz): Excitation due to aeroacoustics
3. High Frequency (600 Hz – 2000 Hz): Excitation due to structure-borne vibration from MVac

Table 5-10: Falcon 9/Falcon Heavy Random Vibration Maximum Predicted Environment (P95/50) at Top of PAF

Frequency	Falcon 9/Falcon Heavy payload Random Vibration MPE (P95/50) (g^2/Hz), All axes
20	0.0044
100	0.0044
300	0.01
700	0.01
800	0.03
925	0.03
2000	0.00644
GRMS	5.13

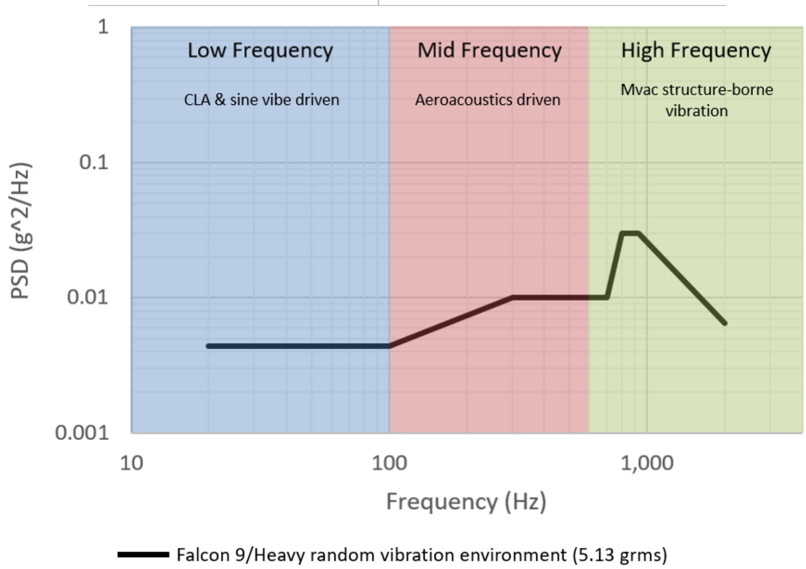


Figure 5-7: Falcon 9/Falcon Heavy Random Vibration MPE

5.3.6.1 RANDOM VIBRATION ATTENUATION

Spacecraft with sensitive components not screened with standard-level qualifications (GEVS or SMC-S-016) may require additional relief from random vibration. SpaceX offers random vibration attenuation as a nonstandard service. For programmatic information, please reach out to SpaceX directly.

5.3.7 ELECTROMAGNETIC

Payloads are subject to the electromagnetic environments in the following sections. Payloads that are powered off during ascent should be powered off starting no later than one hour before launch and remain powered off through deployment plus the time specified in Table 5-14 but may still be exposed to the electromagnetic MPE during launch site processing. Payloads that are powered on during ascent must demonstrate compatibility to the environments in this section. Exceedances will be evaluated on a case-by-case basis.

5.3.7.1 IN-FLIGHT AND PRE-FLIGHT ENVIRONMENTAL EMISSIONS

Customers must ensure that payload materials or components sensitive to RF environments are compatible with the worst-case radiated environment shown in Figure 5-9. LV, including co-payloads and launch site radiated emissions, are shown in Table 5-11 and Table 5-12, respectively. EMI margin is not included. These levels are inclusive of both the F9 and FH configurations.

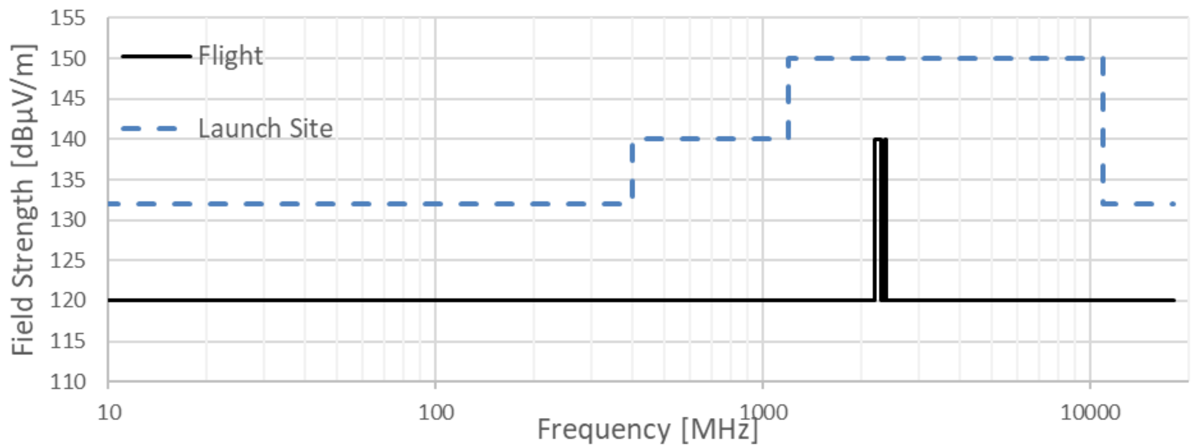


Figure 5-8: In-Flight & Environmental Radiated Emissions / Payload Radiated Susceptibility Limit

Table 5-11: Launch Vehicle Radiated Emissions

Frequency Range (MHz)	E-Field Limit (dBµV/m)
1.0 – 2200.0	120
2200.0 – 2300.0	140
2300.0 – 2360.0	120
2360.0 – 2395.0	140
2395.0 – 18000.0	120

Table 5-12: Launch Site Radiated Emissions

Frequency Range (MHz)	E-Field Limit (dBµV/m)
1.0 – 400.0	132
400.0 – 1200.0	140
1200.0 – 11000.0	150
11000.0 – 18000.0	132

These limits envelop the expected emissions from the LV, co-payloads, and launch site emitters. The customer should assume 26 dB of shielding from launch site sources when testing and integrating the payload in either the PPF or the LV integration hangar.

5.3.7.2 MAXIMUM SPACECRAFT EMISSIONS

The emission envelope for payloads, including 6 dB of EMI safety margin by test, or 12 dB of EMI safety margin by analysis, is shown in Table 5-13. Levels shown are as measured at the spacecraft separation plane.

Table 5-13: Maximum Payload Emissions

Frequency Range (MHz)	by Test (dBµV/m)	by Analysis (dBµV/m)
30.0 – 1000.0	108	102
1000.0 – 1127.0	154	148
1127.0 – 1327.0	33	27
1327.0 – 1475.0	154	148
1475.0 – 1675.0	33	27
1675.0 – 18000.0	154	148

5.3.7.3 PAYLOAD TRANSMITTER TURN-ON DELAY TIME

Standard launch services do not permit use of payload transmitters while integrated to the LV hardware. Payload transmitters may only be enabled after a minimum time after payload separation, as defined in Table 5-14 (values may be interpolated). See Section 7.4.6 for verification requirements for payloads that must be powered on.

Table 5-14: Payload Transmitter Delay Time (seconds)

	EIRP (Watts)	≤0.001	0.01	0.1	1	10	20	100	1000
	EIRP (dBm)	0	10	20	30	40	43	50	60
Separation Velocity (m/s)	0.3	1	2	6	19	58	82	183	578
	0.5	1	2	4	11	35	49	110	347
	1.0	1	1	2	6	18	25	55	174
	2.0	1	1	1	3	9	13	28	87
	5.0	1	1	1	2	4	5	11	35

Additionally, any transmitter centered in the following bands may need to wait to enable these transmitters until "end of mission" as defined by the mission-specific second stage re-entry time or stage passivation.

- Band 1: 2206.0 – 2216.0 MHz
- Band 2: 2227.5 – 2237.5 MHz
- Band 3: 2242.5 – 2260.5 MHz
- Band 4: 2267.5 – 2277.5 MHz
- Band 5: 2365.5 – 2375.5 MHz
- Band 6: 2377.5 – 2387.5 MHz

Customers must inform SpaceX prior to LSA finalization if transmitting inside one of these bands or in any GNSS band.

5.3.7.4 LIGHTNING PROTECTION

SpaceX launch pads at CCSFS/KSC contain full lightning protection systems. The integration facilities and hangars are equipped with lightning grounding systems to protect personnel and hardware from lightning. The SLC-40 and LC-39A launch pads are equipped with overhead wire lightning protection systems. These systems are designed to:

1. Be a preferential path for lightning to prevent direct attachments to personnel and hardware in the protection zone.
2. Avoid side flash between the overhead wires and flight hardware and ground systems.
3. Minimize electromagnetic coupling to flight hardware and ground systems in order to protect sensitive electronics.

5.3.7.5 LIGHTNING RETEST

Well-defined lightning retest criteria are important to minimize both the risk of damage and the risk of missed launch opportunities for spacecraft and launch vehicles. As such, Falcon launch vehicles have well-defined lightning retest criteria that are based on the lightning distance and amplitude data measured using Range-provided lightning monitoring systems. SpaceX requires spacecraft to provide lightning retest criteria based on lightning strike distance and amplitude.

5.3.8 FAIRING INTERNAL PRESSURE

The payload fairing internal pressure will decay at a rate no larger than 2.8 kPa/sec (0.40 psi/sec) from liftoff through immediately prior to fairing separation, except for brief periods during flight, where the payload fairing internal pressure will decay at a rate no larger than 4.5 kPa/sec (0.65 psi/sec), for no more than 5 seconds.

5.3.9 PAYLOAD TEMPERATURE EXPOSURE DURING FLIGHT

The SpaceX payload fairing is a composite structure consisting of an aluminum honeycomb core in between carbon fiber face sheet plies. The emissivity of the inner mold line of the payload fairing surface is approximately 0.9. The fairing thermal insulation on the exterior surface of the composite is sized such that the inner mold line composite surface temperature never exceeds the Bounding Fairing Composite Temperature profile shown in Figure 5-9. Payload fairing jettison timing is determined by payload aerothermal heating requirements and physical limitations of the system. The latest expected mission times for fairing deployment are denoted by dashed vertical lines for both Falcon 9 and Falcon Heavy.

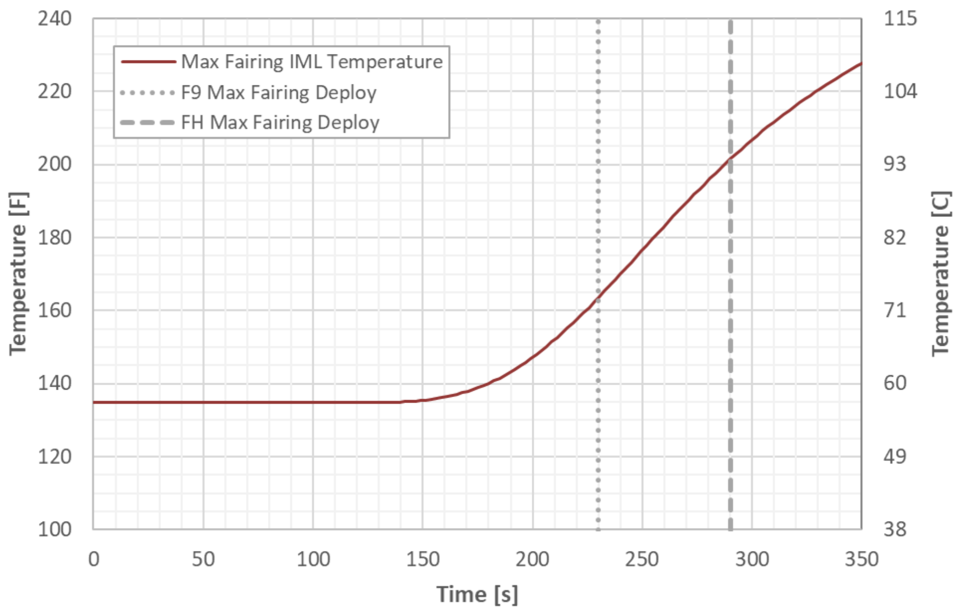


Figure 5-9: Bounding Fairing Composite Temperature Profile

5.3.10 FREE MOLECULAR HEATING

The payload fairing will nominally be deployed when free molecular aero-thermal heating is less than 1,135 W/m^2. Other fairing deployment constraints can be accommodated as a standard service, although they may modestly reduce vehicle performance. Please contact SpaceX regarding mission-unique fairing deployment requirements.

6 PAYLOAD DESIGN REQUIREMENTS

6.1 DESIGN FACTORS

Purpose: To ensure safety and reliability of the payload, the launch vehicle, and personnel present during operations.

Payload systems and structural components, including separation mechanisms, should be held to the minimum design factors shown in Table 6-1 and Table 6-2. Customers should use the separation system's user guide to account for additional load peaking when determining the compatibility of payloads with their selected separation system.

Table 6-1: Factors of Safety

Factor of Safety	Min design factor
Yield (flight, ground)	1.10
Joint gap and slip (interfaces)	1.10
Ultimate (flight)	1.25
Ultimate (ground operations)	1.40
Yield (GSE lifting hardware) [1]	3.0
Ultimate (GSE lifting hardware) [1]	4.0

1. AFSPCMAN 91-710 Vol 3 for detailed requirements

Table 6-2: Peaking Factors

Peaking factor	Min design factor
Separation system interface	Variable [1]

1. Consult Separation System User's Guide for guidance on peaking factor

6.2 FASTENERS AND CABLE TIES

6.2.1 FASTENERS ATTACHING TO SPACEX HARDWARE (IF APPLICABLE)

Purpose: To ensure the structural integrity of the payload and of launch vehicle hardware, once mated.

Any fasteners used to mate the payload to SpaceX hardware must meet the requirements shown in Table 6-3. Contact SpaceX for more information on recommended fastener types and/or part numbers.

Table 6-3: Acceptance Criteria for Fasteners Attaching to SpaceX Hardware

Fastener size	Per standard interface
Locking features	Fastener must incorporate a minimum of one locking feature that does not depend upon preload to function. In order of preference: o Prevailing torque feature, like a nut plate, distorted thread locking nut, or patched fastener o Lock wire/lock cable o Staked fastener head with process hardness check o Thread locker with proper application process hardness check
Thread engagement	Fasteners installed in through-holes shall have a minimum acceptable thread protrusion beyond the end of a nut or nut plate of two thread pitches. This ensures that all the fully formed threads on the fastener can carry load. Fasteners threaded into blind holes shall be selected to prevent contacting the bottom of the hole or interfering with incomplete internal threads.
Installation	Fasteners must be installed by means of an installation procedure that uses a calibrated torque tool, measures installation torque, and verifies retention is functional (e.g. measures prevailing torque and compares to limits, visual verification on lock wire/cable, test coupon for thread locker to test breakaway torque, etc.).

6.2.2 CABLE TIES

All cable ties intended for flight must be non-removable, preferably made from Nylon 6/6 or ETFE/Tefzel, and must be included in vibration testing. Removable cable ties are only for temporary use during in-process harness routing and must be removed before flight. Contact SpaceX for recommended part numbers.

6.3 ISOLATORS

6.3.1 ISOLATORS INTERNAL TO PAYLOAD

Isolators internal to the payload (for example, to isolate secondary components) must meet the following additional design requirements:

- Isolators must have all-metallic fail-safe features.
- Isolated assemblies must be on a pattern of four or more isolators.

6.3.2 ISOLATORS BETWEEN PAYLOAD AND LAUNCH VEHICLE

SpaceX can procure isolated assemblies for the payload to launch vehicle interface as a nonstandard service. Expected equivalent sine environments as defined in Section 5.3.3 do not apply for payloads isolated from the launch vehicle. Please reach out to SpaceX for further information and expected levels.

6.4 PRESSURE VESSELS AND SYSTEMS

6.4.1 DESIGN AND TEST FACTORS

The design and test factors in Table 6-4 shall be used for the design and testing of pressure vessels, lines, and other pressurized components. See Section 7.5 for further detailed verification requirements on pressure vessels and systems.

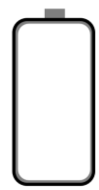
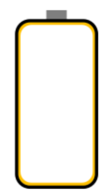
Table 6-4: Design and Test Factors for Pressure Vessels and Systems

<table>
<tr><th>Pressure Component</th><th>Design safety factors</th><th>Qualification test factors
Must be performed on a dedicated Qualification Component</th><th>Acceptance test factors
Must be performed on Component prior to Integration on Flight Unit</th></tr>
<tr><td>US DOT Pressure Vessels</td><td colspan="3">Accepted as is per US DOT certification</td></tr>
<tr><td>Non-US DOT Pressure Vessels</td><td>Yield: 1.5 x MEOP
Ultimate: 2.0 x MEOP</td><td>Proof Pressure: 1.5 x MEOP
Burst Pressure: 2.0 x MEOP</td><td rowspan="5">Proof Pressure: 1.5 x MEOP</td></tr>
<tr><td>Lines and Fittings (Dia. ≥ 1.5 in)</td><td>Yield: 1.5 x MEOP
Ultimate: 2.5 x MEOP</td><td>Not required</td></tr>
<tr><td>Lines and Fittings (Dia.<1.5 in)</td><td>Yield: 1.5 x MEOP
Ultimate: 4.0 x MEOP</td><td>Not required</td></tr>
<tr><td>Valves, Regulators, Cryostats & Other Pressurized Components</td><td>Yield: 1.5 x MEOP
Ultimate: 2.5 x MEOP</td><td>Proof Pressure: 1.5 x MEOP
Burst Pressure: 2.5 x MEOP</td></tr>
<tr><td>Sealed Containers
(MEOP ≤ 1 atm on orbit)</td><td>Yield: 1.5 x MEOP
Ultimate: 2.0 x MEOP</td><td>Not required</td></tr>
</table>

6.4.2 PRESSURE VESSEL SELECTION AND FABRICATION

A pressure vessel is any system containing more than 20,000 J of stored energy (pneumatic and chemical energy) or a MEOP greater than 6.9 barD (100 PsiD). Large, sealed containers that are at atmospheric pressure on the ground are classified as a pressure vessel if they exceed this energy threshold because of the pressure difference that develops on-orbit. Pressure vessel classification and restrictions are shown in Table 6-5.

Table 6-5: Pressure Vessel Classification and Use Restrictions

	Type 1	Type 2	Type 3	Type 4	Type 5
	 All metallic	 Metallic liner with composite hoop overwrap	 Metallic liner with full composite overwrap	 Non-metallic liner with full composite overwrap	 All composite pressure vessel (no metallic liner)
Design Standard & Release	AIAA-S-080 (Current approved release)	AIAA-S-081 (Current approved release)	AIAA-S-081 (Current approved release)	AIAA G-082 [1] (Current approved release)	N/A
Restrictions	Consult Section 6.4.5 for material compatibility			• Use is discouraged • Some restrictions on fluid eligibility apply. See Section 6.4.5	

1. SpaceX may apply additional requirements beyond those defined in AIAA-G-082. Contact SpaceX for more details.

6.4.2.1 US DOT PRESSURE VESSELS

Pressure vessels that are United States Department of Transportation (US DOT) certified and are operated within their published limits and working fluids are strongly preferred over custom vessels.

6.4.2.2 NON-US DOT PRESSURE VESSELS

Any pressure vessels that are not US DOT classified require a SpaceX review of qualification and acceptance testing and must meet the following requirements:

- No Type 2, 3, 4, or 5 pressurized-structure tanks where non-pressure loading makes up more than 15% of maximum combined flight stress (15% Rule).
- No pressure tanks that require pressure stabilization to hold external structural load.
- No additively manufactured tanks. Contact SpaceX for further information.
- No bimetallic welded joints in the pressure vessel lines or payload pressure systems.
- Pressurization state of the tank must not nominally change between payload propellant load and deployment from the launch vehicle, assuming a constant tank temperature. The tank pressure must not exceed the MDP of the pressure vessel between payload propellant load and deployment from the launch vehicle, considering any thermal effects. Use of HTP is treated separately, see Section 6.4.5.
- Pressure vessels must have a contingency pressure relief valve to vent pressure above personnel safe MEOP while in ground operations.
- Qualification must include all testing per applicable AIAA document listed in Table 6-5 based on pressure vessel type, Section 6.4, and AFSPC 91-710 (Section 12). Pressure vessels must hold burst factors of safety on pressure per applicable AIAA document listed in Table 6-5 based on pressure vessel type, not below factors defined in Table 6-4, or overall design factors of safety defined in Section 6.1 on all combined loading cases. Vessels that carry significant loads beyond pressure (do not meet the 15% rule) must include combined loading in qualification testing per Section 6.4.

6.4.3 FULLY INTEGRATED PRESSURE SYSTEMS

A pressure system is any system that is intended to be pressurized and that doesn't meet the previous definition of a pressure vessel. This includes both pressure components like valves, fittings, and lines that have the potential to see internal pressure between delivery of the payload to the launch site and on-orbit deployment. Refer to Table 6-4 for design and test factors.

6.4.4 OTHER PRESSURIZED EQUIPMENT AND SEALED CONTAINERS

Other pressurized equipment are components that do not meet the definitions of pressure vessel or pressure systems but may be pressurized at any point between payload delivery and on-orbit deployment. This may include, for example, batteries and cryostats. Sealed containers that are at atmospheric pressure on the ground may also become pressurized on orbit because of the pressure difference that develops on-orbit (up to 1 atm). Refer to Table 6-4 for design and test factors.

6.4.5 PROPELLANT AND MATERIAL COMPATIBILITY REQUIREMENTS

Accepted material compatibility and standards are per the following industry accepted design guides:

- Uney, P.E. & Fester, D.A. (1972). *Material Compatibility with Space Storable Propellants Design Guidebook*. Martin Marietta Corporation.
- Johnson, H.T. et al (2005). *Fire, Explosion, Compatibility, and Safety Hazards of Hydrogen Peroxide* (Report No. NASA TM-2005-213151). National Aeronautics and Space Administration.

SpaceX applies the following restrictions:

- Hypergolic propellant usage: All hypergolic propellants are prohibited for use in Type 4 and Type 5 pressure vessels.
- Oxidizers: All oxidizers are prohibited for use in Type 4 and Type 5 pressure vessels. Contact SpaceX for further information.
- NTO/Titanium usage: Titanium usage in an NTO-wetted application is prohibited.
- Bimetallic welded joints are prohibited.
- Cryogenic propellants: As an optional service, SpaceX can load certain cryogenic fuels and consumables post encapsulation. See Section 4.3.2 for cryogenic loading specifications and limitations.
- Hydrogen peroxide: Hydrogen peroxide, otherwise known as HTP, may be used as propellant but carries additional requirements on design and analysis. Specific details include:
  - A propellant tank relief must be provided to protect the propellant tank from excessive pressure due to HTP decomposition. This relief should be set for no more than 10% above MEOP.
  - The propellant tank must have a MEOP that envelopes the maximum expected pressure after self-pressurization due to HTP decomposition when the tank is at 32°C (or worst-case temperature profile between payload propellant load and payload separation) over a 60-day period.
  - The relief outlet should be configured such that there is no danger to personnel in case of tank relief.
  - The tank, and if so equipped, tank positive expulsion diaphragm, must be compatible with HTP. This includes any material on the gas side of the diaphragm, including tank weldment alloys, tank cleaning agents, etc.
  - To minimize the possibility of reactions, all materials that may come in contact with HTP must be cleaned and passivated, and designs must minimize excessive surface area contact with, and entrapment of, HTP.

Any material combinations outside of this specification require SpaceX approval and may require testing modifications.

6.4.6 FAULT TOLERANCE FOR PRESSURANT/PROPELLANT RELEASE

The pressure and propellant system must be designed to tolerate a minimum number of credible failures and prevent an overall system failure or mishap due to inadvertent pressurant and/or propellant release.

- For systems using hypergolic propellants, or if a system failure may lead to a catastrophic hazard, the system must have dual fault tolerance (three inhibits to propellant release). *This can be accomplished, for example, through the use of three valves in series.*
- For all other pressure/propellant systems, the system must be at least single fault tolerant (two inhibits to propellant release). *This can be accomplished, for example, through the use of two valves in series.*

Inhibits shall be independent and cannot be combined. *For example, a single electrical command of two valves in series is not a dual fault tolerant system.*

A burst disk can be used in series with a relief valve to demonstrate two inhibits to pressurant/propellant release.

For further details, please refer to Chapter 3 of AFSPC 91-710.

6.5 SOLID PROPULSION SYSTEMS

Solid propulsion ion thrusters are generally acceptable for use and do not have the same restrictions as pressure vessels. Examples of ion thrusters that use solid propellants include gridded electrostatic ion thrusters and field-emission electric propulsion (FEEP). All solid propulsion systems require at least one ignition inhibit.

7 VERIFICATION

Customers must verify the compatibility of the payload with the maximum predicted environments defined in Section 5. SpaceX will review the customer's chosen verification approach as well as test results during mission integration to ensure mission safety. Where possible, verification methods have been adapted from publicly available standards such as SMC-S-016, GSFC-STD-7000 (GEVS) and other NASA/AIAA standards. Mission-unique limit levels and CLA levels will be developed during the mission integration process and will serve as the basis for the verification activities. Alternate verification approaches may be acceptable, but coordination with SpaceX is required.

7.1 VERIFICATION TEST APPROACH

SpaceX allows three approaches to environmental verification testing at payload level, as detailed below. Note that payloads may utilize different verification strategies for each environment. For example, a dedicated qualification article may be used to validate the primary structure and verify the quasi-static levels, while a protoqualification approach may be used to verify other environments. SpaceX provides a Payload Environments and Test Template for customers to communicate and coordinate the verification approach.

1. Flight Unit Protoqualification: The flight unit or the first individual payload flight unit is subjected to protoqualification test levels. Follow-on identical units are tested at acceptance levels. SpaceX prefers testing at the fully integrated payload assembly level, even if the payload consists of multiple smaller payload constituents. With this approach, the protoqualification test validates both structural design and workmanship, while allowing for reduced test factors and durations.

2. Unit/Fleet Qualification and Acceptance: A dedicated qualification unit (not flown), that is identical to the flight unit is subjected to testing at qualification levels and every flight unit is tested to acceptance test levels. The acceptance tests must be performed at the fully integrated payload assembly level. With this approach, qualification testing validates the structural design and design margin while the acceptance test(s) validate workmanship.

3. Constellation/Lot Acceptance Testing: Available for constellation-style programs consisting of 10 or more identical payloads (payloads do not need to be flown together in a single launch). Allows for reduced testing at Integrated payload level and can be combined with either a protoqualification or a fleet qualification approach. See Section 7.3.

The environments verification approach in this section is designed to ensure the safety of customer-provided flight hardware and the launch vehicle. Throughout this user's guide, tests that are "advised" are designed to ensure on-orbit health and functionality of the payload but are not required to fly on a SpaceX Falcon 9/Falcon Heavy mission. Tests that are "required" must be completed by the customer to ensure mission safety through payload separation.

7.1.1 ENVIRONMENTAL TESTING SETUP

Customer-provided GSE is required for testing, to adapt the spacecraft interface to the shaker table. A diagram of the flight configuration versus test configuration is shown in Figure 7-1 for customers utilizing a clamp-band style separation system, for illustration. The qualification and suitability of separation systems supplied by SpaceX will be reviewed for the specific payload application.

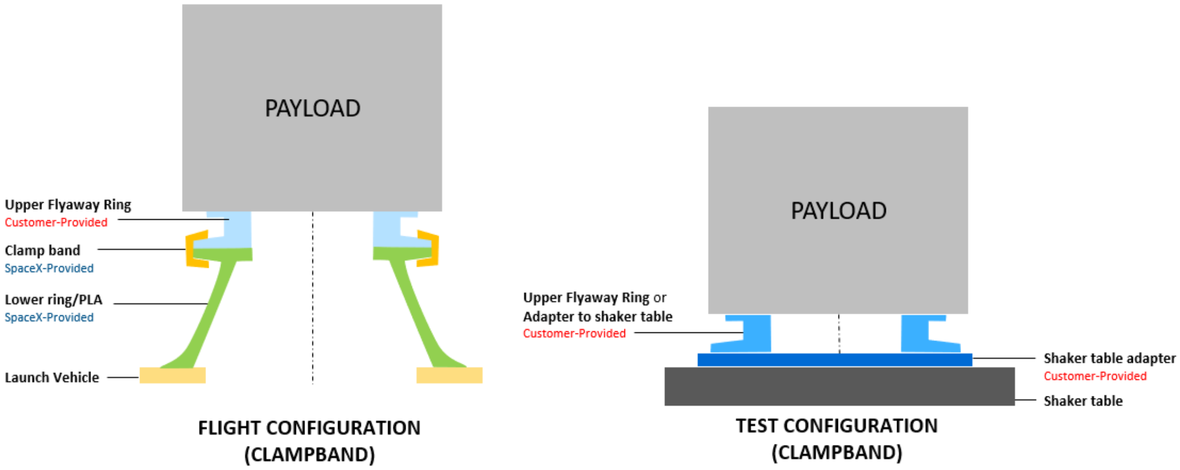


Figure 7-1: Flight vs. Test Configuration for Payloads Using Clampband Configuration

7.1.2 TEST DOCUMENTATION REQUIREMENTS

Customers must deliver to SpaceX:

- A test approach summary, using the SpaceX test template, including any and all test-like-you-fly exceptions and deviations from this guide, for review by SpaceX prior to payload testing, and in accordance with the SOW.
- Propulsion system details using the SpaceX test template, for review by SpaceX prior to payload testing, according to requirements as specified in Section 6.4 or Section 6.5, if applicable.
- Verification results, using the SpaceX test template, including test results and other artifacts per requirements defined in Section 7, for review by SpaceX in accordance with the SOW. The results must include all *new* test-like-you-fly exceptions for approval by SpaceX, including details on test versus flight boundary conditions and any hardware not included in the test set up that will be in the flight configuration. If customer chooses not to complete any "advised" tests, an acknowledgment of the inherent risks to the payload incurred by not completing the "advised" testing must be included.

7.2 PAYLOAD TEST LEVELS

7.2.1 TEST REQUIREMENTS

Payload testing must conform to Table 7-1. These levels are applicable to integrated testing of the payload.

Table 7-1: Payload Test Levels and Durations

Test	REQUIRED OR Advised	Unit/Fleet Qualification and Acceptance Approach		Flight Unit
		Qualification	Acceptance Must be performed on fully integrated payload	Protoqualification Must be performed on the 1st fully integrated payload
		Unit Not flown	*Unit Flown*	*Unit Flown*
Static Load [1]	REQUIRED	Level: Min 1.25 times the limit load	Level: Min 1.0 times the limit load	Level: Min 1.25 times the limit load
Sine Vibration	REQUIRED	Level: Limit Levels x 1.25 Duration: 2 oct./minute sweep rate in each of 3 axes	Level: Limit Levels x 1.0 Duration: 4 oct./minute sweep rate in each of 3 axes	Level: Limit Levels x 1.25 Duration: 4 oct./minute sweep rate in each of 3 axes
Shock	Advised	Level: MPE + 3 dB WITH Actuations: 2 times in each of 3 axes OR 2 actuations of device	Not Required	Level: MPE + 3 dB WITH Actuations: 2 times in each of 3 axes OR 2 actuations of device
Acoustic	See Section 7.2.2 as a guide to determine REQUIRED test(s) [2]	Level: MPE + 3 dB Duration: 2 minutes	Level: MPE Duration: 1 minute	Level: MPE + 3 dB Duration: 1 minute
Random Vibration		Level: MPE + 3 dB Duration: 2 minutes in each of 3 axes	Level: MPE Duration: 1 minute in each of 3 axes	Level: MPE + 3 dB Duration: 1 minute in each of 3 axes
Activation Inhibits [3]	REQUIRED	Verification that activation inhibits function as intended	Verification that activation inhibits function as intended	Verification that activation inhibits function as intended
Electromagnetic Compatibility [4]	REQUIRED *for payloads Powered ON*	By test: 6 dB EMISM OR By analysis: 12 dB EMISM	Not required	By test: 6 dB EMISM OR By analysis: 12 dB EMISM
Thermal Vacuum and Thermal Cycle [5]	Advised	Level: Acceptance ± 10 °C Duration: 27 cycles total	Level: Envelope of MPT and min. range (-24 to 61°C) Duration: 14 cycles total	Level: Acceptance ± 5 °C Duration: 20 cycles total
Integrated Pressure Leak Test [6]	REQUIRED	Level: MEOP per Table 6-4 Duration: 5 min	Level: MEOP per Table 6-4 Duration: 5 min	Level: MEOP per Table 6-4 Duration: 5 min

1. Quasi-static load testing can be achieved through a variety of methods, including either sine vibration (sweep), static load, sine burst, or a combination of one or more tests. Static load testing may be conducted on a separate qualification model, even if the payload's principal test approach is protoflight qualification. SpaceX prefers, for small payloads (under 500 kg), the use of sine vibration or sine burst for verifying quasi-static loading.
2. Random vibration shaker testing is often aggressive when it comes to larger spacecraft. Therefore, the customer must determine whether the acoustic or random vibration flight environment is enveloping of the spacecraft responses that are not screened by other tests. See Section 7.2.2 on methodology for evaluation and selection of the correct test and Sections 7.4.4 and 7.4.5 for more details on verification.
3. Verification that the inhibits to the activation of any hazardous systems (such as deployable appendages, propulsion, and undesired RF transmission) function as intended. Verification must be conducted as part of at least one integrated dynamic test (sine vibration, acoustic, or random vibration), see Section 7.4.6.
4. EMISM (6 dB by test, 12 dB by analysis) is already included in Table 5-12. See Section 7.4.7 for further guidance on electromagnetic compatibility verification.
5. Thermal cycles can be accrued as a combination of thermal cycling in air and thermal vacuum. It is recommended to include at least four cycles of thermal vacuum unless strong rationale exists that the payload is not sensitive to vacuum.
6. Additional requirements apply to individual pressure vessels and systems, see Section 7.5. Pressure systems that do not meet material compatibility requirements specified in Section 6.4.5 must contact SpaceX for specific leak testing requirements.

7.2.2 ACOUSTIC VERSUS RANDOM VIBRATION TEST DOWNSELECTION

Customers must assess and decide on the verification strategy to pursue for the mid- to high-frequency environment (100 – 2,000 Hz). The following is meant to be a guide only. It is the customer's responsibility to assess the payload's susceptibility to one or the other environment.

Ultra-light payloads (under 500 kg) should generally pursue a random vibration test verification strategy (unless customer can demonstrate payload is not susceptible to random vibration testing), while heavy-mass payloads (over 1,800 kg) should generally pursue an acoustic test verification strategy. Payloads in the light- to medium-mass class (500 to 1,800 kg) should evaluate which environment envelopes the highest response on components susceptible to medium-to-high frequency vibration. Environment susceptibility is highly dependent on the payload's architecture, mass, exposed surface area, components, and component mounting.

Purpose: This section details the methodology for determining whether payloads are driven by the acoustic or random vibration environment (see Table 7-1); in other words, to determine whether an acoustic or random vibration test is sufficient to qualify and screen the payload's secondary interfaces and components for flight.

Verification: Customers must list the method selected and provide details on the methodology pursued and the assessment results to inform the choice of integrated test. Note the levels may be modified (increased) to envelop one or the other environment. In other words, customers may notch up but may not go below flight level with test margin.

Method	Method A: Response comparison by test	Method B: Response comparison by analysis or hybrid analysis/test
Method overview	Compare component responses from an acoustic and low-level random vibration test	Compare component responses from acoustic and random vibration high-fidelity analysis or an acoustic test and random vibration high-fidelity analysis

Method A

1. Select relevant interfaces and/or secondary components of interest. For example:
   - *Net CG acceleration of an avionics box*
   - *Force at mounting interface between payload structure and a deployable appendage*
   - *Acceleration at the center of a large solar array panel*
2. Exclude components with a cumulative acceleration/force response >95% at 100 Hz (screened by sine vibration testing).
3. Conduct a base-driven vibration low-level test to determine transfer function from base input to selected component locations.
4. Compute predicted random vibration responses from flight random vibration environment at the locations established from Steps 1 and 2.
5. Conduct an acoustic test; measure and/or correlate responses at same locations.
6. Calculate equivalent rms force/acceleration at each location, excluding contribution from 0-100 Hz band.
7. Compare equivalent rms force/acceleration at each location and determine overall which environment envelopes responses.

Method B

1. Select relevant interfaces and/or secondary components of interest. For example:
   - *Net CG acceleration of an avionics box*
   - *Force at mounting interface between payload structure and a deployable appendage*
   - *Acceleration at the center of a large solar array panel*
2. Exclude components with a cumulative acceleration/force response >95% at 100 Hz (screened by sine vibration testing).

3. Compute predicted random vibration responses from flight random vibration environments, using a high-fidelity, correlated random vibration model.
4. Conduct an acoustic test; measure and/or correlate responses at same locations OR use a high-fidelity acoustics analysis to predict the responses at same locations.
5. Calculate equivalent rms force/acceleration at each location, excluding contribution from 0-100 Hz band.
6. Compare equivalent rms force/acceleration at each location and determine overall which environment envelopes responses.

7.3 CONSTELLATION TESTING (LOT ACCEPTANCE TESTING)

Constellations with 10 or more identical payloads may elect to pursue a constellation/lot acceptance testing (LAT) approach. This test approach provides a reduced testing cadence on a spacecraft lot basis.

Eligibility

- The constellation consists of 10 or more identical payloads that are flown on one or across multiple SpaceX launches.
- Payloads do not need to be flown together on a single launch to be eligible for this approach, but all payloads need to be identical, interchangeable, and manufactured and integrated in the same manner.
- Customers must submit the information as required in this section and coordinate with SpaceX to ensure they are eligible to pursue a constellation/lot acceptance testing approach. Otherwise, customers must revert to test each flight unit (see Section 7.1).

Minimum Test Requirements

- The first five flight unit serial numbers (consecutively manufactured and integrated) and then flight units at least every fifth serial number must be fully tested at integrated level.
- Example test schedule with minimum test requirements is shown in Appendix I: Test Schedule for Constellations (Table I-1). Customers should submit a test schedule, based on their constellation size, documenting the actual test schedule with full constellation size. Any deviations from minimum test requirements should be justified.
- Retest triggers (Type 1 and/or Type 2, as detailed below), pre-agreed between SpaceX and the customer, will be used to conduct additional tests on the flight units, if the trigger(s) meet the relevant criteria.
- Customer must conduct subscale workmanship screening of all external components on the payload, at minimum for all serial numbers that are not tested at integrated level.

Retest Triggers

Retest triggers ensure that both SpaceX and the customer can maintain a high reliability and safety of the payload(s) and the launch vehicle. Retest triggers are split into two types – Type 1 (penalty retest) and Type 2 (delta qualification). Refer to Table 7-2 for requirements on retest and Table I-2 for an example of a Type 2 retest trigger schedule change.

Table 7-2: Constellation Testing - Retest Triggers

	Retest Trigger Type 1 – Penalty Retest	Retest Trigger Type 2 – Delta Qualification
Rationale	To rescreen a flight unit for workmanship (arising from a high amount of rework on that Serial Number or perceived differences in Test vs Flight). Rescreening ensures reliability during launch is maintained	To delta qualify the payload (arising from a change in payload design, or change/drift in workmanship/production)
Retest Trigger(s)	One or several of the following triggers are met on any flight Serial Number that requires integrated testing per agreed upon LAT schedule: 1. Spacecraft not tested in integrated manner; e.g., mass dummies used in place of external mounted components 2. Rework of primary load path or externally mounted interfaces, resulting in more than twenty fasteners reworked on secondary structures, such as panels, covers, etc. 3. Rework of fasteners smaller than #3 (or smaller than M2.5)	One or several of the following triggers are met on any flight Serial Number: 1. Any change that affects payload structural load path or interfaces with externally mounted appendages *(Examples could include a change in payload primary structure or externally mounted secondary structure)* 2. Any changes detected from component level acceptance testing *(Examples could include a drift in component level natural frequencies, substantial change in component mass or MOI)* 3. Major change in assembly and/or manufacturing processes (Examples could include a major change in final assembly work instructions, secondary retention methods, suppliers/personnel involved in final integration, production line interruptions for 6+ months, etc.)
Retest	Perform random vibration or acoustic testing (depending on required test, refer to Section 7.2) at MPE levels for 30 seconds (in each of 3 axes for random vibration).	• Perform a delta protoqualification of the Serial Number where the change was implemented and/or detected (if the Serial Number is not part of the agreed upon integrated test schedule, an integrated test must be performed) • Perform an acceptance test of the Serial Number immediately following the delta protoqualification test • If successful, resume agreed-upon lot acceptance test schedule

Verification/Documentation Requirements

Customer to provide the following evidence for review by SpaceX:

- Component-level environments derivations (component level MPE) and subscale component test plan
- General design details of interfaces with secondary or externally mounted components, including details on choice and methods for secondary retention
- Externally mounted interface margin details, including fastener out (fail safe) analysis
- General installation and integration procedures
- General quality and product assurance processes

7.4 ENVIRONMENTAL VERIFICATION REQUIREMENTS

7.4.1 QUASI-STATIC LOADING

Purpose: To verify that the payload's structural load path and interfaces are qualified to the flight environments and to ensure structural integrity of the payload to launch vehicle interface.

Verification: Testing is REQUIRED to the quasi-static load test levels and durations defined in Section 5.3.2 (flight environments) and Section 7.2 (test factors).

- Quasi-static load testing can be achieved through a variety of methods, including either sine vibration (sweep), static load, sine burst, or a combination of one or more tests.
- Static load testing may be conducted on a separate qualification model, even if the payload's main test approach is protoflight qualification. For ultra-light payloads (under 500 kg), SpaceX prefers the use of sine vibration or sine burst for verifying quasi-static loading. Please refer to the Rideshare payload User's Guide.
- The test levels should be derived from combined axial and lateral loading to meet the required interface forces/line loading.
- Significant deviation between as-tested and flight CG locations and payload mass may result in underqualified primary load paths and interfaces, if using a dynamic test to verify this requirement. Customers should aim to replicate as close as possible in the test the CG position and mass of the flight article. Customers must account for CG and mass differences in test and adjust levels and/or use fluid simulants to represent propellant mass, where necessary.

7.4.2 SINE VIBRATION

Purpose: To ensure payloads are compatible with loads on primary and secondary structures with modes <100 Hz.

Verification: Testing is REQUIRED to the sine vibration test levels and durations defined in Table 7-1 in accordance with the MPE defined in Section 5.3.3.

- Secondary notching of the input sine vibration levels must stay above CLA levels.
- Any notching must be pre-coordinated with SpaceX for approval at least two weeks in advance of testing. SpaceX also provides remote, near-real time support for customer vibration testing as a standard service.
- Significant deviation between as-tested and flight CG locations and payload mass may result in underqualified secondary structures. Customers should aim to replicate as close as possible in the test the CG position and mass of the flight article. Customers must account for CG and mass differences in test and adjust levels and/or use fluid simulants to represent propellant mass, where necessary.
- This test may be coupled with the activation inhibit verification as described in Section 7.4.6.

7.4.3 SHOCK

Purpose: To ensure payloads are compatible with shock environments experienced during flight.

Verification: Testing or analysis is ADVISED to the shock test levels and durations defined in Table 7-1 in accordance with the MPE defined in Section 5.3.5. Alternatively, customers may show compliance via analysis of all shock-critical components to the shock levels defined in this section.

- Verification by analysis must show that all shock-sensitive components are qualified to a higher level than the MPE. Attenuation propagated to the component's location on the spacecraft is accepted and is the customer's responsibility to show the attenuation analysis.
- Customers are ultimately responsible for verifying compliance to the MPE defined in Section 5.3.5. To ensure mission safety, separation systems provided by the customer must be approved by SpaceX.

7.4.4 ACOUSTIC

Purpose: To ensure payloads are compatible with acoustic environments inside the launch vehicle fairing. To ensure structural integrity of the payload, secondary structures, large surfaces, and other components during ascent.

Verification:

- If customer demonstrates that the payload is not susceptible to acoustic excitation, OR that responses from acoustic excitation are screened through an integrated random vibration test, using methodologies described in Section 7.4.5 or other customer methodology, then an acoustic test is ADVISED (not required).
- Otherwise, an acoustic test is REQUIRED. This test may be coupled with the activation inhibit verification as described in Section 7.4.6.

7.4.5 RANDOM VIBRATION

Purpose: To ensure structural integrity of the payload during flight dynamic events and to verify power inhibit systems. Exposure to the random vibration environment ensures that primary and secondary structures, payload constituents, and smaller components are exposed to flight loads plus margin. This ensures mission and co-payload safety.

Verification:

If customer demonstrates that the payload is not susceptible to random vibration excitation, OR that responses from random vibration excitation are screened through an integrated acoustic vibration test using methodologies described in Section 7.4.4 or other customer methodology, then only a random vibration c*omponent evaluation/analysis* is REQUIRED per Section 7.4.5.1. (Integrated random vibration shaker testing is not recommended for medium- and heavy-class payloads.)

If verifying compliance to this environment through integrated random vibration testing, notching of the primary mode of the payload to avoid an over-test is acceptable. Notching is only permitted to prevent the payload from exceeding the quasi-static load levels defined in Section 5.3.2. Notching to protect secondary structure or constituent responses is not permitted because that would result in an under-test as related to flight environments. SpaceX recommends the use of the following methods for notching, in descending order of preference:

1. Interface force limiting
2. Acceleration response limiting using a flight-correlated analytical model
3. Manual notching using a flight-correlated analytical model

Refer to industry-accepted standards for dynamic model correlation and notching for more information, such as NASA-HDBK-7004 and SMC-S-004.

7.4.5.1 COMPONENT-BY-COMPONENT RANDOM VIBRATION EVALUATION

Applicability: Component-by-component evaluation of the random vibration environment is only required for payloads which do not have an integrated random vibration test or are not screened or qualified by an integrated acoustic test (if an acoustic test is required).

Method:

1. Identify components susceptible to random vibration and/or near the interface plane and their in-plane and out-of-plane qualification levels. Components that are effectively screened by integrated tests such as sine vibration or acoustics should not be included in this assessment. Use the SpaceX-supplied environmental test template to perform the assessment.
2. Compare each component's qualification level with the random vibration qualification levels (MPE + 3dB), as constructed from the limit levels in Section 5.3.6, or the component's qualification level with the predicted component response from the input random vibration qualification levels (MPE + 3dB). Identify deviations in the SpaceX-supplied environmental test template.

7.4.5.2 BAND SPLITTING

Applicability: Band splitting may be used as part of the integrated random vibration test on a case-by-case basis. This is only permitted if the test facility requires a reduction in interface loads to meet the vibration shaker table force limitations. Band splitting must follow the following rules:

- Maximum three bands
- Minimum 1/3 Octave overlap between bands
- No band splitting at or near a payload primary mode
- The unit must be exposed to minimum workmanship levels (0.004 g^2/Hz) in every test. Hence every test needs to have a frequency range of 20 – 2,000Hz, with one side of the band being reduced to minimum workmanship while the other is being tested to the full levels
- All tests must be performed with the same unit
- Qualification or protoqualification tests should target reaching the random vibration MPE grms as defined in Section 5.3.6.

7.4.6 ACTIVATION INHIBITS

Purpose: To ensure that any deployable, transmission, and/or propulsion systems are isolated from sources of power up until payload separation. If a payload is designed to be powered OFF during ascent, to ensure the payload remains powered off until payload separation.

Verification: Testing is REQUIRED to verify that activation inhibits function as intended, as part of at least one integrated dynamic test (sine vibration, acoustic, or random vibration).

IMPORTANT: To verify that activation inhibit systems function as expected, all necessary power components and harnesses must be fully integrated and in a flight-like state. Batteries must be in their flight-like charge state and any RBF/GSE inhibits must be removed. Verification testing must show that power to the deployable, propulsion, and other hazardous secondary devices was successfully inhibited from a mechanical separation signal, and not because of other factors such as software delays. If a payload is designed to be powered OFF during ascent, the test must additionally show that power to the payload and any transmitting devices was successfully inhibited.

7.4.7 ELECTROMAGNETIC

Purpose: To ensure that launch vehicle and launch site radiated emissions do not compromise the electrical integrity of the payload and to ensure that payload emissions do not compromise the safety of the launch vehicle or of co-payloads.

Verification: For payloads powered ON, testing or verification by analysis is REQUIRED to the electromagnetic compatibility test levels and durations defined in Table 7-1 in accordance with the environments defined in Section 5.3.7.

Verification by test may be performed in-house per MIL-STD-461 with supporting test documentation or obtained from an IEC-17025 accredited (or equivalent) test facility. Verification by analysis must provide electromagnetic circuit and wiring emissions analysis. Payloads that require power during ascent must inform SpaceX prior to launch services agreement (LSA) finalization.

7.4.8 VENTABLE VOLUMES

Purpose: To limit the differential pressure experienced by the payload to ensure mission and co-payload safety.

Verification: Customers are ADVISED to conduct a venting analysis to the environment detailed in Section 5.3.8.

7.4.9 THERMAL

Purpose: To ensure payloads are compatible with the thermal environments experienced during flight.

Verification: Testing is ADVISED to the combined thermal vacuum and thermal cycle test levels and durations defined in Table 7-1 in accordance with the environments defined in Section 5.3.9.

7.5 VERIFICATION FOR PRESSURE VESSELS AND SYSTEMS

7.5.1 PRESSURE VESSELS AND SYSTEMS GENERAL REQUIREMENTS

Purpose: To verify that pressure systems and components are qualified for flight and do not pose a hazard to ground personnel, co-payloads, and the launch vehicle.

Verification: For all pressurized systems, customers are REQUIRED to provide the following evidence:

1. Document detailing system design criteria, MEOP derivation for flight (including thermal conditions), and ground cases for all pressurized components, features, and pressure vessels, including valve set points and relief device sizing
2. System schematic using standard P&ID symbols and an (excel) tabulated parts list, including valves, reliefs, transducers, and reference designators for all parts
3. Pressure vessel classification type
4. Overall pressure vessel and pressure system qualification and acceptance strategy (see Sections 6.4 for relevant standards and test factors)
5. Document detailing combined system test-like-you-fly exceptions between test and flight including rationale.

Systems that were previously approved by SpaceX may be exempt from providing this information as long as the pressure systems are identical to the systems previously reviewed and approved.

7.5.2 PRESSURE SYSTEM MATERIAL COMPATIBILITY

Purpose: To verify that pressure system materials are compatible with stored fluids, including propellants.

Verification: All customers are REQUIRED to provide a comprehensive list of pressure system materials for a compatibility assessment and comply with requirements as detailed in Section 6.4.5. The list must include:

- All pressure system materials within the pressure vessel, and all other pressurized components, AND
- All working fluids, processing fluids, and expected/potential by-product fluids
- For systems using HTP, the customer shall additionally provide:
    - An analysis predicting the decay rate and subsequent propellant tank pressure increase over a 60-day period.
    - Perform the analysis assuming a maximum allowable storage temp of 32°C (or worst-case temperature profile between payload propellant load and payload separation).
    - A list of materials that may contact HTP (including gas-side of positive expulsion diaphragm, if used), and must provide evidence that these materials are compatible with HTP.

7.5.3 LEAK TESTING

Purpose: To verify that pressure vessels and fully integrated pressure and propulsion systems do not pose a hazard to ground personnel and the launch vehicle.

Verification: Customers using pressure vessels and pressure systems are REQUIRED to perform leak testing at pressure vessel and pressure system level according to the standards called out in Section 6.4. System-level leak testing must be verified post environmental testing of the integrated payload.

8 FACILITIES

8.1 SPACEX EAST COAST LAUNCH FACILITIES

8.1.1 CAPE CANAVERAL SPACE FORCE STATION, FLORIDA

SpaceX operates a Falcon 9 launch site at Space Launch Complex 40 (SLC-40) at Cape Canaveral Space Force Station (CCSFS), Florida. SLC-40 was previously used by the U.S. Air Force for Titan III and Titan IV launches, and it has been extensively modified by SpaceX to accommodate the Falcon 9 launch vehicle.

The SLC-40 launch pad is located at 28˚ 33.72' (28.5620°) N latitude, 80˚ 34.630' (80.5772°) W longitude. Launch azimuths from SLC-40 support low- to mid-inclination LEO, high-inclination LEO orbits including polar orbits, and SSO, GTO, and Earth-escape orbits (Section 3.1).

SpaceX facilities at SLC-40 (Figure 8-1) include a launch vehicle integration hangar, propellant and pressurant storage and supply areas, a launch pad, and lightning towers. A SpaceX administrative facility is located adjacent to the launch complex.

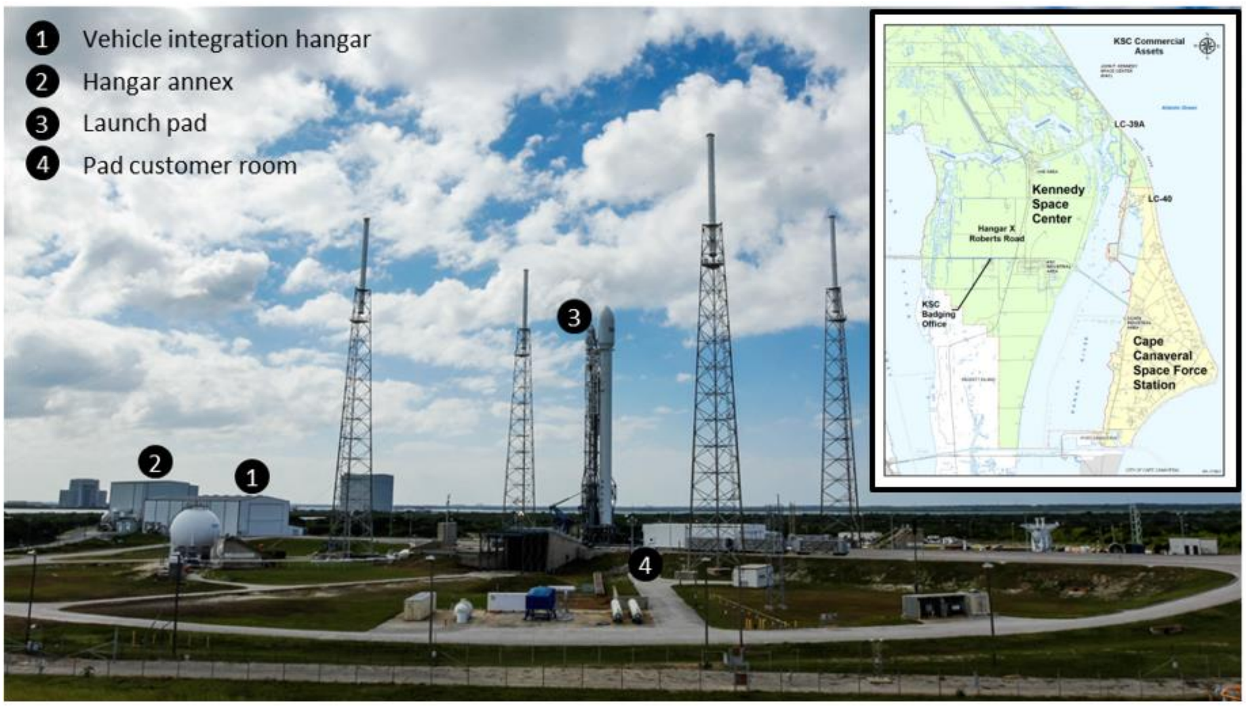


Figure 8-1: Space Launch Complex 40 at Cape Canaveral Space Force Station, Florida

SpaceX provides the use of an off-pad PPF as a standard service for CCSFS launch operations. CCSFS processing and launch operations, including PPF services, are described in Section 10.

Figure 8-2: Falcon 9 launches from SLC-40 (left) with another Falcon 9 ready to launch from LC-39A (right)

8.1.2 KENNEDY SPACE CENTER, FLORIDA

SpaceX operates a single Falcon 9 and Falcon Heavy launch site at Launch Complex 39A (LC-39A) at John F. Kennedy Space Center, located on Merritt Island along the central Florida coast. NASA constructed LC-39A (Figure 8-3) in the early 1960s to conduct missions under the legendary Apollo program and, later, with the space shuttle. In April 2014, SpaceX signed a 20-year lease with NASA for use of historic LC-39A. After facility upgrades in 2016, SpaceX completed its first LC-39A launch on February 19, 2017, with Falcon 9 launching CRS-10 as part of an ISS commercial resupply mission. SpaceX has since continued the pad's legacy, launching more than 100 Falcon 9 and Falcon Heavy missions from the pad.

The LC-39A launch pad is located at 28.6082° N latitude, 80.6041° W longitude. Launch azimuths from LC-39A support low- to mid-inclination LEO, high-inclination LEO orbits, GTO, and Earth-escape orbits (Section 3.1).

Figure 8-3: LC-39A at Kennedy Space Center, Florida

Located 8 miles from the main KSC gate, at LC-39A (Figure 8-3) SpaceX constructed a hangar designed to receive, integrate, and roll out Falcon 9 and Falcon Heavy launch vehicles (Figure 8-3). With 55,000 sq ft of floor space and 34,000 sq ft of high bay space, the hangar contains 90-ton, 50-ton, and 30-ton bridge cranes as well as integration rails, electrical support equipment, and GN2, GHe, and other supplies for performing launch vehicle processing and integration with the encapsulated payload.

The maximum incline that the integrated launch vehicle experiences during transportation from the hanger to the pad is 2.9 degrees and occurs as it is moved up the ramp.

SpaceX provides the use of an off-pad PPF (located on CCSFS) as a standard service for KSC launch operations. Payload processing and launch operations, including PPF services, are described in Section 10.

8.1.3 CCSFS & KSC PERSONNEL ACCOMMODATIONS

8.1.3.1 ACCESS AND BADGES

CCSFS is a U.S. Space Force range with controlled access. SpaceX will facilitate pre-approval, badging, and access for customer personnel requiring access to CCSFS. Once badged, customer personnel will have access to the appropriate areas of the launch base. Non-U.S. persons are subject to additional pre-approval and escort requirements, which will be facilitated by SpaceX. For all customers processing their payloads at the SpaceX PPF, they will require CCSFS badges.

KSC is a NASA range with controlled access and different badging requirements and processes from CCSFS. For customers launching from LC-39A on KSC, SpaceX will facilitate badging for personnel who need access to hangar and pad facilities closer to the launch date.

8.1.3.2 TRANSPORTATION, LODGING, AND SERVICES

Customers typically fly commercial transport to Orlando International Airport, rent cars at the airport, and find lodging between Titusville and Cocoa Beach for the duration of their stay in Florida. Customer personnel who are U.S. persons may use their own rental cars for on-base transportation. For non-U.S. personnel with proper badging, SpaceX provides a shuttle service from an off-base parking lot to the various facilities used for launch and payload processing. The area offers a full range of services; your mission manager can provide you with additional detailed recommendations. SpaceX does not provide lodging for customer personnel during CCSFS or KSC launch campaigns.

8.1.3.3 AVAILABLE FACILITIES FOR CUSTOMERS

As a standard service, SpaceX provides desk and office space for customer personnel at CCSFS or KSC in a facility separate from the PPF.

These facilities are available from customer arrival through launch + 3 days. Offices are provided with U.S.-standard power (120V, 60 Hz), high-speed internet service. There are also designated control rooms which can be configured to monitor payload status during the launch campaign. Similar rooms are also available at the pad and in the hangar facility to support final system checks or countdown operations as needed

SpaceX Launch and Landing Control is located at Hangar X. The facility is equipped with fiber-optic connections to the launch site and a connection into the launch site's main data system, allowing easy data transfers between the control facility, the pad, and the Range, along with required external users and agencies. A customer room that can accommodate eight people is provided within the facility for customer technical management personnel.

8.2 VANDENBERG SPACE FORCE BASE, CALIFORNIA

SpaceX's California launch site is located within Vandenberg Space Force Base (VSFB). VSFB is an active installation of the U.S. Space Force, Space Launch Delta 30 (SLD-30), and is the location of the Western Range. Figure 8-4 shows VSFB with pertinent facilities labeled. On the southern half of the base, SpaceX Runway Operations (Annex and Hangar), Customer Support Building (CSB), and Pad EGSE Room are situated at Space Launch Complex 4 (SLC-4), while Falcon maintenance, fairing maintenance, and payload processing facility (PPF) are located at Space Launch Complex 6 (SLC-6). SpaceX Launch and Landing Control is located on the northern half of the base, along with Vandenberg Airfield (KVBG) and Lockheed Martin Astrotech payload processing facility (APF).

Figure 8-4: SpaceX Vandenberg Facilities

Figure 8-5: SLC-4E Site Overview

The SLC-4 East (SLC-4E) launch pad is [located](#) at 34˚ 37.92' (34.6320°) N latitude, 120˚ 36.64' (120.6107°) W longitude. Launch azimuths from SLC-4E support high-inclination LEO orbits, including polar orbits and SSO (Section 3.1). SLC-4E processing and launch operations are described in Section 10.

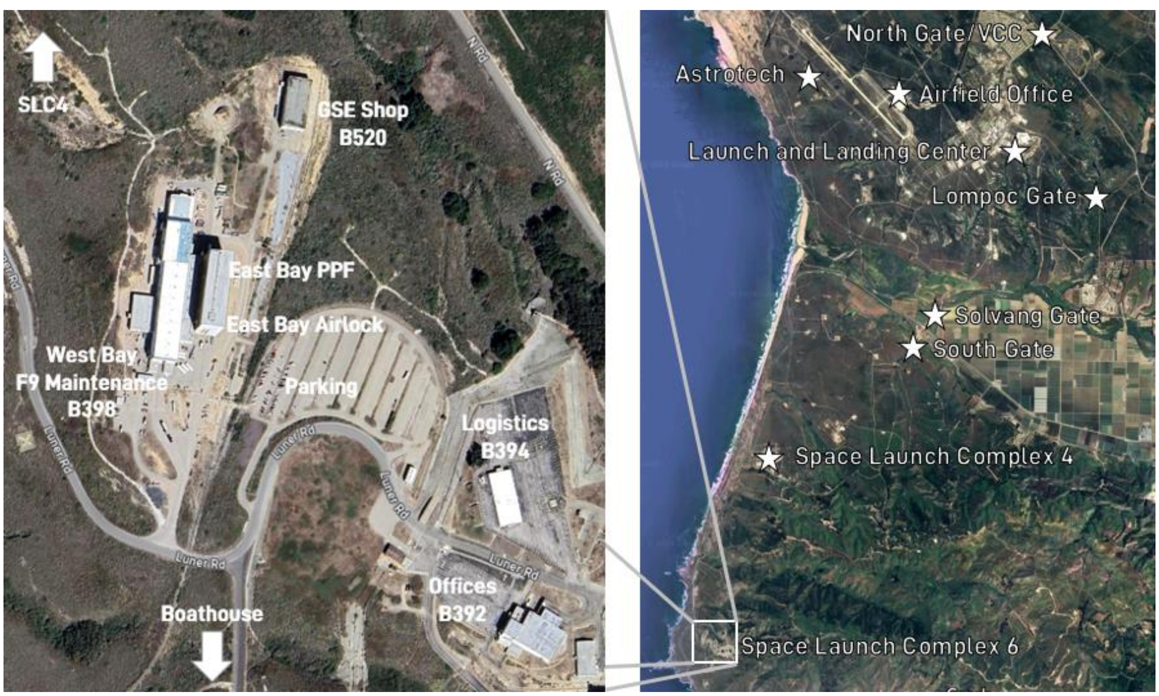


Figure 8-6: SLC-6 & Building 398

At SLC-6, SpaceX has multiple support buildings. The primary SpaceX facilities currently in use at SLC-6 are Building 398 (Falcon 9 & fairing maintenance, Starlink & PPF), Building 394 (Shipping/Receiving), Building 520 (GSE), and an adjacent parking lot.

8.2.1 VSFB PERSONNEL ACCOMMODATIONS

8.2.1.1 ACCESS AND BADGES

VSFB is a U.S. Space Force base with controlled access. SpaceX will facilitate pre-approval, badging, and access for customer personnel requiring access to VSFB. Once badged, customer personnel will have access to the appropriate areas of the launch base. Non-U.S. persons are subject to additional pre-approval and escort requirements, which will be facilitated by SpaceX.

8.2.1.2 TRANSPORTATION, LODGING AND SERVICES

Customers typically fly commercial transport to Los Angeles International Airport (LAX), rent cars at the airport, and find lodging between Lompoc and Santa Maria for the duration of their stay in California. The drive between LAX and VSFB takes approximately 3 hours. Customers occasionally fly into Santa Barbara Airport (SBA) as well; the drive from SBA to VSFB takes about an hour. Customer personnel who are U.S. persons may use their own rental cars for on-base transportation. SpaceX does not provide lodging for customer personnel during VSFB launch campaigns. The area offers a full range of services; your mission manager can provide you with additional detailed recommendations.

8.2.1.3 AVAILABLE FACILITIES FOR CUSTOMERS

SpaceX may provide desk and office space for customer personnel at SLC-4E if required. Offices will be provided with U.S.-standard power (120 V, 60 Hz) and high-speed internet service.

The customer room located at the pad, shown below in Figure 8-7, is located adjacent to the launch mount at SLC-4Ein the Launch Support Building (Building 715), which is a concrete reinforced bunker. The customer pad EGSE room is centrally located along the west side of the main pad building and equipped to support customer EGSE racks and GN2 purge interfaces for pad and day of launch operations.

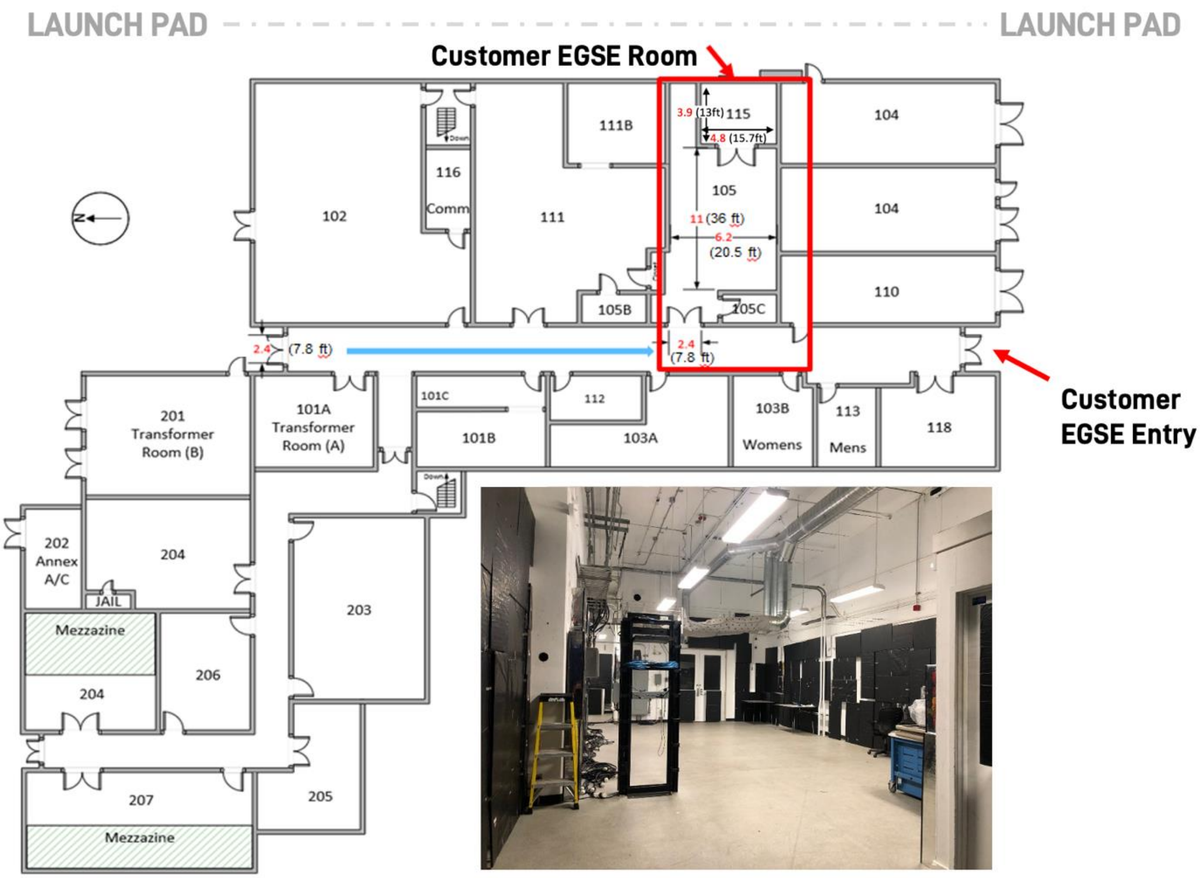


Figure 8-7: Pad Customer Room

SpaceX Launch and Landing Control is in the northern section of VSFB (also called North Base), about 7 miles from the SLC-4E launch site and is where SpaceX performs day-of-launch operations with launch partners.

The Launch and Landing Control will accommodate a prearranged roster of customer personnel, with telemetry monitoring devices and audio consoles during a countdown rehearsal and on the day of launch. The Launch and

Landing Control has rooms to support customer EGSE racks and workstations, and capabilities to route information to government partners.

Figure 8-8: Customer Control Rooms at SpaceX Launch and Landing Control

Located 3.5 miles south-southwest of SLC-4 and originally built during the mid-1980s, Building 398 was originally designed to support Space Shuttle solid rocket booster (SRB) assembly and checkouts. It was then repurposed to support Atlas and Delta SRB assembly until it was leased by SpaceX. It has now become the center of Falcon 9 and payload fairing maintenance in the west bay, and payload processing in the east bay. Several support buildings around SLC-6 are now leased by SpaceX.

Figure 8-9: Building 398 at SLC-6

Figure 8-10: Building 398 PPF Map

Building 398 PPF is composed of an airlock and three independently operating processing bays with matching control/EGSE rooms supported by garment/changeout rooms for personnel entry, with connections to common areas shared with SpaceX personnel. Solid and hypergolic fuels are not supported due to facility permitting and explosive citing, but other types of gaseous/liquid fueling may be performed. Technical details on each processing bay may be found in the following sections, but a brief overview of each area is as follows:

- Airlock is used for hardware ingress and egress and is shared space with Starlink processing.
- Bay 1 is separated by a 13' high security partition from the rest of the clean room.
- Bays 2 and 3 have no permanent partition and are often treated as a single large processing bay.
- Control rooms are nearly identical and are intended to operate independently.
- Gowning rooms provide badge-controlled changeout areas for all three bays.
- Conference rooms, café, and bathrooms are shared areas with Falcon, fairing and payload processing.

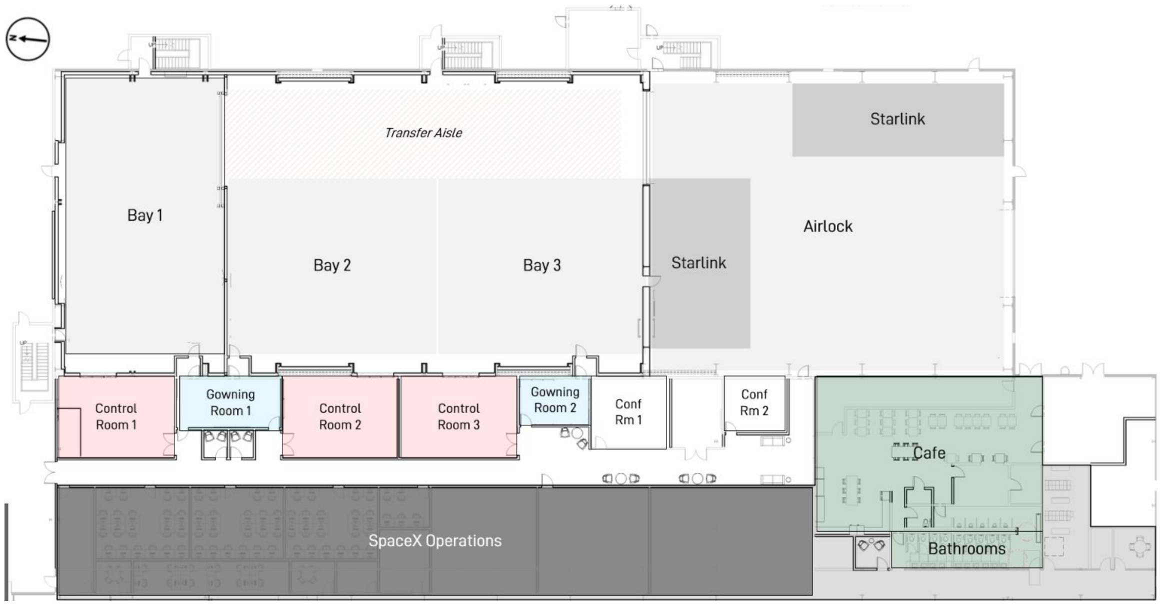


Figure 8-11: Building 398 PPF Layout

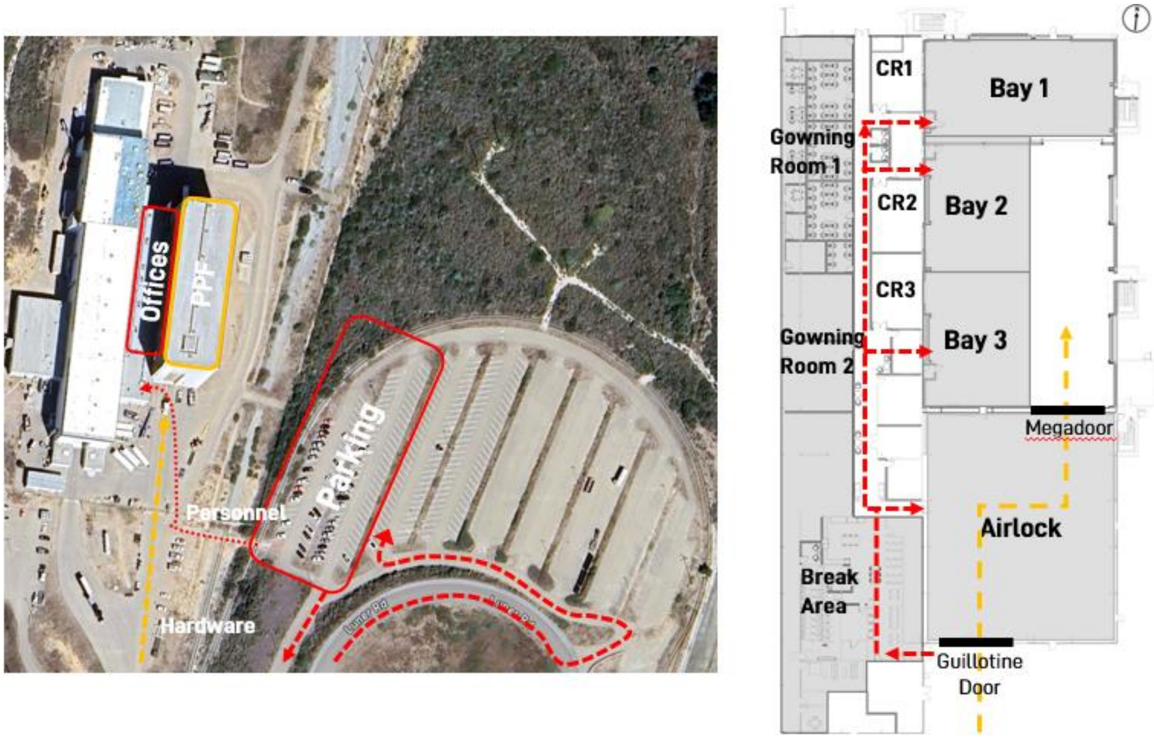


Figure 8-12: Building 398 Personnel and Hardware Access

8.3 HAWTHORNE, CALIFORNIA

SpaceX's Dragon, Falcon 9, Falcon Heavy, and Merlin engine production facilities (Figure 8-13) are conveniently located in Hawthorne, CA, a few miles inland from Los Angeles International Airport. The design and manufacturing facility ranks among the largest manufacturing facilities in California. Facilities include multiple Falcon 9 and Falcon Heavy stage manufacturing stations, fairing production and integration stations, and nine stations for final assembly of the Merlin engine.

Figure 8-13: SpaceX in Hawthorne, California

8.4 ROCKET DEVELOPMENT FACILITY—MCGREGOR, TEXAS

Structural and propulsion testing are performed at the SpaceX Rocket Development Facility in McGregor, Texas (Figure 8-14). Conveniently located two hours from both Austin and Dallas, the site is staffed with test engineers, technicians, and management personnel. At this facility, every Falcon 9 and Falcon Heavy first and second stage and every Merlin engine undergoes acceptance testing before first flight. Merlin engine refurbishment work is also performed at SpaceX's three Falcon launch sites and at SpaceX's Rocket Development Facility.

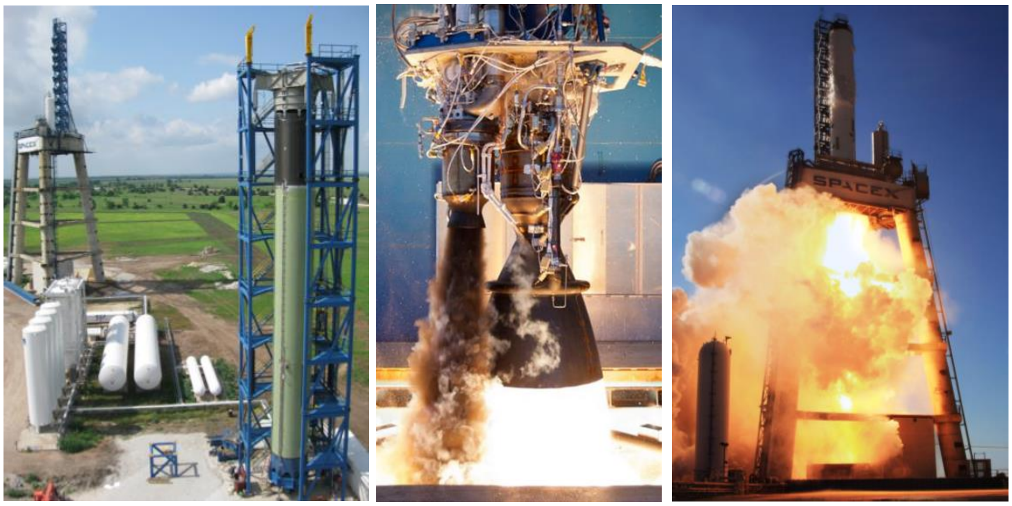


Figure 8-14: Rocket Development Facility in McGregor, Texas

8.5 GOVERNMENT OUTREACH AND LEGAL AFFAIRS—WASHINGTON, DC

SpaceX's government outreach and licensing team is located in Washington, DC.

9 MISSION INTEGRATION AND SERVICES

9.1 CONTRACTING

Falcon launch services are available via direct contract with SpaceX and through certain managed procurement services. To begin your direct contract relationship with SpaceX, please contact the SpaceX Sales department. The Sales department will work with you to develop a launch services contract.

9.2 MISSION MANAGEMENT

To streamline communication and ensure customer satisfaction, SpaceX provides each Falcon launch services customer with a single technical point of contact from contract award through launch (Figure 9-1). Your mission manager will be responsible for coordinating mission integration analysis and documentation deliverables, planning integration meetings and reports, conducting mission-unique design reviews (as required), and coordinating all integration and test activities associated with the mission. The mission manager also coordinates all aspects of launch vehicle production, Range and Range Safety integration, and all mission-required licensing leading up to the launch campaign. The mission manager works closely with the customer, SpaceX technical execution staff, and all associated licensing agencies in order to achieve a successful mission.

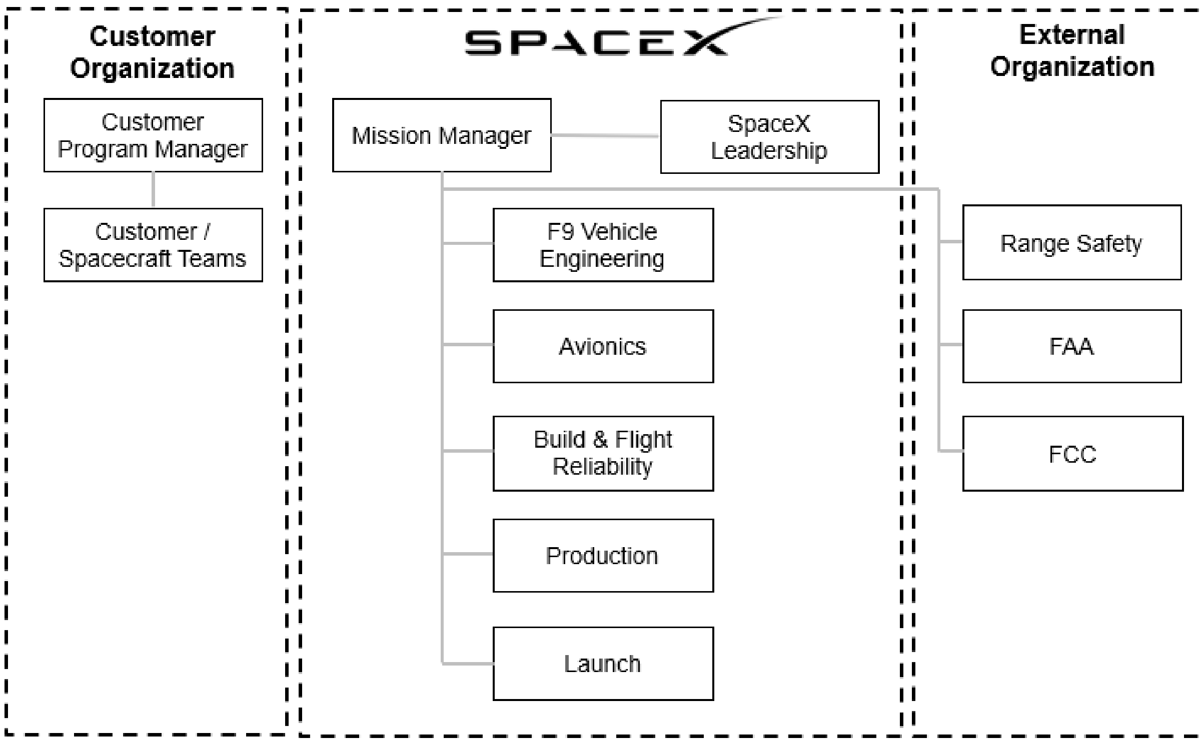


Figure 9-1: Mission Management Organization

The mission manager will work with the customer to create a spacecraft-to-launch-vehicle interface control document (ICD): the master document for a Falcon launch vehicle mission. Following signature approval of the ICD, SpaceX maintains configuration control of the document.

Once the payload arrives at the launch site, a dedicated launch site mission manager will coordinate with the customer team regarding the execution of all launch site payload operations including logistics, physical accommodation of customer hardware and associated ground support equipment, hazardous operations, and combined operations.

9.3 STANDARD SERVICES

As part of any Falcon launch service, SpaceX will:

- Provide personnel, services, hardware, equipment, documentation, analyses, and facilities to support mission planning, launch vehicle production and acceptance, payload integration, and launch.
- Secure required launch licensing, including Federal Aviation Administration (FAA) and State Department licenses, with input from the payload customer. (Note: Customers are responsible for any launch licenses specific to payload operation).
- Secure third-party liability insurance for the launch (Note: Customer retains responsibility for satellite insurance at all times).
- Provide all Range and safety documents for the payload provider to complete (per AFSPCMAN 91-710 and 14 CFR Part 400).
- Facilitate the Range and Range Safety integration process.
- Provide up to two sets of 37- or 61-pin satellite-to-launch-vehicle in-flight disconnect electrical connectors, or integrate customer-provided mission-unique connectors.
- Provide a 1,575-mm bolted interface compatible with the 62.01-in. diameter medium-class payload mechanical interface defined in the EELV Standard Interface Specification, or a 2,624-mm bolted interface as defined in Section 4.1.5 and Appendix A: PAF Mechanical Interfaces.
- Provide one 937-mm or 1,194-mm or 1,666-mm (36.89-in. or 47.01-in. or 65.59-in.) adapter and low-shock clampband separation system, or integrate a customer-provided mission-unique separation system per Section 4.1.7 and Appendix B: Payload Mechanical, Electrical and Purge Standard Interfaces.
- Provide an adapter and technical support for a mechanical interface compatibility verification test at a facility of the customer's choosing.
- Provide support to the customer for the verification of the payload by providing interface information, environments, and constraints to help customer ensure the validity of the payload verification activities. This support includes informal review and feedback on test levels and responses compared to the SpaceX-provided maximum predicted environments.
- Provide 48 cumulative hours of remote on-call SpaceX support for payload sinusoidal vibration testing, including nights and weekends. The customer shall give SpaceX at least one week's prior notice for documentation reviews and two weeks' prior notice for on-call test support.
- Provide transportation for the customer's spacecraft container and all ground support equipment (GSE) from the launch site landing location (as designated by SpaceX) to the spacecraft processing location, if necessary.
- Provide ISO Class 8 (Class 100,000 cleanroom) integration space for the payload and GSE prior to the scheduled launch date, including facilities and support to customer's hazardous operations.
- Provide certified mechanical GSE to support physical mating of the payload to the payload adapter, perform fairing encapsulation, and integrate the encapsulated system with the launch vehicle.
- Process the launch vehicle, integrate and encapsulate the payload within the fairing, and test electrical interfaces with the payload.
- Provide conditioned air into the fairing during encapsulated ground processing.

- Conduct a review of the countdown procedure and a verification of the countdown voice communication system prior to launch with the customer's launch operations team supported by SpaceX mission management.
- Launch the payload into the specified orbit within the specified environmental constraints as defined in the Interface Control Document.
- Perform 3-axis attitude control or spin-stabilized spacecraft separation.
- Perform a collision avoidance maneuver (as required).
- Verify spacecraft separation from the launch vehicle and provide an orbit injection report.
- Deliver a final post-flight report, which will include payload separation confirmation, ephemeris, payload environments, significant events, and any mission-impacting anomalies.

A detailed SOW and deliverables list, including these standard services, will be developed during contract negotiation.

9.4 SCHEDULE

Table 9-1 provides a standard launch integration schedule, starting at contract signature and proceeding through the post-flight summary. A detailed schedule, including the required customer deliverables, is developed during contract negotiation.

Table 9-1: Standard Launch Integration Schedule

Estimated Schedule	Title	Purpose
L-24 months	Contract signature	Provide authority to proceed with work
L-18 months	Mission integration kickoff	Present the project schedule, a summary of mission requirements and proposed preliminary design solutions for any mission-unique requirements
L-9 months	Completion of mission integration analyses	Deliver mission-unique design and analysis results to the customer and prepares the ICD for signature
L-2 months	Launch campaign readiness review	Verify that all people, parts, and paper are ready for the shipment of the payload to the launch site and are ready to begin launch site activities
L-1 day	Launch readiness review	Verify readiness to proceed with the countdown and launch, including launch Range and FAA concurrence
Separation + TBD minutes	Orbit injection report	Delivers best-estimate state vector, attitude, and attitude rate based on initial data
Launch + 8 weeks	Flight report	Reports the flight, environments, separation state, and a description of any mission-impacting anomalies and progress on their resolution

9.5 CUSTOMER DELIVERABLES

Table 9-2 and Table 9-3 provide an overview of standard documentation and information required from the customer. Note: These lists are not all-inclusive but rather represent minimum requirements. Depending on the specific payload, additional customer requirements may apply.

Table 9-2: Required Documents and Data for All Payloads

Customer Deliverables	Description
Payload safety data	Provides detailed payload information to support generation of Range Safety submittals, requirements tailoring and launch operations planning. Includes hazard analyses and reports, vehicle break-up models and detailed design/test information
Finite-element and CAD models	Used in coupled loads analyses and compatibility assessments. Specific format and other requirements are supplied during the mission integration process
Environment analysis inputs	Payload inputs for SpaceX environment analyses. Includes payload CAD, thermal model and others, as required
Inputs to ICD	Describes all mission-specific requirements and detailed launch vehicle to payload interfaces. SpaceX generates and controls the ICD, but input is required from the customer. ICD compliance verification is required prior to launch
Environmental test statement and data	Defines the payload provider's approach to qualification and acceptance testing, including general test philosophy, testing to be performed, objectives, test configuration, methods and schedule. Actual test procedures are not required. Specific qualification and acceptance test data may be required prior to launch to demonstrate compatibility with the launch environments
Launch site operations plans and procedures	Describes all aspects of mission activities to be performed at the launch site. Operating procedures must be submitted for all payload operations that are accomplished at the launch site and are subject to Range Safety review. Hazardous procedures must be approved by Range Safety
Mission data	Information in support of reviews is required throughout the mission integration process

Table 9-3: Additional Required Documents and Data for Non-US Persons and Non-US Government payloads

Customer Deliverables	Description
FAA payload determination information	Non-US government payloads must be reviewed by the FAA to determine whether their launch would jeopardize public safety and other US interests (Title 14 CFR part 415 subpart D). Payload providers may need to provide additional information to enable SpaceX to submit an application for review
Launch site visitor information	To obtain the appropriate access, SpaceX requires information for all customer personnel to be submitted prior to visiting the launch site
Launch site GSE details	Details on GSE that a non-US customer plans to bring to the launch site are required for import/export compliance

9.5.1 PAYLOAD LICENSING AND REGISTRATION

Customer will flow down its responsibilities relating to payload licensing and registration (including registration pursuant to the Convention on Registration of Objects Launched into Outer Space) to each of its customers, in writing. Evidence of proper flow-down will be provided to SpaceX upon request.

9.5.2 COORDINATION WITH SPACE SITUATIONAL AWARENESS

9.5.2.1 PRE-LAUNCH REGISTRATION

The customer is responsible for registering all deployed objects with the 18th SPCS to assist with tracking and identification. Information can be found at https://www.space-track.org on how to register a payload and the process for communicating and coordinating with the 18th SPCS. If required, SpaceX can provide direct contact information with personnel from the 18th SPCS.

Additionally, if any of the payload's operational, transfer, or disposal orbits cross the ISS altitude, NASA requests direct coordination at jsc-dl-topo-iwg@mail.nasa.gov for ISS conjunction deconfliction.

SpaceX also recommends customers consider adopting and following the best practices outlined in the NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook, which can be found at https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf.

9.5.2.2 POST-LAUNCH REGISTRATION

The customer is responsible for publishing forward predicted satellite ephemerides with covariance to:

- Space-Track: https://www.space-track.org
- SpaceX Space Traffic Coordination: Details at https://docs.space-safety.starlink.com/, contact space-safety-onboarding@spacex.com for pre-launch setup and testing.

An important benchmark is uploading ephemerides within Launch + 3 hours when the Launch COLA analysis expires. SpaceX additionally submits post-launch ephemeris for each deployment event based on Stage 2's state and estimated deployment impulse, but customer-provided orbit determination from satellite telemetry (e.g., from GPS) is more accurate.

If customers are unable to generate propagated ephemeris and covariance, SpaceX strongly recommends they work with a commercial provider to contract for this work (SpaceX can provide recommendations). Publishing predictions drastically improves and accelerates the cataloging process by USSPACECOM and enhances collision avoidance screening.

9.5.3 ENTRY AND EXIT VISAS

The customer is responsible for obtaining any visas required for customer's personnel, including customer's related third parties and guests. SpaceX can provide letters of invitation for customer's launch campaign personnel to support the issuance of U.S. entry visas by the U.S. Department of State.

9.5.4 ANOMALY, MISHAP, ACCIDENT, OR OTHER EVENT

In the event of an anomaly, mishap, accident, or other event resulting in property damage, bodily injury or other loss, customer will cooperate with SpaceX, any insurers, and federal, state, and local government agencies, in their respective investigations of the event, including the completion of witness statements, if applicable. Such cooperation will include providing all data arising out of or related to the payload, any ground support, and any activities relating to the performance of the Agreement, reasonably requested by SpaceX, the insurers, or federal, state, and local agencies. Notwithstanding customer's obligation to cooperate, SpaceX may use reasonable means to independently access such information. Customer and customer's customers may not make any public comment, announcement, or other disclosure regarding such event without SpaceX's review and approval.

10 OPERATIONS

Falcon launch vehicle operations are described in this section for launches from CCSFS and KSC (Section 8.1) and VSFB (Section 8.2). SpaceX launch operations are designed for rapid response . Customers are strongly encouraged to develop launch readiness capabilities and timelines consistent with a rapid prelaunch concept of operations.

10.1 OVERVIEW AND SCHEDULE

The Falcon launch vehicle system and associated operations have been designed for minimal complexity and minimal time at the pad (Figure 10-1). Customer payload processing is performed in a PPF. After completion of standalone spacecraft operations (typically over a 15-day period) by L-7 days, SpaceX performs the adapter mate and fairing encapsulation at the PPF. The spacecraft is then transported to the integration hangar. Final processing of the launch vehicle occurs in the integration hangar at the launch complex prior to being loaded on the transporter-erector. The launch vehicle is processed in the integration hangar at the launch complex and then loaded on the transporter-erector. The encapsulated assembly is mated to the launch vehicle at approximately L-2 days, followed by end-to-end system checkouts. Falcon 9 and Falcon Heavy systems are designed for rollout and launch on the same day, but SpaceX can perform an earlier rollout and conduct a longer countdown if required.

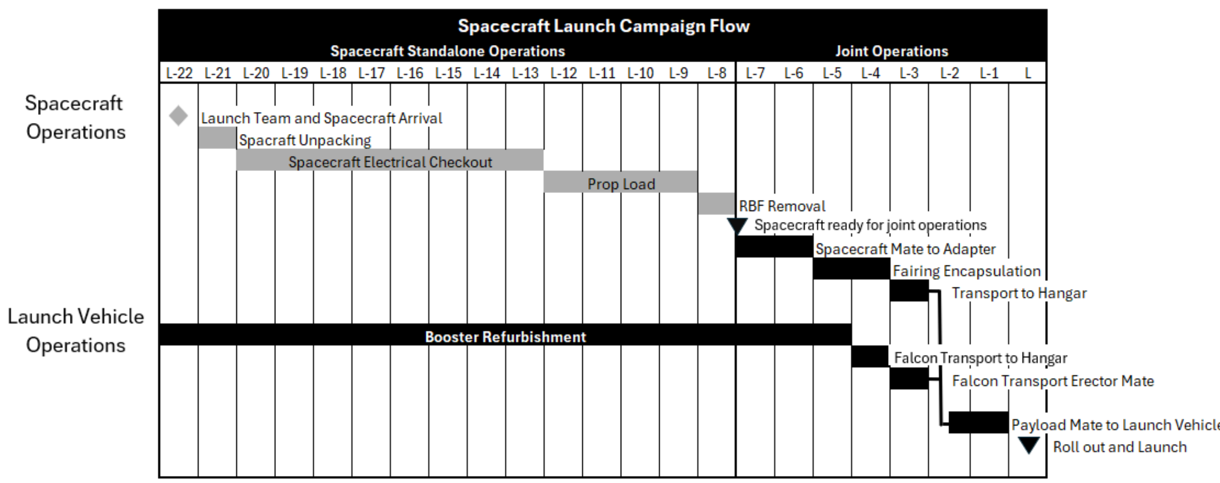


Figure 10-1: Reference Falcon Launch Vehicle Processing, Integration, and Launch Operations Schedule

10.2 SPACECRAFT DELIVERY AND TRANSPORTATION

For standard service processing and integration, payloads should be delivered to the launch site four weeks prior to launch. Alternative delivery schedules can be arranged as a nonstandard service.

Customers typically deliver their payloads via air, maritime, or ground transport.

The Eastern Range offers two convenient landing locations on base for customers delivering their payloads and associated equipment via air transport: the Shuttle Landing Facility at KSC (also known as the Launch and Landing Facility) and the CCSFS Skid Strip, as well as several other airports in the vicinity. Maritime delivery near Port Canaveral is also an option.

Vandenberg provides one landing location at the VSFB airfield, approximately 14 miles north of the launch complex. Non-U.S. payloads coming to VSFB via the airfield must clear customs at LAX or another port of entry prior to arrival at VSFB.

As a standard service, SpaceX will arrange for the customer's spacecraft container and all associated test and support equipment to be offloaded from the aircraft and transported to the PPF, provided the aircraft lands at a SpaceX designated airport. Ground transport services can also be provided by AstroTech Space Operations or Spaceport

Systems International; SpaceX can facilitate these as a nonstandard service. For arrivals from airports located off base or via sea, customers are responsible for arranging transport up to base security gates.

10.3 SPACECRAFT PROCESSING

SpaceX provides an ISO Class 8 (Class 100,000) PPF for processing customer spacecraft, including equipment unloading, unpacking/packing, final assembly, nonhazardous flight preparations, and payload checkout. The PPF is available to customers from four weeks prior to launch, with 16 hours per day standard availability and access during that period. Additional time in the PPF may be available as a nonstandard service. The PPF layouts for VSFB and CCSFS are shown in Figure 10-2, Figure 10-3, Figure 10-4, and Figure 10-5 respectively.

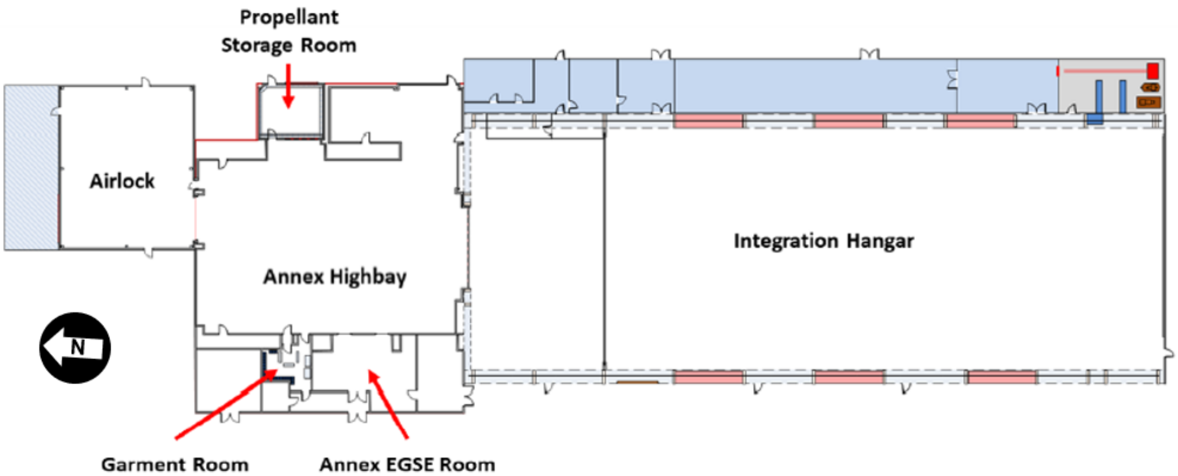


Figure 10-2: VSFB Annex and Integration Hangar Layout

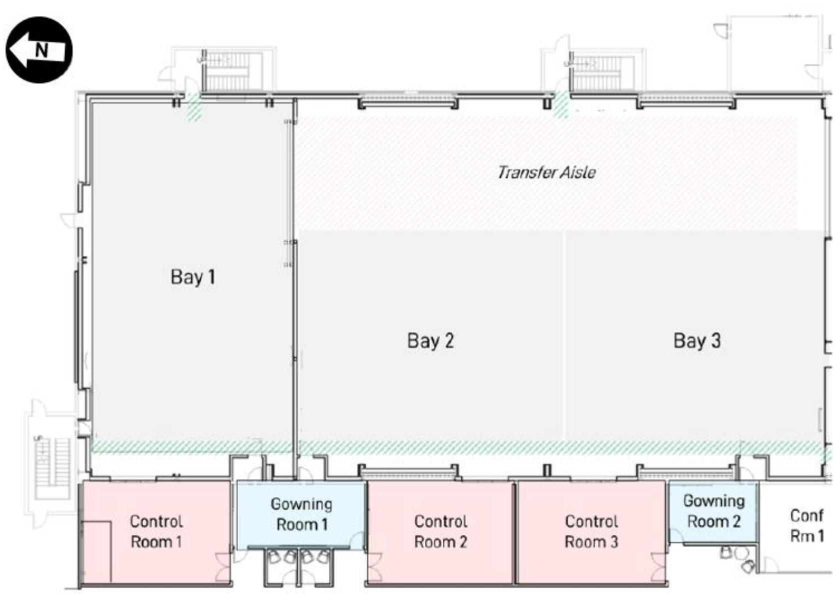


Figure 10-3: VSFB Building 398 for Non-Hypergol Payloads Floor Plan

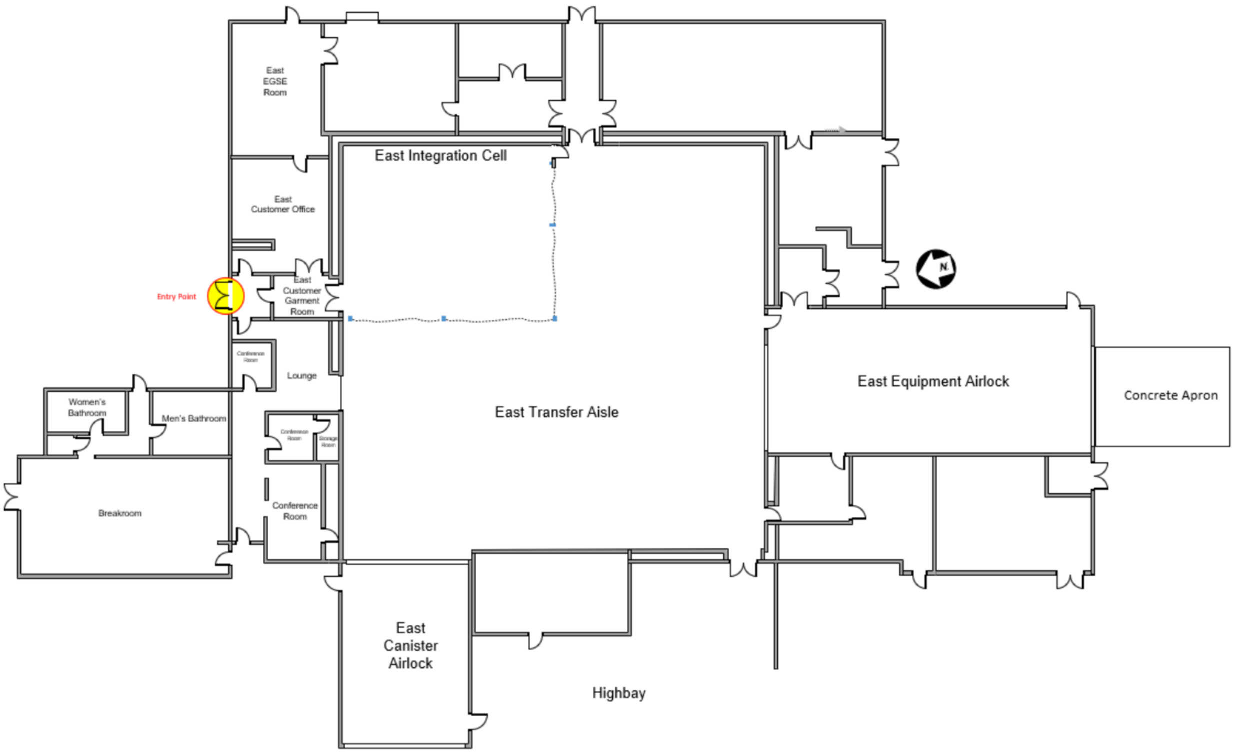


Figure 10-4: CCSFS PPF East Bay Floor Plan

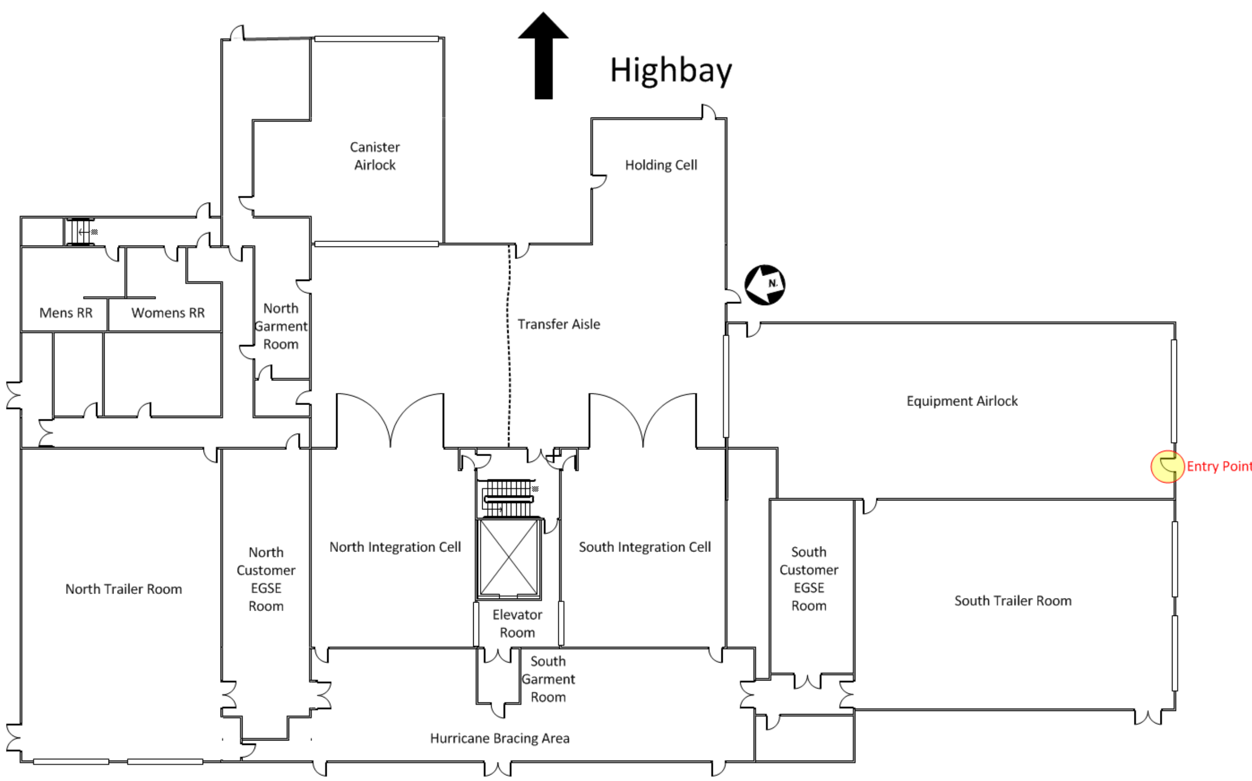


Figure 10-5: CCSFS PPF West Bay Floor Plan

Services and equipment provided for satellite processing within the PPF are outlined in Table 10-1. Additional space is provided for customer GSE and operations personnel. A facility HVAC system maintains PPF environments. SpaceX will continuously monitor relative humidity, temperature, and cleanliness in the PPF. Air cleanliness with measured monitoring using witness plates is available as a nonstandard service. The customer must supply any necessary cables and converters for its GSE to interface with PPF power. SpaceX can supply alternative power sources as a nonstandard service.

The PPF (excluding Building 398 in Vandenberg) is also designed to accommodate hazardous operations such as hypergolic propellant loading and ordnance installation. Any required fueling operations will be performed by customer personnel with assistance from SpaceX personnel. All personnel must use certified SCAPE suits, pass a physical medical evaluation, and attend SCAPE training classes.

All spacecraft processing operations within the PPF must be completed by L-7 days to allow for mating to the payload adapter, fairing encapsulation, and transportation to the launch vehicle integration hangar in preparation for launch.

Table 10-1: Services and Equipment for Payload Processing

	CCSFS	VSFB
Clean Room		
Dimensions	No less than 9.1 m x 9.1 m (30 ft x 30 ft) of dedicated spacecraft processing floor space, including for payload fueling operations.	No less than 29.2 m x 20.7 m floor size (95.8 ft x 67.9 ft)
Exterior door	No less than 10.36 m high x 5.76 m wide (34 ft x 18 ft 8 in)	No less than 6.01 m high x 6.01 m wide (20 ft x 20 ft)
Temp/Clean	See Table 5-2 (PPF facility HVAC)	See Table 5-2 (PPF facility HVAC)
Overhead Crane		
Quantity	2	2
Max hook height	East PPF: Airlock Crane: 10.4 m (34 ft) Cleanroom Crane: 30.5 m (100 ft) West PPF: Airlock Crane: 12.2 m (40 ft) Cleanroom Crane: 30.5 m (100 ft)	22.03 m (72.28 ft), airlock and cleanroom
Capacity	East PPF: Airlock Crane: 15,000 kg (15 T) Cleanroom Crane: 50,000 kg (50 T) West PPF: Airlock Crane: 5,000 kg (5 T) Cleanroom: 50,000 kg (50 T) Both certified for hypergolic lifting	Airlock Crane: 31,751 kg (35 T) Cleanroom Crane: 31,751 kg (35 T)
Hoist Speed (min/max)	50.9 cm/min (1.67 ft/min), airlock 27.4 cm/min (0.1 ft/min), cleanroom	0.61 cm/min (0.02 ft/min), airlock and cleanroom
Operation modes	Independent	Independent
Access Equipment		
	45-ft boom lifts, pallet jack, lifting hardware, ladders, movable platforms	Pallet jack, lifting hardware, ladders, movable platforms
Electrical		
60 Hz AC	120V 1-phase, 120/208V 3-phase, and 480V 3-phase service	120V 1-phase and 120/208V 3-phase service
50 Hz AC	220/380V – WYE, 3-Phase, 5-Wire with UPS back up	220/380V- WYE, 3-Phase, 4-Wire with UPS backup
Grounding	Per MIL-STD-1542	Per MIL-STD-1542

	CCSFS	VSFB
GN_2 Supply		
Quality	MIL-PRF-27401, Grade B	MIL-PRF-27401, Grade B
Pressure	28,613 kPa (4,150 psi)	34,473 kPa (5,000 psi)
Flow rate	1,699.2 Nm^3/hr (1,000 scfm)	1,699.2 Nm^3/hr (1,000 scfm)
Helium Supply		
Quality	MIL-PRF-27407, Grade A	MIL-PRF-27407B, Type 1, Grade B
Pressure	39,300 kPa (5,700 psi)	41,368 kPa (6,000 psi)
Flow rate	1,699.2 Nm^3/hr (1,000 scfm)	1,699.2 Nm^3/hr (1,000 scfm)
Compressed Air Supply		
Pressure	827 kPa (120 psi)	862 kPa (125 psi)
Communications		
Administrative phone	VOIP phones	VOIP phones
Paging system	Yes	Yes
Area warning system	Yes	Yes
Security		
Locking facility	Yes	Yes
Launch site badges	Yes	Yes
Video monitoring	Yes	Yes

As an alternative nonstandard service, SpaceX can arrange the use of commercial processing facilities near CCSFS or VSFB for payload processing. If a payload is processed at a facility other than the SpaceX-provided PPF, SpaceX can provide environmentally controlled transportation from that facility to the launch vehicle integration hangar.

10.4 JOINT OPERATIONS AND INTEGRATION

Joint operations begin seven days before launch. Payload attachment to the PAF and fairing encapsulation are performed by SpaceX within the PPF (Figure 10-6). Fairing encapsulation is performed in the vertical orientation. Transportation is performed in the vertical orientation, and environmental control is provided throughout the transportation activity. Once at the launch vehicle integration hangar, the encapsulated assembly is rotated to horizontal and mated with the launch vehicle already positioned on its transporter-erector.

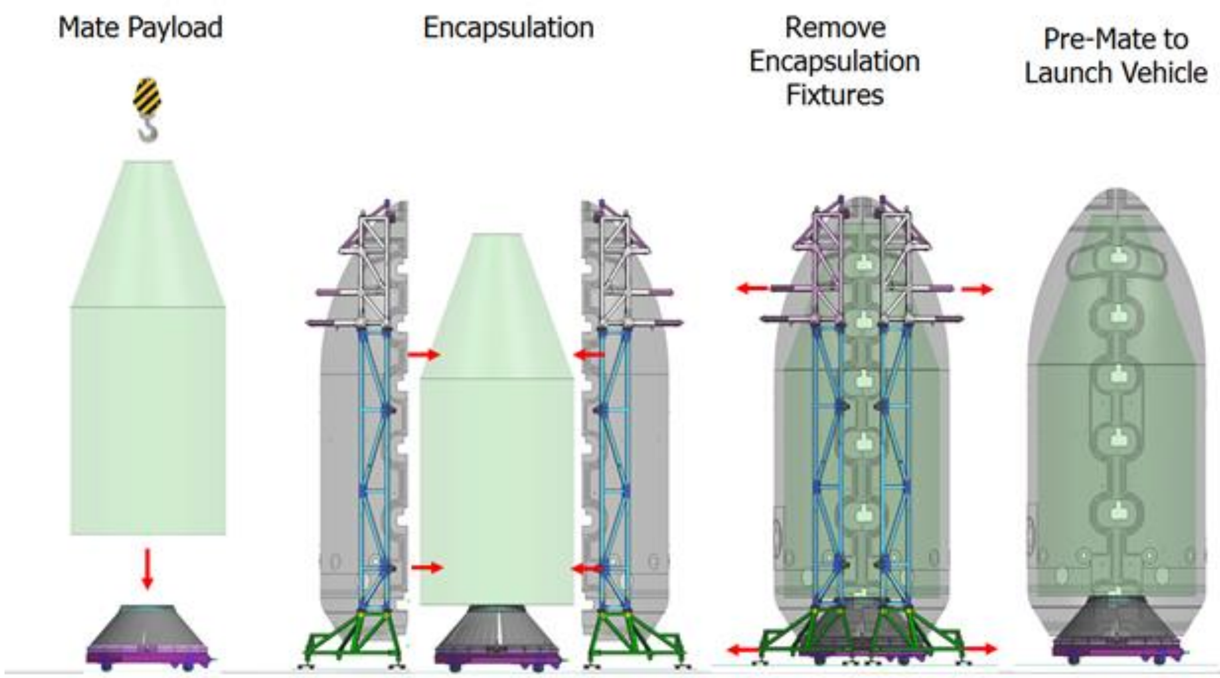


Figure 10-6: Payload Encapsulation and Integration Sequence

Once the encapsulated assembly is mated to the launch vehicle, the hangar facility HVAC system is connected via a fairing air conditioning duct to maintain environmental control inside the fairing. The payload is then reconnected to EGSE (if required) and electrical interfaces are verified. At this point, the integrated launch vehicle is ready for rollout and launch (Figure 10-7).

Figure 10-7: Falcon 9 on the Transporter-Erector in the Integration Hangar and During Rollout

10.5 LAUNCH OPERATIONS

10.5.1 ORGANIZATION

The main decision-making roles and responsibilities for launch operations are shown in Table 10-2. Note that this list is not inclusive of all roles participating in the launch but is rather limited to those that have direct input in the decision-making process.

Table 10-2: Launch Control Organization

Position	Abbreviation	Organization
Chief Engineer	CE	SpaceX
Mission Manager	MM	SpaceX
Launch Director	LD	SpaceX
Range Operation Commander	ROC	Launch Range
Operations Safety Manager	OSM	Launch Range

The launch control organization and its lines of decision-making are shown in Figure 10-8. The details of the launch control organization are somewhat dependent on the mission and customer. A customer launch director, representing the customer organization and the payload, will interface with the SpaceX mission manager and coordinate the launch countdown operations. The customer launch director may either be co-located with the SpaceX mission manager in the Launch and Landing Control , or in an adjacent customer control room.

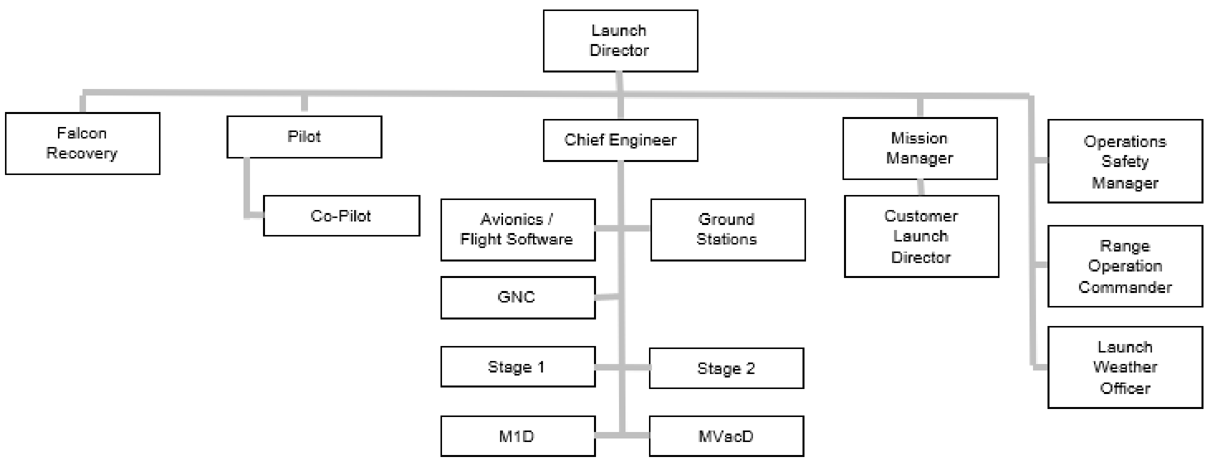


Figure 10-8: Launch Control Organization

10.5.2 SPACECRAFT CONTROL CENTER

SpaceX provides a spacecraft control center for remote payload command and control operations during the launch countdown. Customer EGSE and spacecraft personnel will be located within the spacecraft control center during launch. The spacecraft control center includes full fiber-optic voice, video, and internet connectivity to the launch site, SpaceX Launch and Landing Control (Section 10.5.3), and other Range facilities.

10.5.3 LAUNCH AND LANDING CONTROL

The SpaceX console design is modular and expandable (Figure 10-9). SpaceX uses standard modern computer and display systems with software designed for industrial system control. Consoles also include voice communications capabilities, including voice nets, voice-over-internet protocol (IP) integration with remote sites, and IP phones. Video viewing and control are provided using the video-over-IP systems.

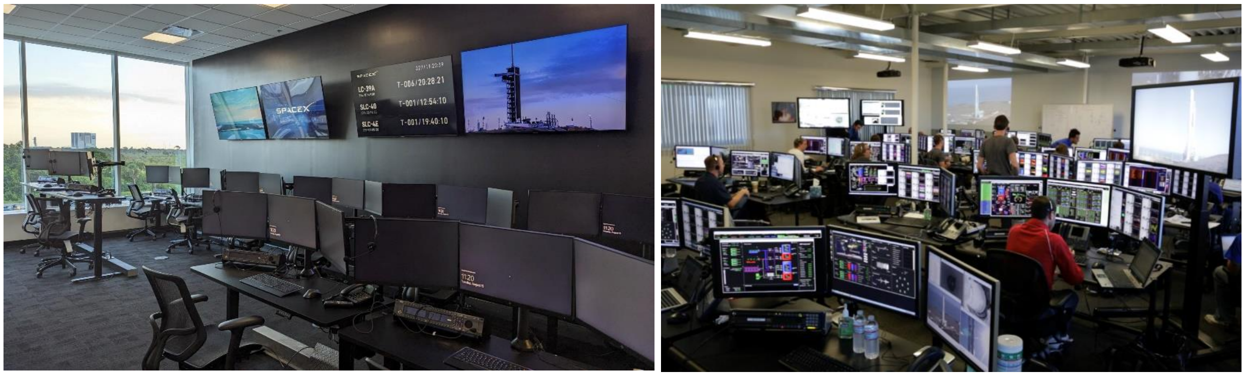


Figure 10-9: SpaceX Launch and Landing Control at the Eastern Range (left) and the Western Range (right)

10.5.4 ROLLOUT, ERECTION, AND PAD OPERATIONS

After readiness is verified, the integrated Falcon vehicle may be rolled out from the hangar to the pad on its transporter-erector (Figure 10-10). Once the vehicle is at the pad, the payload air conditioning system is reconnected, maintaining environmental control through liftoff. Electrical connectivity is provided via ground cables (Section 4.4.5). The vehicle will typically be erected only once, although the capability exists to easily return it to a horizontal orientation if necessary.

Figure 10-10: Launch Vehicle Rollout and Erection

Physical access to the payload while the vehicle is outside of the hangar requires special accommodations and is a nonstandard service. Payload access is not available while the launch vehicle is vertical.

10.5.5 COUNTDOWN

Early in the countdown, the vehicle performs LOX, RP-1, and pressurant loading, and it executes a series of vehicle and Range checkouts. The transporter-erector strongback is retracted just prior to launch. Automated software sequencers control all critical Falcon vehicle functions during terminal countdown. Final launch activities include verifying flight termination system status, transferring to internal power, and activating the transmitters. Engine ignition occurs shortly before liftoff, while the vehicle is held down at the base via hydraulic clamps. The flight computer evaluates engine ignition and full-power performance during the prelaunch hold-down, and if nominal criteria are satisfied, the hydraulic release system is activated at T-0. A safe shutdown is executed should any off-nominal condition be detected.

10.5.6 RECYCLE AND SCRUB

Falcon launch vehicle systems and operations have been designed to enable recycle operations when appropriate.

In the event of a launch scrub, the transporter-erector and launch vehicle will typically stay vertical. Remaining on the pad provides uninterrupted payload-to-EGSE connectivity through the T-0 umbilical, eliminating the need to relocate EGSE from the instrumentation bay to the hangar after a scrub. However, for any long-duration launch postponements, SpaceX will return the vehicle on the transporter-erector to the hangar.

10.6 FLIGHT OPERATIONS

10.6.1 LIFTOFF AND ASCENT

During first stage powered flight, Falcon's flight computers will command shutdown of the nine first stage engines based on achieving the target velocity or on remaining propellant levels. The second stage burns an additional five to six minutes to reach initial orbit, with deployment of the fairing typically taking place early in second stage flight. Subsequent operations are unique to each mission but may include multiple coast-and-restart phases as well as multiple spacecraft separation events.

10.6.2 SPACECRAFT SEPARATION

After reaching the spacecraft injection orbit and attitude, the Falcon vehicle issues redundant spacecraft separation commands, providing the electrical impulses necessary to initiate spacecraft separation. Indication of separation is typically available via second stage telemetry.

10.6.3 CONTAMINATION AND COLLISION AVOIDANCE

If a contamination and collision avoidance maneuver (CCAM) is necessary following payload deploy to ensure needed separation distance from the deployed payload and Falcon's second stage, the second stage can perform a CCAM if deemed necessary. A CCAM is provided as a standard service for individual primary payloads. For multi-manifested and secondary payloads, please contact SpaceX regarding collision avoidance requirements.

10.6.4 POST-LAUNCH REPORTS

SpaceX will provide a quick-look orbit injection report to the customer shortly after spacecraft separation, including a best-estimate spacecraft separation state vector. A final, detailed post-flight report is provided within eight weeks of launch.

10.6.5 DISPOSAL

SpaceX makes every effort to mitigate space debris by responsibly passivating and disposing of hardware on orbit. Customer-specific requirements on disposal may impose modest reductions to the performance specifications indicated in Section 3.2.

10.7 SAMPLE MISSION PROFILE

Sample mission profiles for Falcon 9 and Falcon Heavy are shown in Figure 10-11 and Figure 10-12, and sample Falcon 9 timelines for a GTO mission and LEO mission are shown in Table 10-3 and Table 10-4. Note: each flight profile is unique and will differ from these examples.

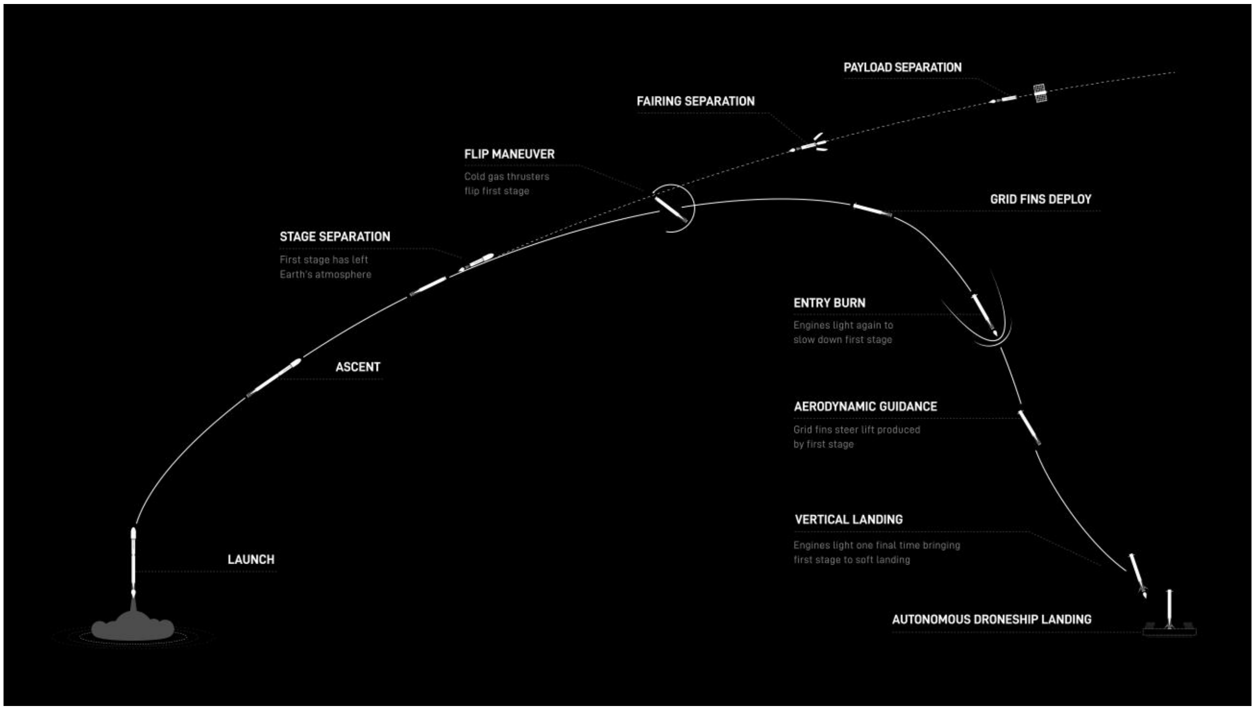


Figure 10-11: Falcon 9 Sample Mission Profile

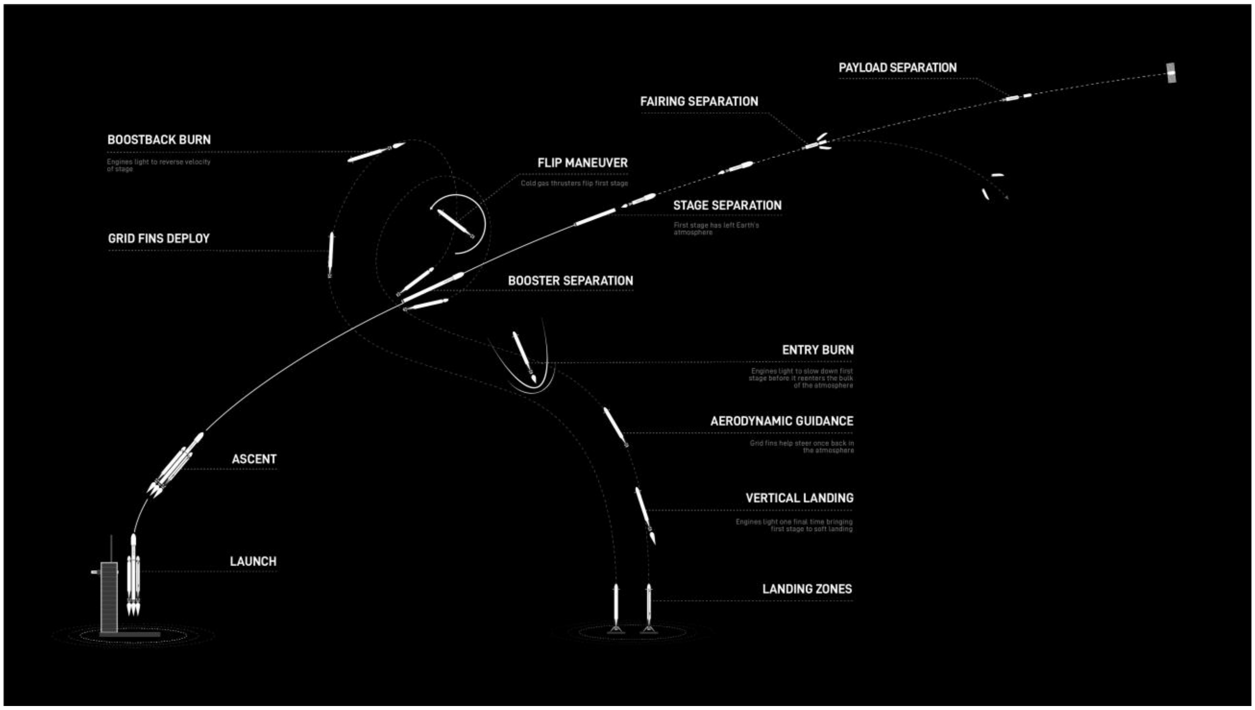


Figure 10-12: Falcon Heavy Sample Mission Profile

Table 10-3: Falcon 9 Sample Flight Timeline—GTO Mission

Mission Elapsed Time	Event
T - 3 s	Engine start sequence
T + 0	Liftoff
T + 74 s	Maximum dynamic pressure (max Q)
T + 147 s	Main engine cutoff (MECO)
T + 151 s	Stage separation
T + 158 s	Second engine start-1 (SES-1)
T + 222 s	Fairing separation
T + 484 s	Second engine cutoff 1 (SECO-1)
T + 1636 s	Second engine start-2 (SES-2)
T + 1696 s	Second engine cutoff-2 (SECO-2)
T + 1996 s	Spacecraft separation

Table 10-4: Falcon 9 Sample Flight Timeline—LEO Mission

Mission Elapsed Time	Event
T – 3 s	Engine start sequence
T + 0	Liftoff
T + 67 s	Maximum dynamic pressure (max Q)
T + 145 s	Main engine cutoff (MECO)
T + 148 s	Stage separation
T + 156 s	Second engine start-1 (SES-1)
T + 195 s	Fairing separation
T + 514 s	Second engine cutoff-1 (SECO-1)
T + 3086 s	Second engine start-2 (SES-2)
T + 3090 s	Second engine cutoff-2 (SECO-2)
T + 3390 s	Spacecraft separation

11 SAFETY

11.1 SAFETY REQUIREMENTS

Falcon customers are required to meet AFSPCMAN 91-710 Range User's Manual and FAA 14 CFR Part 400 requirements in the design and operation of their flight and ground systems. These requirements encompass mechanical design, electrical design, fluid and pressurant systems, lifting and handling systems, ordnance and RF systems, GSE, and other design and operational features. SpaceX will serve as the safety liaison between the customer and the Range.

11.2 HAZARDOUS SYSTEMS AND OPERATIONS

Most launch ranges consider hazardous systems and operations to include ordnance operations, pressurized systems that operate below a 4-to-1 safety factor, lifting operations, operations or systems that include toxic or hazardous materials, high-power RF systems and laser systems, and a variety of other systems and operations. The details of the system design and its operation will determine whether the system or related operations are considered hazardous. Typically, additional precautions are required for operating systems that are considered hazardous, such as redundant valving between pressurant and propellant. Additional precautions will be determined during the safety approval process with SpaceX and the Range. All hazardous operations require procedures that are approved by both SpaceX and the Range prior to execution. Ordnance operations, in particular, require coordination to provide reduced RF environments, cleared areas, safety support, and other requirements.

11.3 WAIVERS

For systems or operations that do not meet safety requirements but are believed to be acceptable for ground operations and launch, a waiver is typically produced for approval by the Range safety authority. Waivers require considerable coordination and are considered a last resort; they should not be considered a standard practice.

12 CONTACT INFORMATION

If you are considering SpaceX launch services, please contact the SpaceX Sales department:

SpaceX

Attention: Sales

1 Rocket Rd.

Hawthorne, CA 90250

sales@spacex.com

APPENDIX A: PAF MECHANICAL INTERFACES

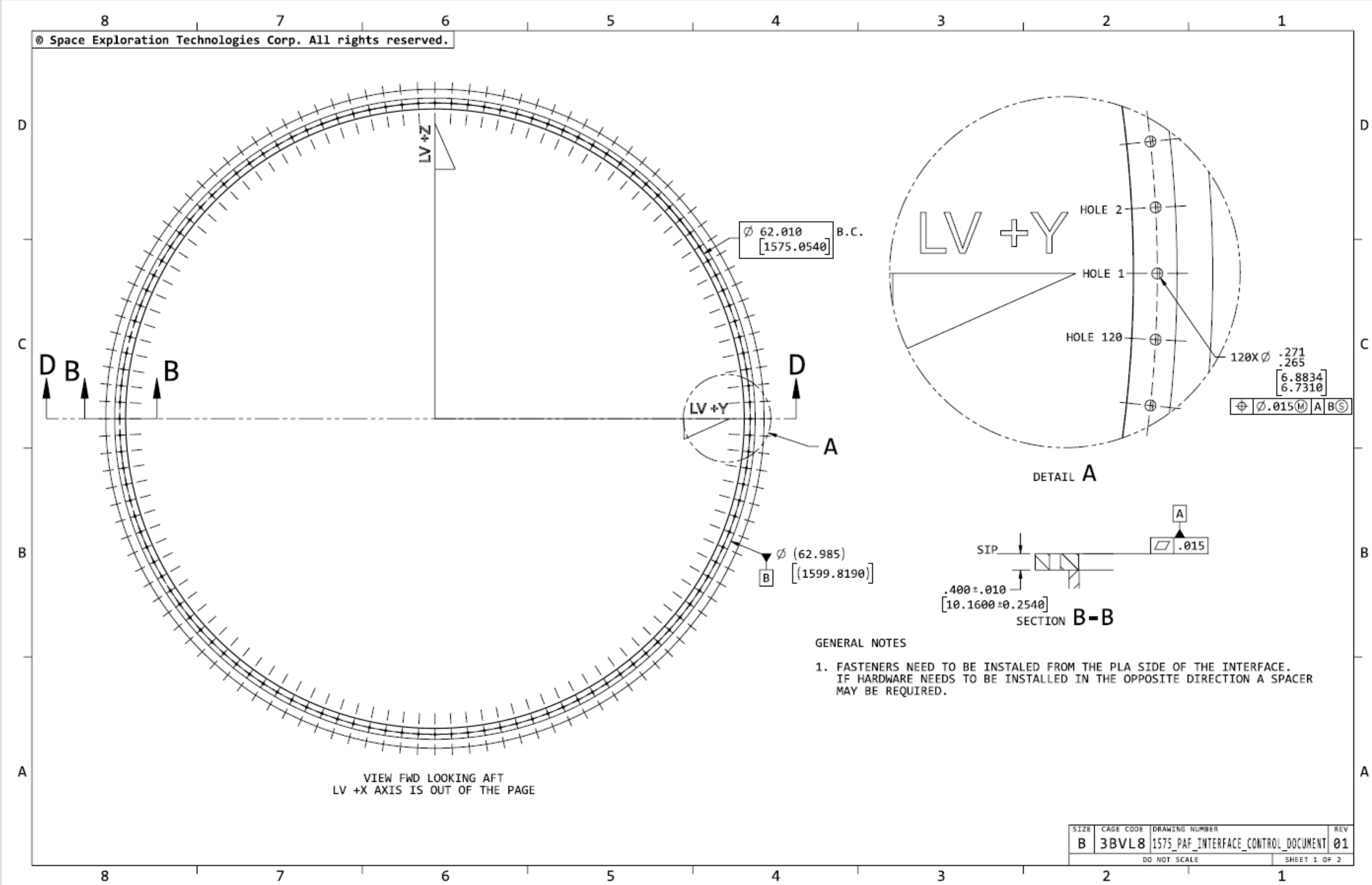


Figure A-1: 1,575-mm PAF Interface Drawing

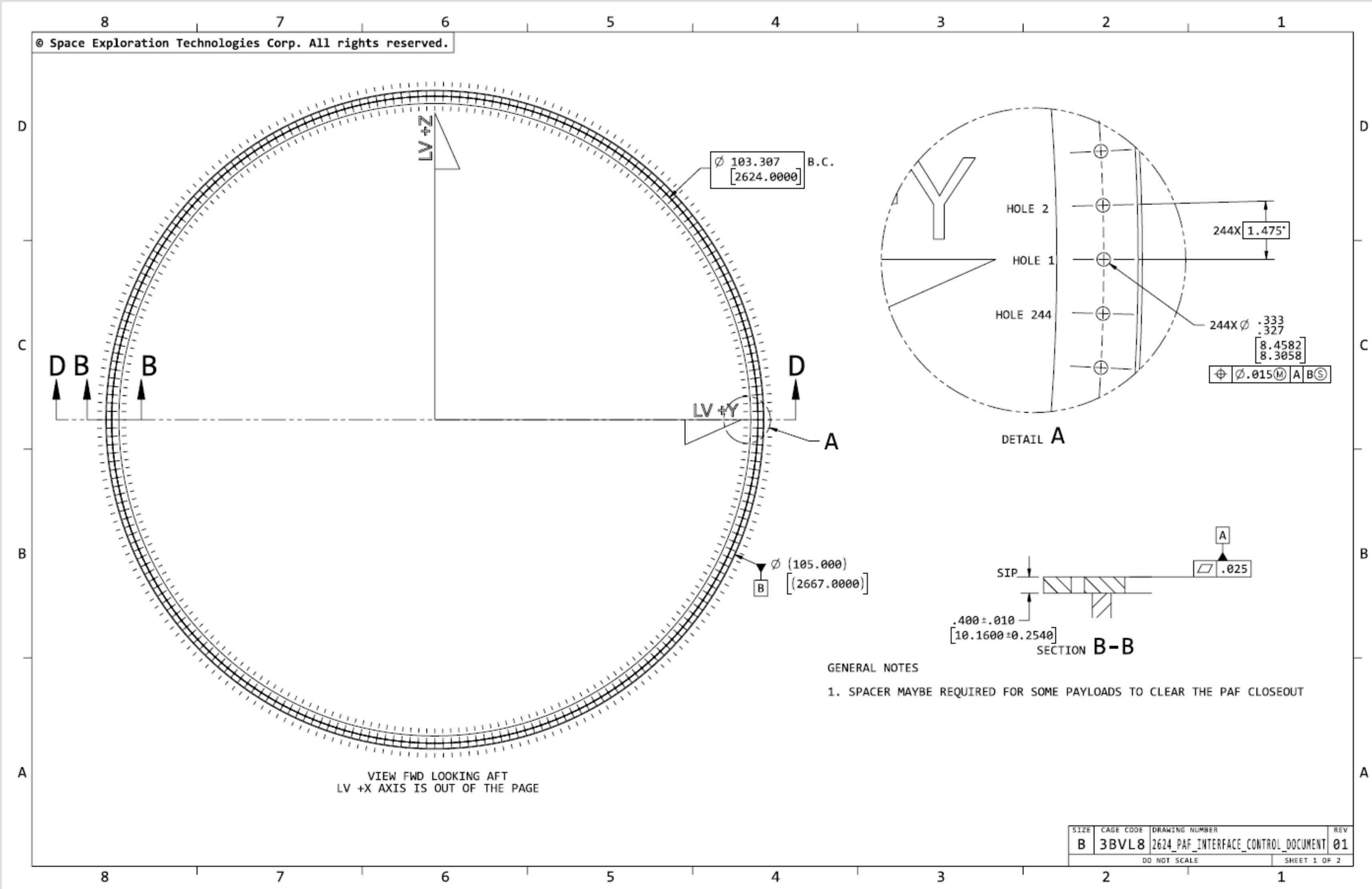


Figure A-2: 2,624-mm PAF Interface Drawing

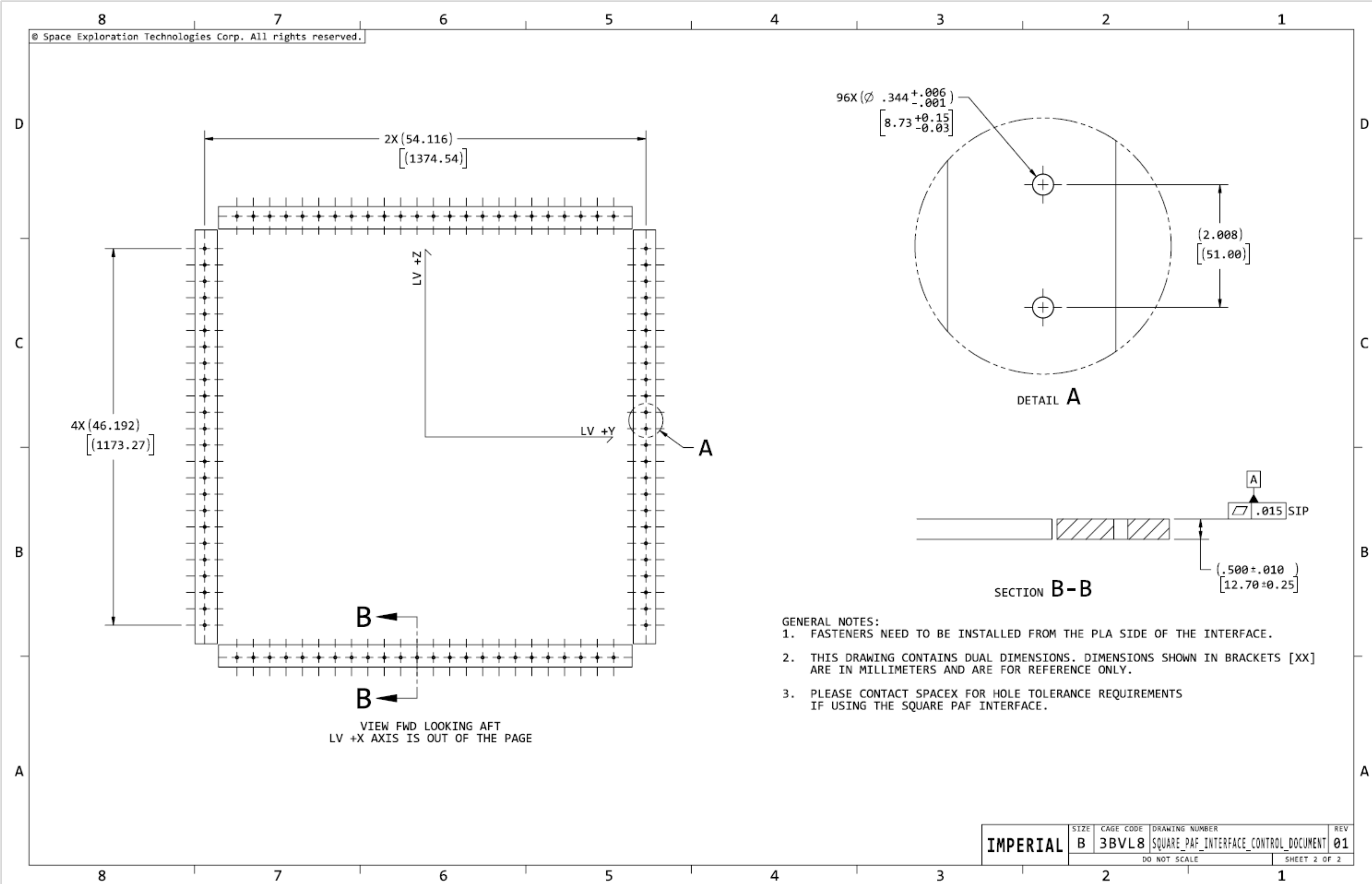


Figure A-3: Square PAF Interface Drawing

APPENDIX B: PAYLOAD MECHANICAL, ELECTRICAL AND PURGE STANDARD INTERFACES

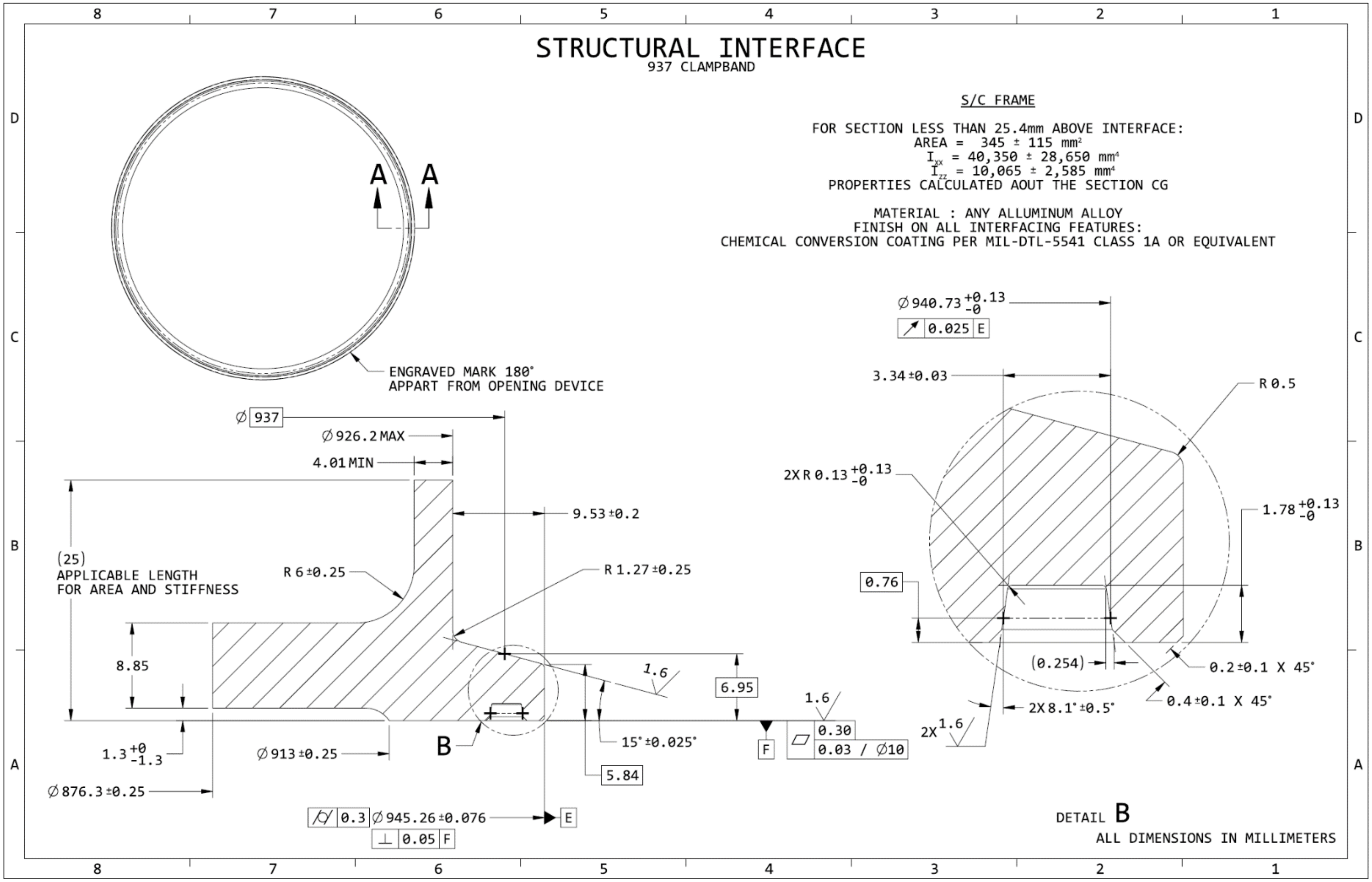


Figure B-1: 937-mm Clampband Mechanical Interface

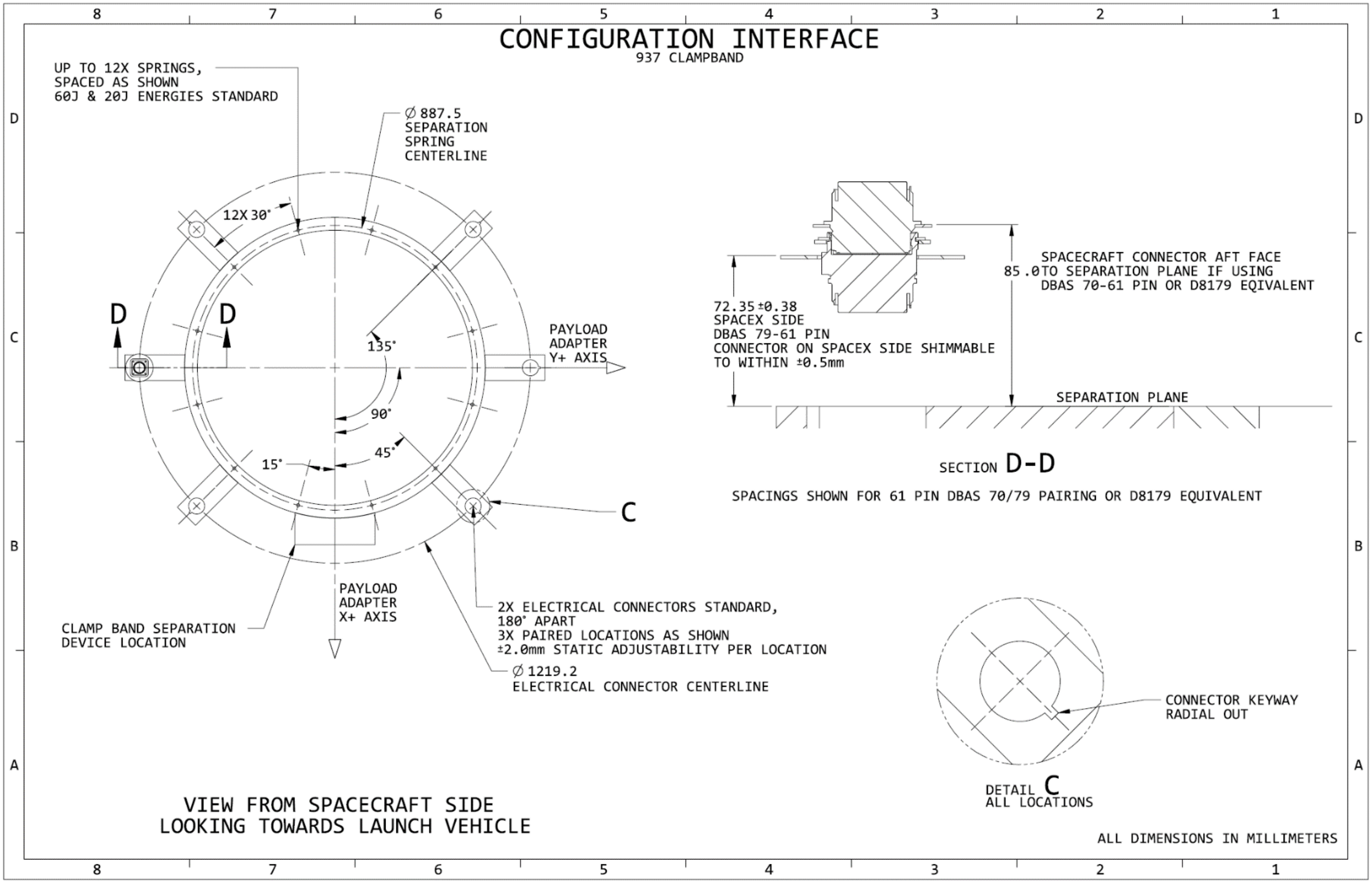


Figure B-2: 937-mm Clampband Electrical Interface

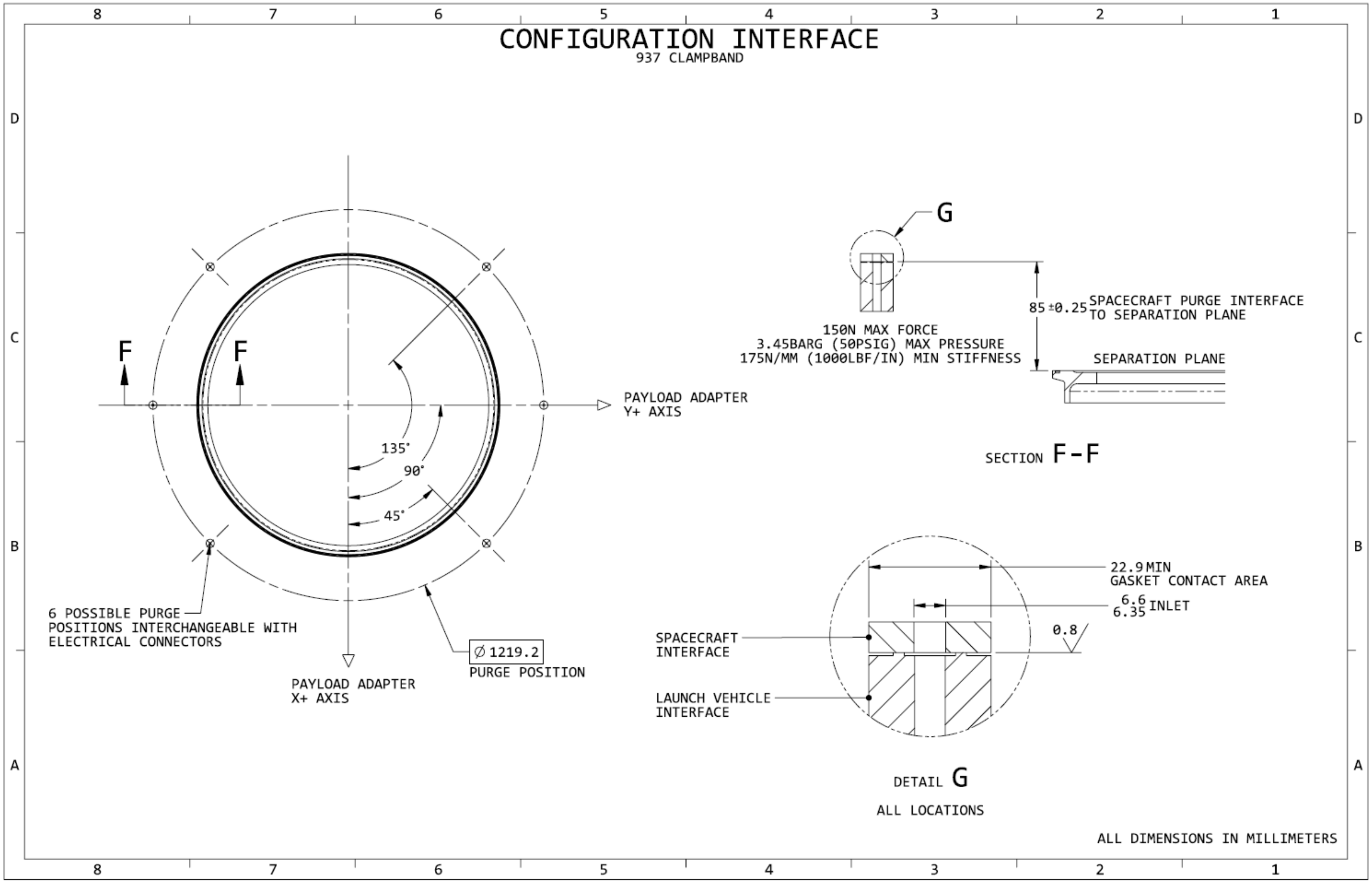


Figure B-3: 937-mm Clampband Purge Interface (Nonstandard Service)

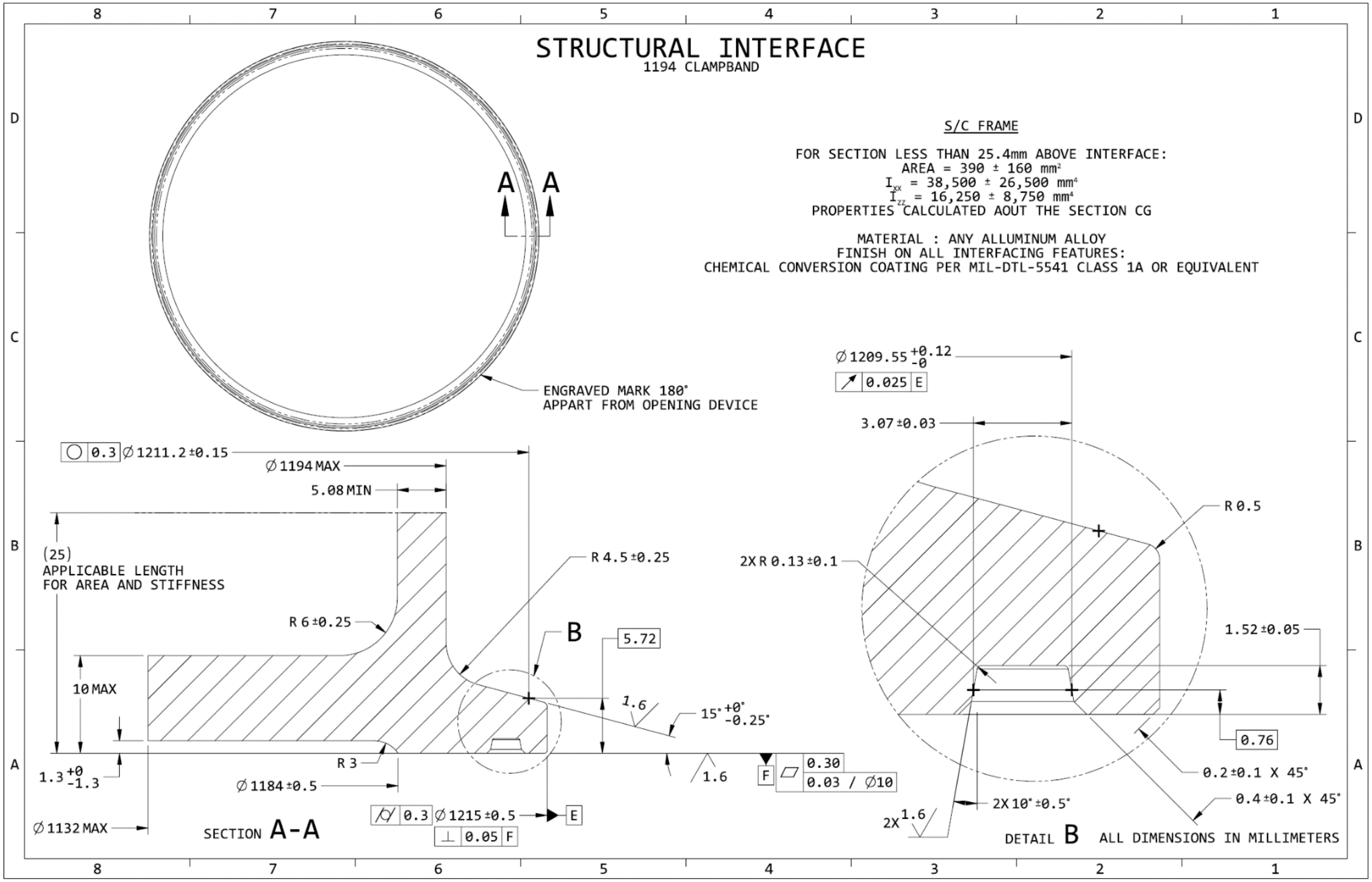


Figure B-4: 1194-mm Clampband Mechanical Interface

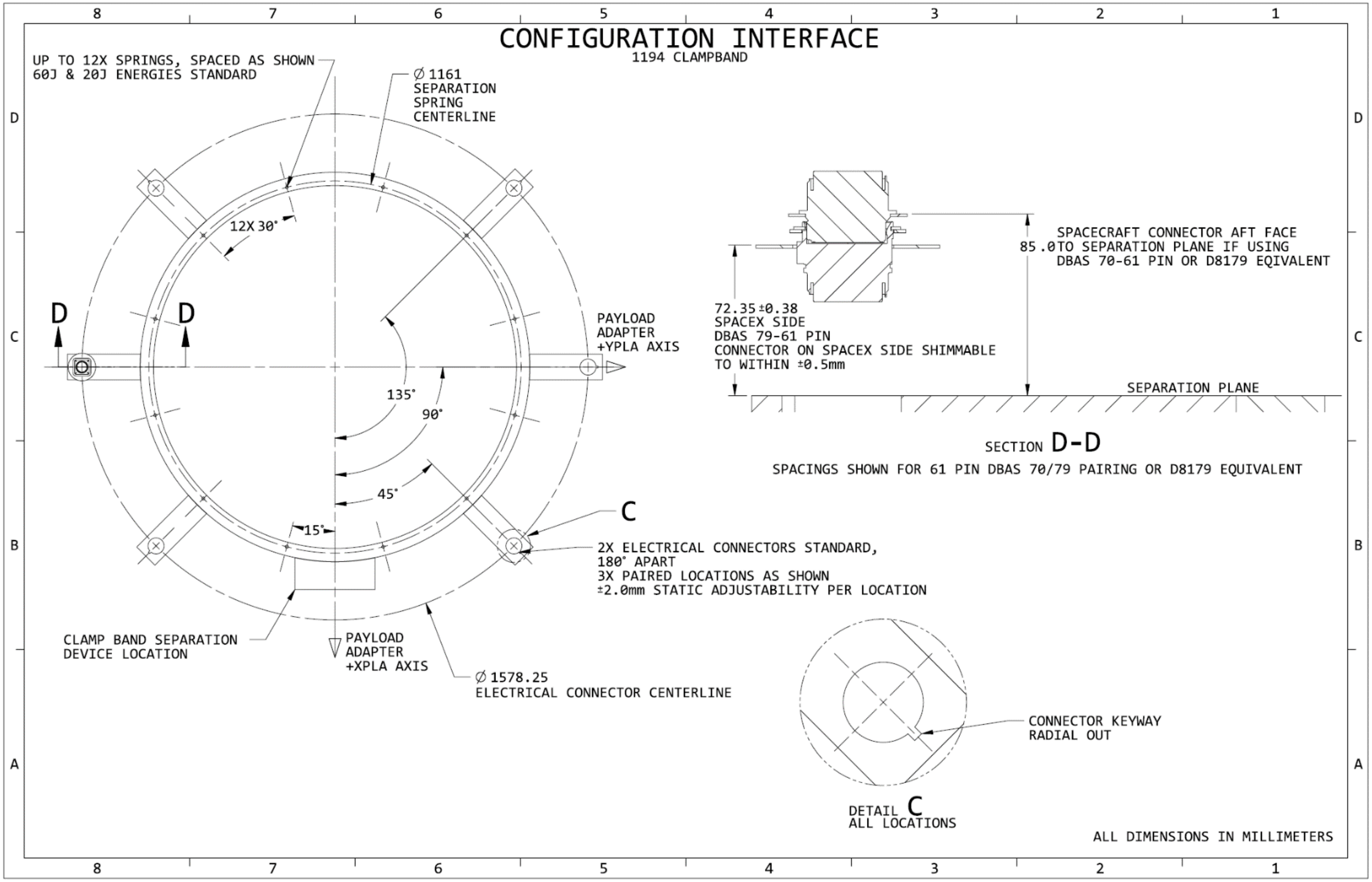


Figure B-5: 1194-mm Clampband Electrical Interface

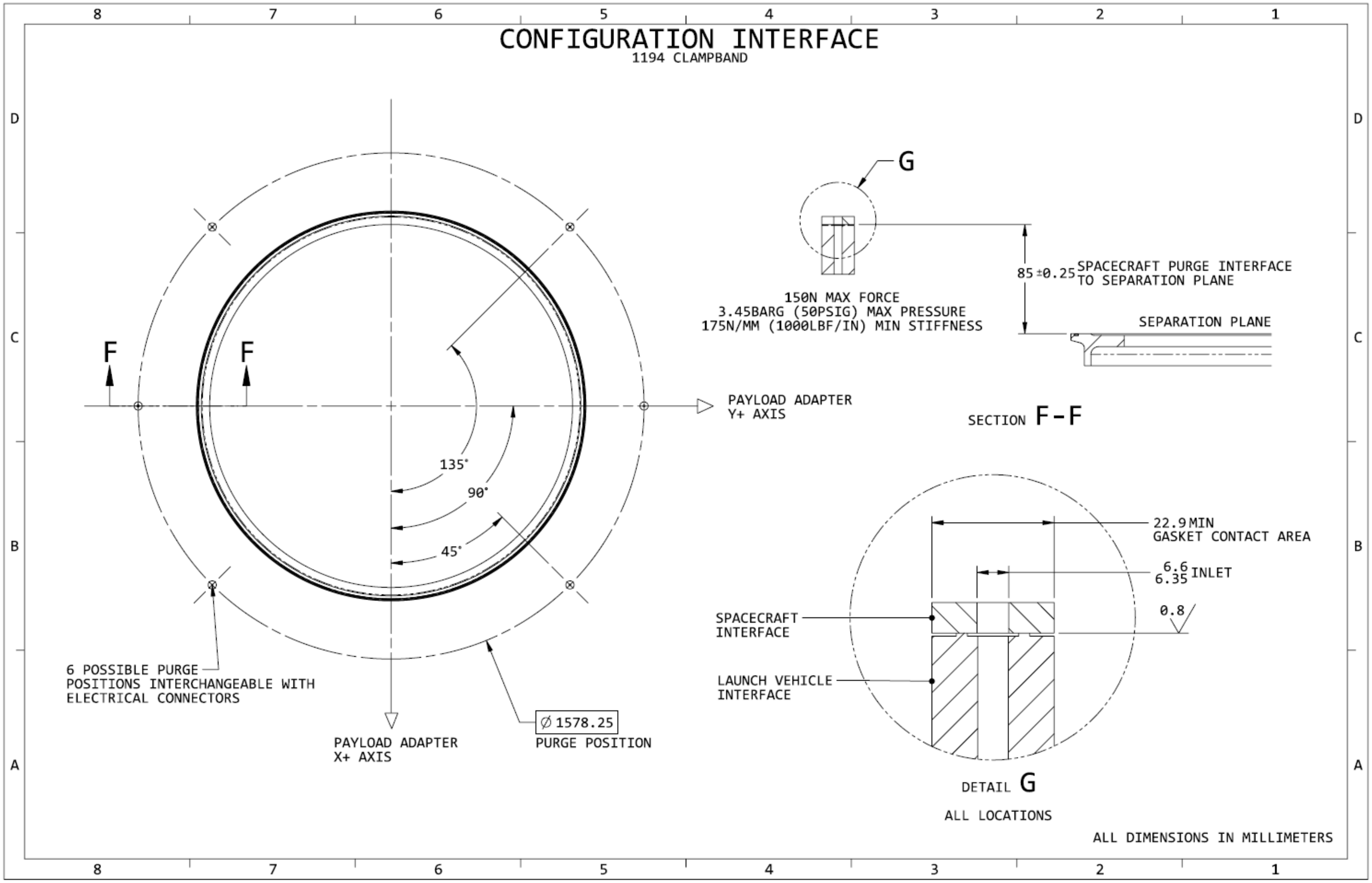


Figure B-6: 1194-mm Clampband Purge Interface (Nonstandard Service)

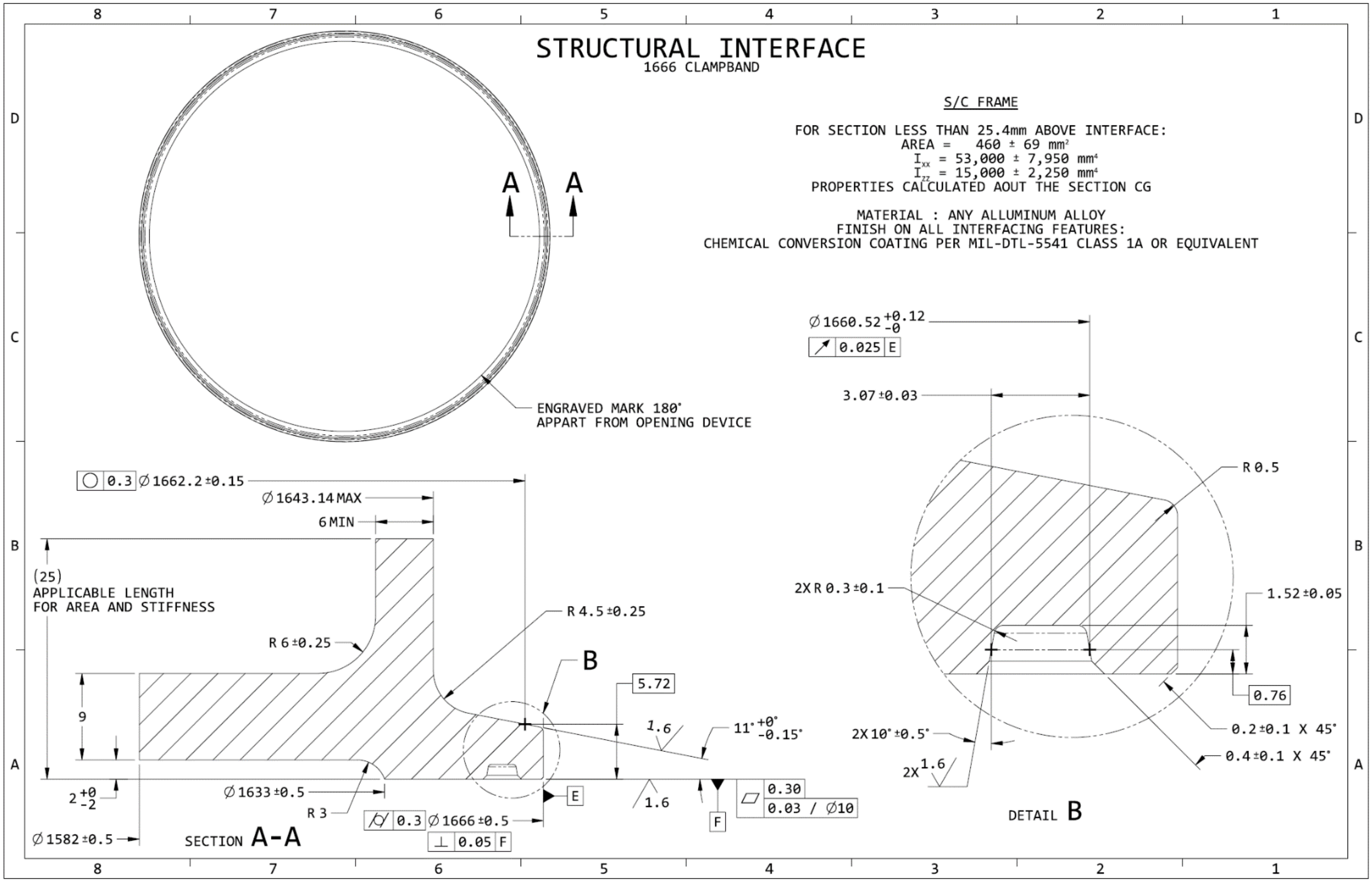


Figure B-7: 1666-mm Clampband Mechanical Interface

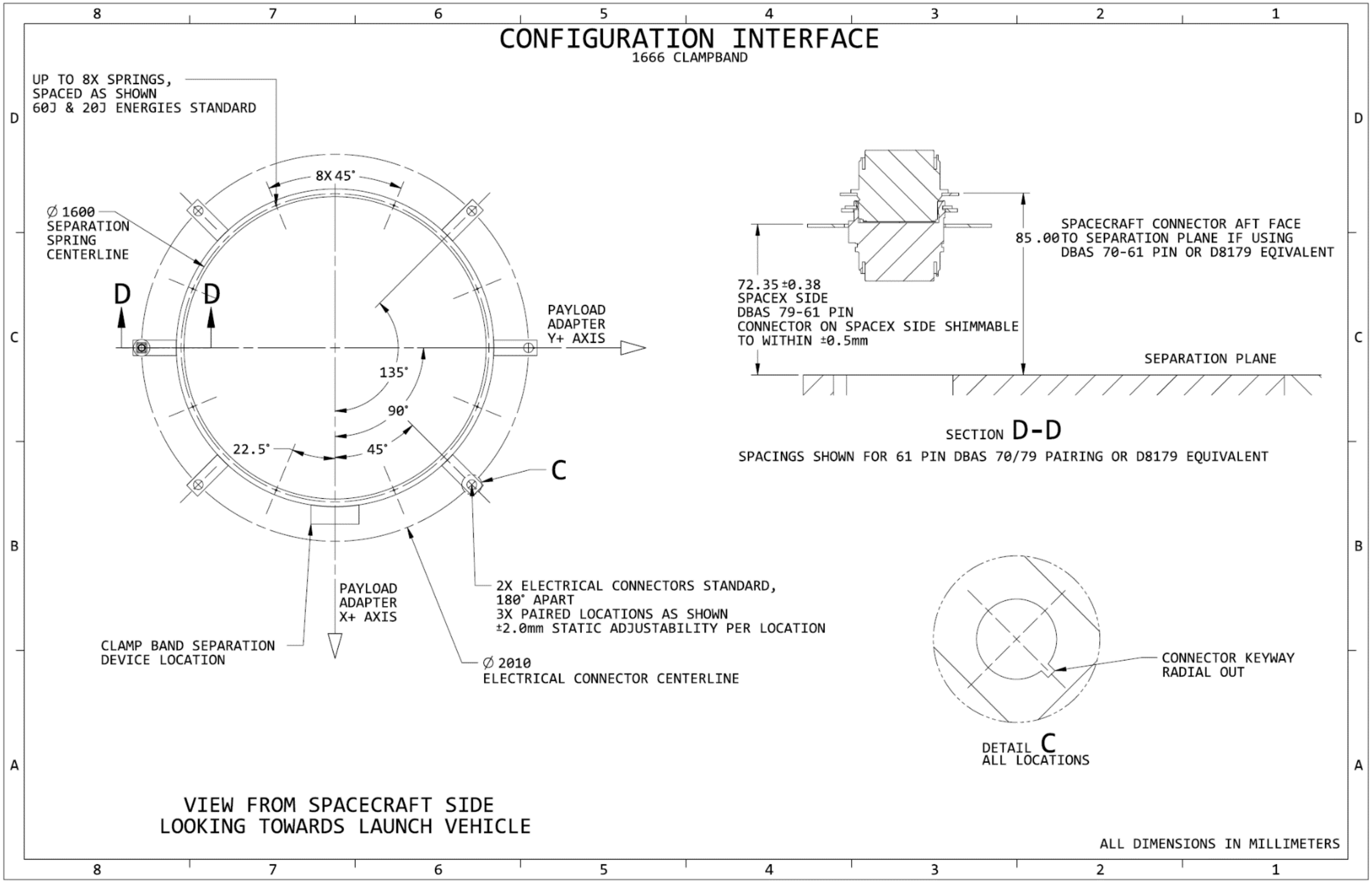


Figure B-8: 1666-mm Clampband Electrical Interface

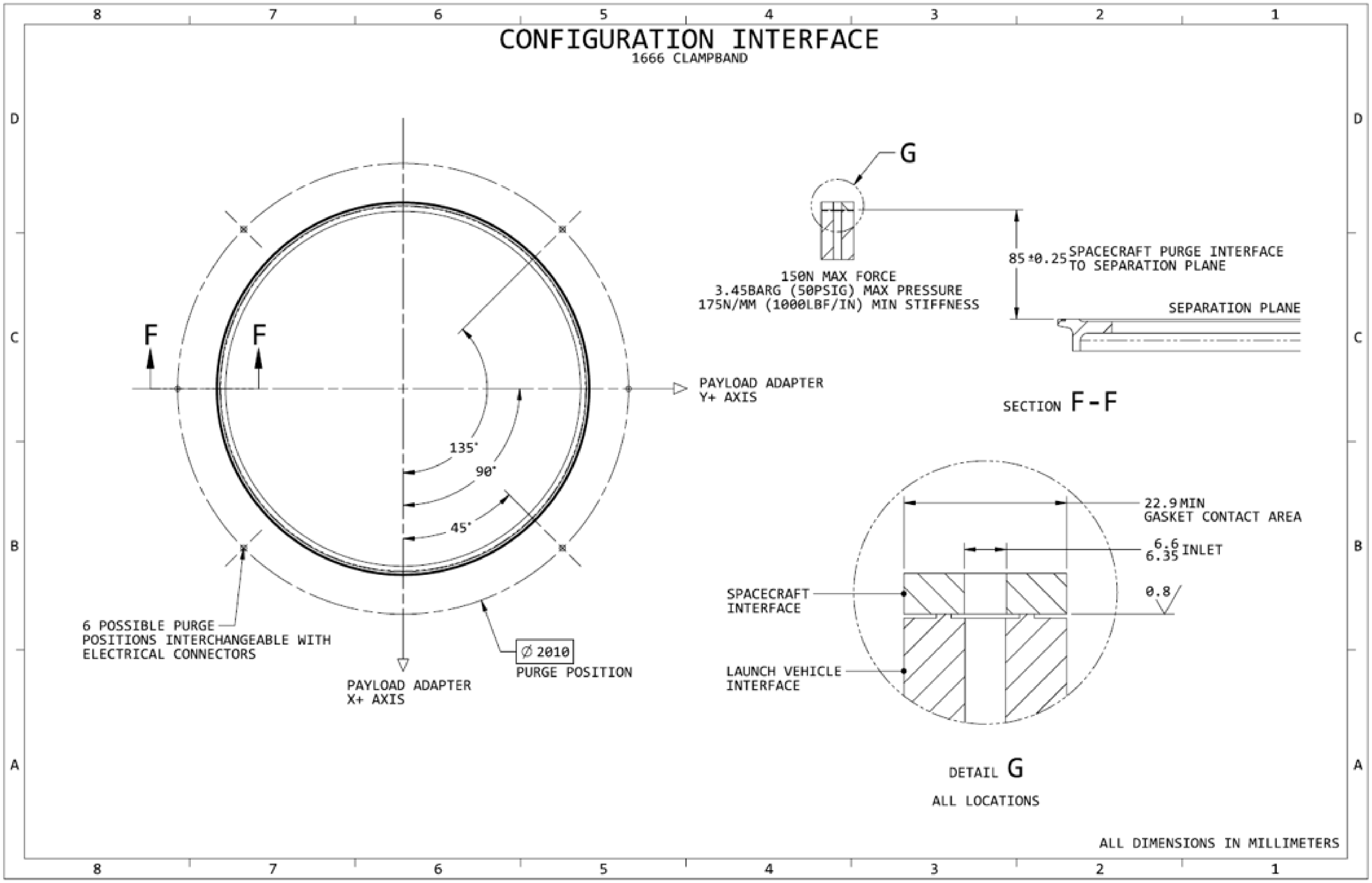


Figure B-9: 1666-mm Clampband Purge Interface (Nonstandard Service)

APPENDIX C: CONSTELLATION PAYLOAD MECHANICAL INTERFACES AND KEEP-IN VOLUMES

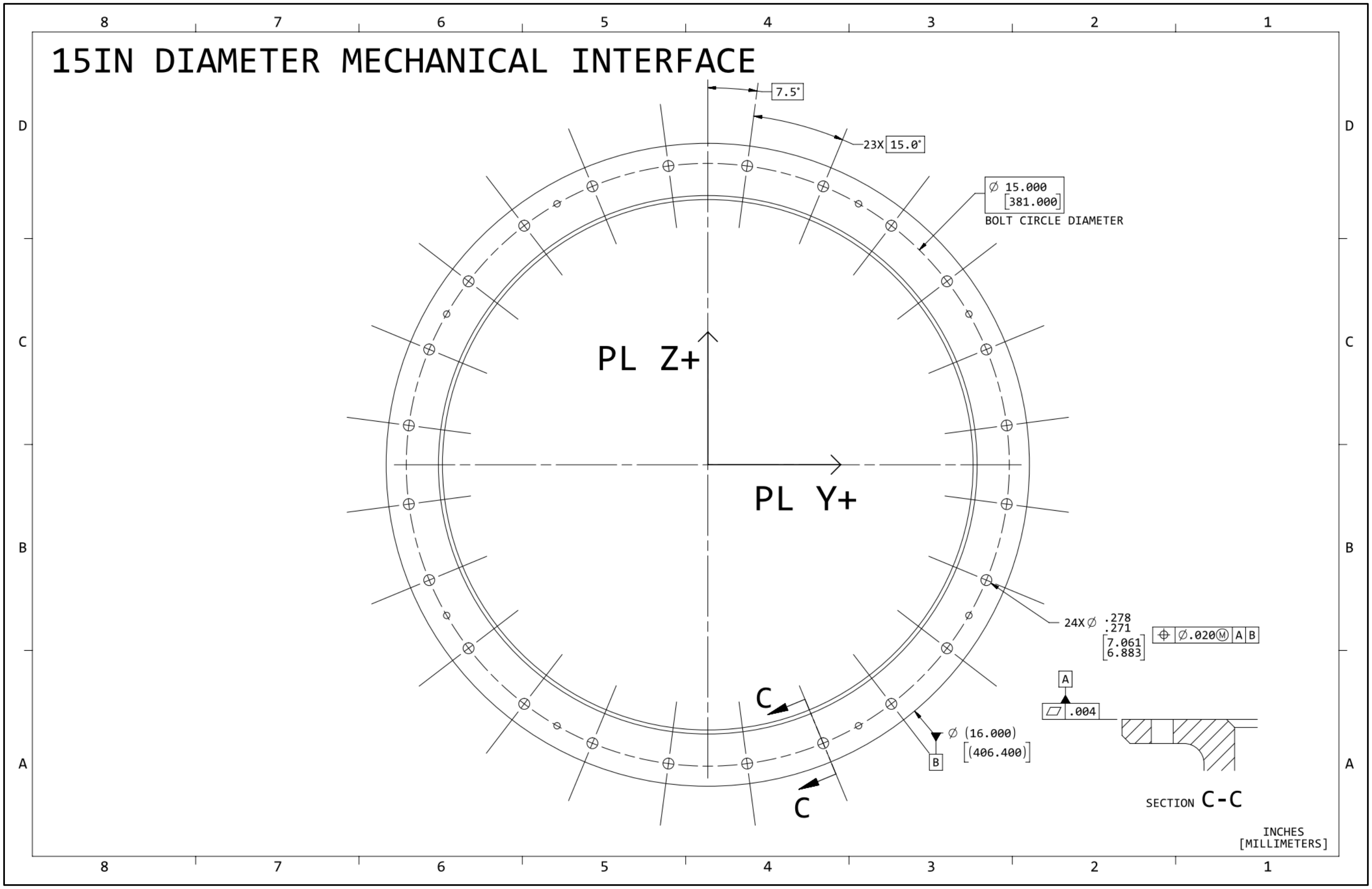


Figure C-1: 15" Diameter Mechanical Interface for Constellation Payloads

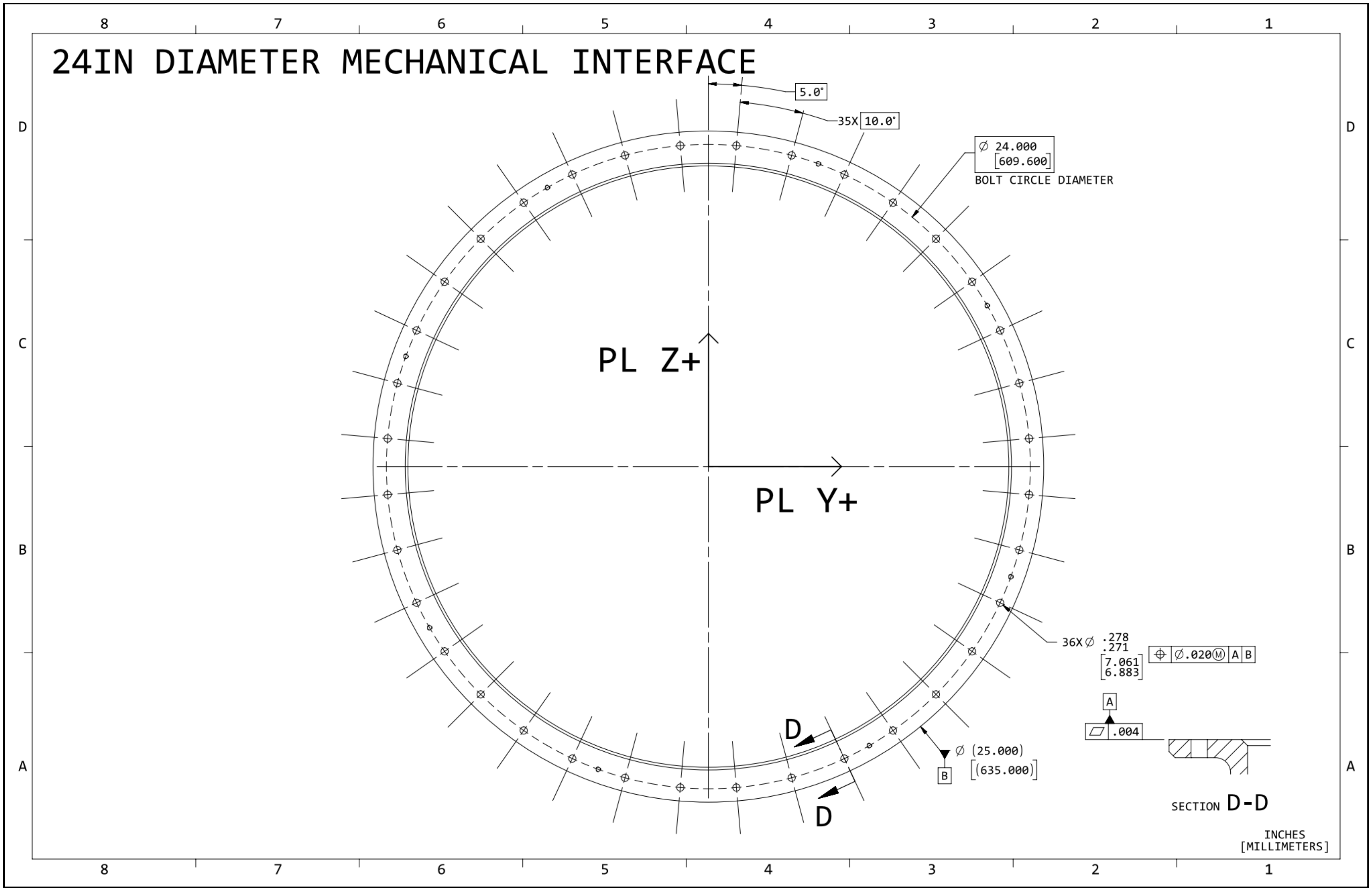


Figure C-2: 24" Diameter Mechanical Interface for Constellation Payloads

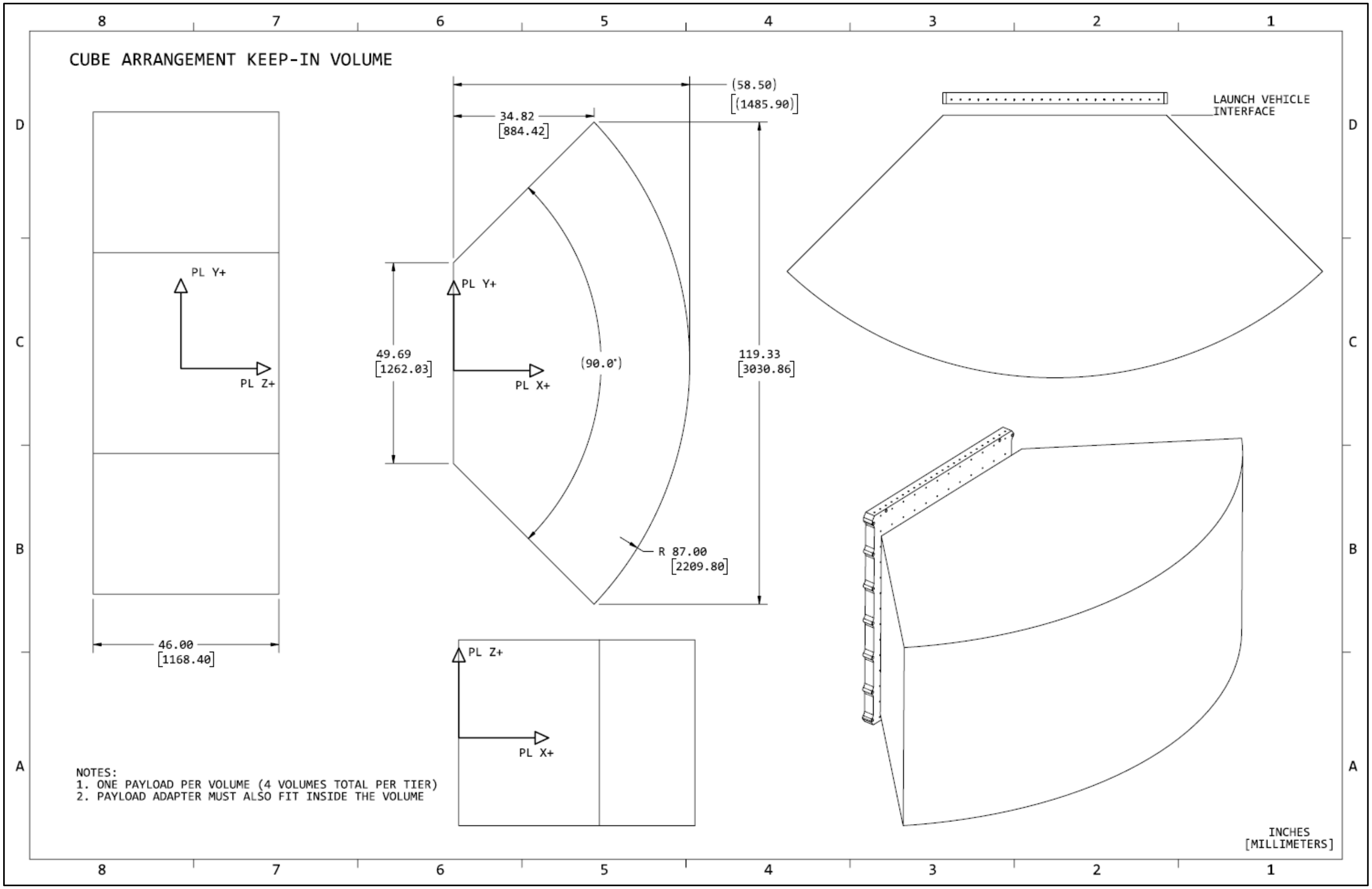


Figure C-3: Cube Arrangement Keep-In Volume for Constellation Payloads (no Acoustic Blankets)

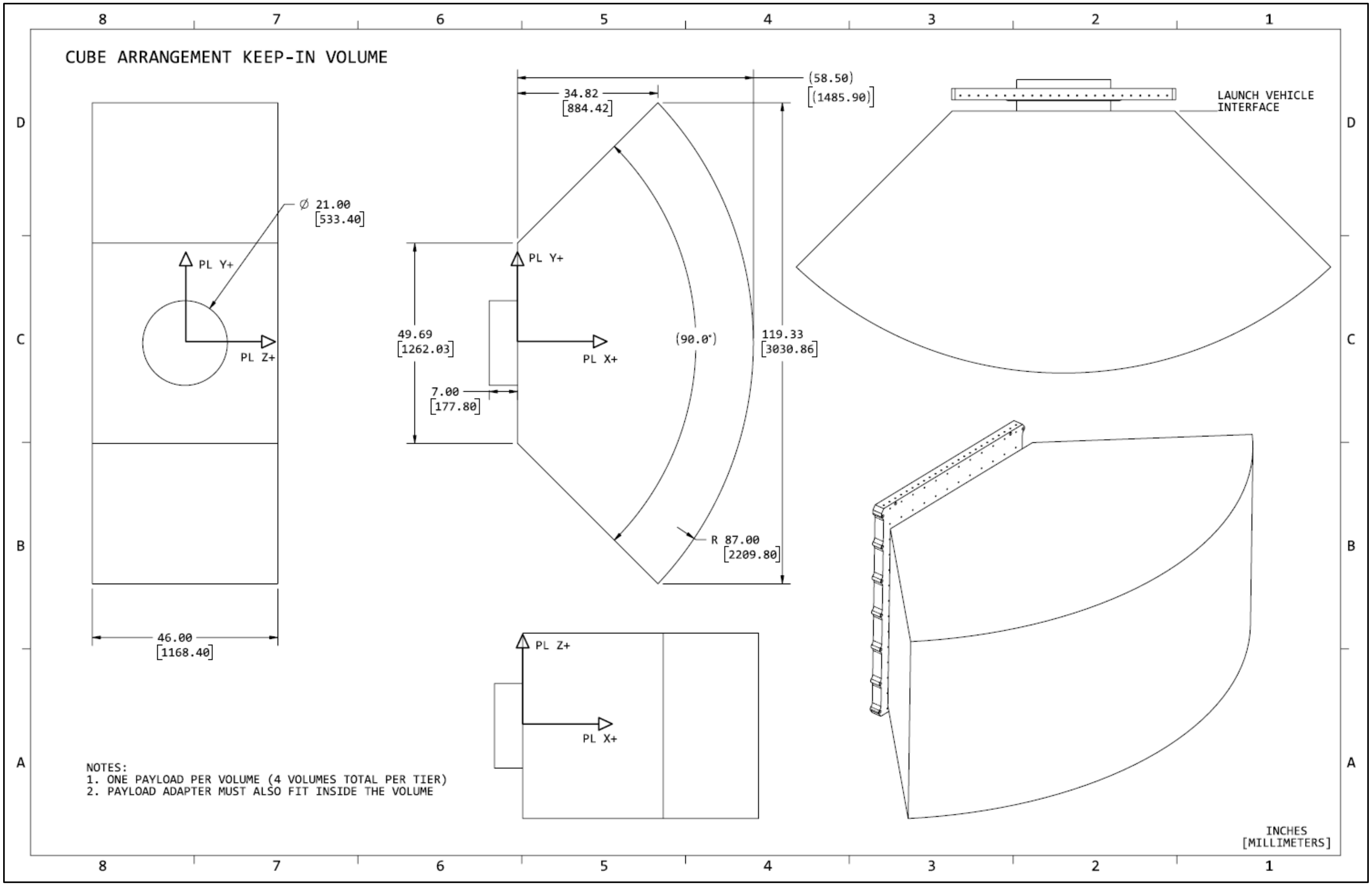


Figure C-4: Cube Arrangement Keep-In Volume for Constellation Payloads with Intrusion (no Acoustic Blankets)

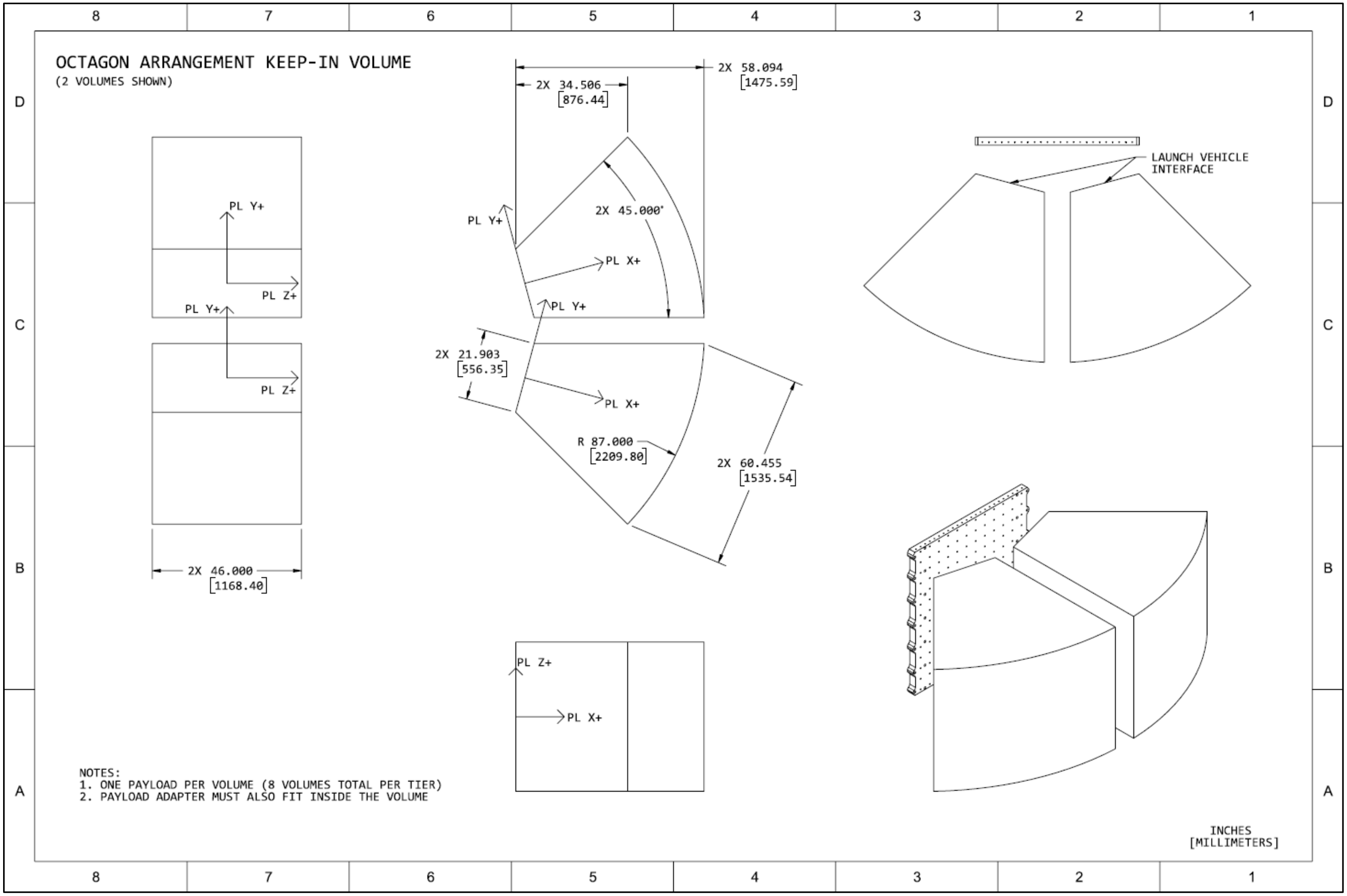


Figure C-5: Octagon Arrangement Keep-In Volume for Constellation Payloads (no Acoustic Blankets)

APPENDIX D: CRYOGENIC PROPELLANT INTERFACE

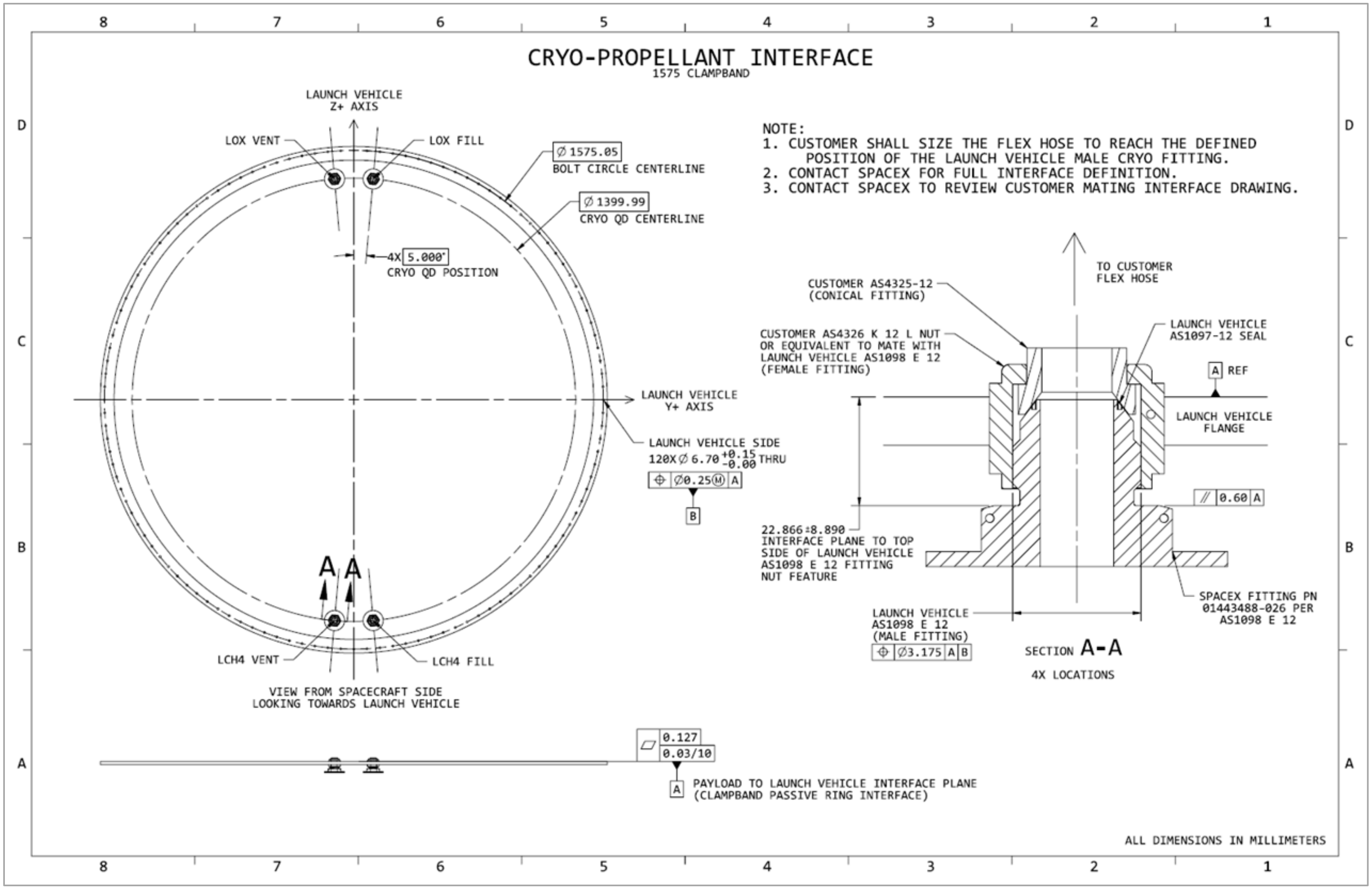


Figure D-1: Cryo-Propellant Mechanical Interface (1,575 mm Clampband)

APPENDIX E: PAYLOAD CAD MODEL REQUIREMENTS

Customer must provide SpaceX a CAD model of the payload in NX Parasolid (preferred) or STEP 214 or lower file format. SpaceX will integrate the payload CAD model with the models of the launch vehicle second stage, SpaceX-provided mechanical interface, and fairing for visualization, integration, clearance check, and operations development purposes.

The payload CAD model must be simplified by the customer and focus primarily on outer mold line and interface fidelity (to facilitate efficient model manipulation and processing). Customer must limit their CAD model complexity, as requested by SpaceX, to only the details and interfaces necessary for integration with the launch vehicle, while retaining the basic structure of the payload. Spurious information must be removed from the model by customer before transmission to SpaceX (an example of unnecessary detail is thousands of bodies within a CAD model representing individual cells on a solar array).

Mass properties are provided in concert with CAD. This mass data must match exactly with the delivered CAD coordinate system configuration and units. The payload coordinate system should preferably follow the coordinate system described in Section 4.1.2.

The payload CAD model must include the following information in order for SpaceX to analyze clearances, prepare compatibility drawings, and produce payload ICD images:

- Payload interface to launch vehicle. This includes:
  - Payload mechanical interface to launch vehicle
  - Electrical connectors and associated brackets, as defined in AV2052 (Electrical ICD)
  - Pusher pads
- Components subject to review for clearance analysis. This includes:
  - External components to review for clearance to fairing volume (e.g. solar array panels, aft and forward antenna components, reflectors)
  - Any components in the immediate vicinity (<20 cm) of the interface components above
  - Any components which protrude below the separation plane
- Any points which may require access after encapsulation
- Simple payload bus structure.

The payload CAD model must NOT include:

- Internal payload or bus components
- Spurious details, including individual solar array cells, fasteners, antenna, reflectors, etc., that do not add to the understanding of external volumes.

Prior to delivering CAD to SpaceX, please verify:

- All SpaceX hardware has been removed
- Entire payload is fully contained within the desired flight configuration keep-in volume
- Unnecessary detail that does not add to the understanding of external volumes has been removed
- Simplified bodies fully envelope OML of actual payload
- All direct LV interface bodies are included
- Payload is properly configured – origin is at SpaceX standard interface, clocked correctly, preferably using the SpaceX payload coordinate system (Section 4.1.2), and agrees with the corresponding mass properties
- File size is 100 MB or less
- The file type is Parasolid (.x_t), preferred by SpaceX. Alternatively, the file format is STEP 214 or lower file format

APPENDIX F: PAYLOAD DYNAMIC MODEL REQUIREMENTS

The payload dynamic model shall be provided to SpaceX as a Craig-Bampton reduced model. SpaceX provides a dynamic model summary template for customers to ensure the following requirements are met.

Payload Craig-Bampton Model Definition

Model Requirements

- The model file should be no larger than 500 MB
- The units of the model shall be clearly defined (English or SI)
- The model will be delivered as a multipoint interface model (see Interface Requirements section)
- The model shall be Craig-Bampton formatted
- Modal damping shall be specified (see Damping Definition section)
- Any uncertainty factor applied to the modal responses shall be defined (see Uncertainty Factor section)
- The model shall have frequency content up to 150 Hz
- All output requests shall be clearly defined (see Analysis Outputs section)
- The model shall be an accurate, in good faith, representation of the payload including primary and secondary structures
- Slosh effects shall be included, slosh modes identified, and method of scaling for acceleration shall be clearly defined

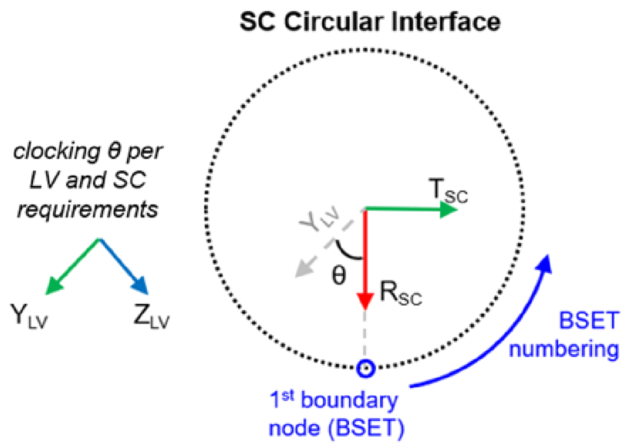
Interface Requirements

- The interface to the launch vehicle shall remain physical with six degrees of freedom at each interface node
- The location of the interface shall match the payload to launch vehicle mechanical interface definition (e.g., if customer is providing the separation system, it must be included in the model)
- Boundary node locations shall be clearly defined in accordance with the following table for all payload interfaces matching the provided diameters. This ensures correspondence with payload adapter models

Boundary Grid Numbering

Interface Diameter (mm)	Number of Boundary Grids
937	120
1194	240
1575	120
1666	360
2624	244
2795	180
3117	180

- Interface points not defined at the payload to launch vehicle interface plane will not be allowed
    - Exception: The customer can prove their necessity and the interface point is sufficiently stiff, e.g. no electrical connections or ducting
- The coordinate system used for the boundary degrees of freedom relative to the launch vehicle (payload clocking) shall be a cylindrical output coordinate system with the origin at the center of the interface. This coordinate system will be defined only once and in a clear manner. Boundary nodes will be numbered sequentially and ordered counterclockwise (i.e., about LV +X in a right-hand coordinate system). Example is shown in the figure below.
- All grid points (in the DTM) for which fairing relative deflections are desired shall include all three translations sequentially. If an acceleration-based DTM is provided for launch vehicle to payload relative deflection calculations, then the displacement-based portion shall also be provided.



Boundary coordinate system definition example

<u>Matrix Requirements</u>

- The model shall Include mass, stiffness, and Output Transformation Matrices
- The mass and stiffness matrices (M and K, respectively) shall be provided as complete matrices
- The M and K matrices shall be defined as shown below:
  - i are the modal degrees of freedom
  - b are the boundary degrees of freedom
  - ω_i^2 is a diagonal matrix of the eigenvalues
  - K_{bb} is the stiffness from the boundary degrees of freedom

$$M = \begin{bmatrix} M_{bb} & M_{bi} \\ M_{ib} & I \end{bmatrix}, K = \begin{bmatrix} K_{bb} & 0 \\ 0 & \omega_i^2 \end{bmatrix}$$

- Output Transformation Matrices (OTM) a.k.a. data recovery matrices (DRM) used to recover payload responses (R), shall be in one of the three forms shown below, where $\ddot{x}$ are accelerations and x are displacements.

$$\{R\} = [DRM1]\begin{Bmatrix} \ddot{x}_b \\ \ddot{x}_i \end{Bmatrix}$$

$$\{R\} = [DRM2]\begin{Bmatrix} x_b \\ x_i \end{Bmatrix}$$

$$\{R\} = [DRM1]\begin{Bmatrix} \ddot{x}_b \\ \ddot{x}_i \end{Bmatrix} + [DRM2]\begin{Bmatrix} x_b \\ x_i \end{Bmatrix}$$

  - Responses may be recovered using a $DRM1$ (acceleration transformation matrix), a $DRM2$ (displacement transformation matrix), or using both a $DRM1$ and a $DRM2$.
  - DRM1 and DRM2 shall each be provided as separate matrices.
  - Load transformation matrices for element forces, pressures, stresses, etc. shall be recovered with either a $DRM1$, or using both a $DRM1$ and a $DRM2$.
- Total number of recoveries shall be limited to 5,000 rows.
- Time histories are not a standard output and will not be provided unless determined necessary by SpaceX
- Definition of the Craig-Bampton model rows and columns shall be provided to facilitate coupling of the payload to launch vehicle model.
- Labels for the rows of the (DRM) shall be provided for inclusion in results tables.
- All LTM matrices shall be defined such that they produce loads when multiplied by accelerations (not in Gs) and displacements: e.g. inch/sec2 and rad/sec2 and inch and radian or other consistent units.

Analysis Outputs

The following standard CLA outputs are delivered in Microsoft Excel and are reported by load case unless otherwise specified:

- Payload Net-CG response max/min table
- OTM response max/min tables*
- Interface force max/min tables
- Interface sine vibration curves with Q specified by customer
- Relative displacements (between payload and fairing)

* OTM = Output Transformation Matrix. May also be referred to as a DRM (data recovery matrix). OTMs can include DTM (displacement transformation matrix), ATM (acceleration transformation matrix), LTM (load transformation matrix) and others.

The output coordinate system of the interface force max/min tables and the interface sine vibration curves is dependent on the coordinate system in which the grid points are defined. The available coordinate systems are:

For a multi-point interface with a single coordinate system:

- LV coordinate system
- SC coordinate system (as defined by the coordinate system of the spacecraft interface DOF in the stiffness/mass matrices)

For a multi-point interface with multiple coordinate systems:

- LV coordinate system
- SV coordinate system (as defined by the coordinate system of the first boundary point in the stiffness/mass matrices)

If outputs in any other coordinate system are desired, then the customer shall generate and provide such outputs in the ATM and/or LTM response recovery matrices.

Damping Definition

Diagonal modal damping shall be defined as a percent of critical (and may vary from mode to mode) unless there is firm rationale why full matrix damping should be exercised, such as the existence of an internal highly damped isolation system with known physical characteristics.

Expected slosh mode damping shall be included in the damping definition.

Uncertainty Factor

SpaceX, as a standard practice, will apply a model uncertainty factor to all responses that reflects launch vehicle maturity. However, if customer desires the application of a larger model uncertainty factor, this shall be specifically requested. Under no circumstance will the model uncertainty factor be less than that used in SpaceX standard practice.

Documentation

SpaceX requests that the customer fill out the "spacecraft_customer_template" excel file when providing their dynamic model. This standardized template eases coupling of the spacecraft to the LV and ensures that required information is provided in a clear format.

SpaceX also requests that the payload dynamic model and populated customer template be accompanied by any customer generated supporting documentation (in the customer desired format) as needed. Provided documentation should include:

1. Definition of units used (SI or English)
2. Definition of the payload coordinate system relative to the launch vehicle
3. Location of all interface grids in payload coordinate system
4. Comparison of unreduced (FEM) and condensed (Craig-Bampton) models
    a. Mass
    b. Center of gravity relative to interface
    c. Strain energy
    d. First seven modes of free-free analysis
    e. Modal analysis, including modal effective mass
5. A list of all frequencies
6. Pictures and/or descriptions and frequencies of the first few mode shapes (including the three fundamental modes in X, Y, and Z)
7. Definition of damping
8. Definition of the model response (dynamic) uncertainty factor
9. Definition of output format and requests, e.g., interface loads, interface accelerations, net CG loads, internal payload loads, shock response spectra (SRSs), etc. If SRSs are requested, the number of rows shall be limited to 500.
10. If internal payload responses are requested, provide appropriate DRMs (ATMs, DTMs, and LTMs) as well as tables defining the rows of these matrices
11. Definition of any payload limit loads, including primary structure and component level, in order for SpaceX to evaluate the CLA results (net CG, interface loads, and ATM/DTM/LTM) and determine if the CLA indicates an exceedance of payload structural capability
12. Definition of slosh mode frequencies and mode numbers, along with expected damping and method for scaling relative to acceleration.

The above list is not all-inclusive, and customer is encouraged to provide additional information that will assist SpaceX in processing the payload dynamic model for the coupled loads analysis.

APPENDIX G: PAYLOAD THERMAL MODEL REQUIREMENTS

Model Definition and Thermal Analysis

SpaceX will perform an integrated launch thermal analysis demonstrating temperature response during encapsulated phases from hangar rollout to payload deploy. This analysis will couple the SpaceX payload compartment thermal model with the payload thermal model provided by customer and will analyze the combined models during a simulated launch.

Customer shall produce a coarsened thermal model of its payload(s), with a node(s) added for convection. The payload thermal model shall be in Thermal Desktop (.dwg) file format whose units must be Joules, seconds, inches, lb, °C, and shall meet the model requirements described below. This model should contain less than 5,000 nodes total, including a maximum of four independent interfaces to the launch vehicle (note: SpaceX may accommodate additional nodes or interfaces upon request and mutual agreement). For *n* number of duplicate payloads in a single launch, each individual payload should be comprised of less than 5,000/*n* nodes. SpaceX will thermally connect surfaces in the Thermal Desktop '*tag set*' 'PL_CONVECT' with the expected air temperature during ground phases, thermally connect surfaces in the Thermal Desktop '*tag set*' 'PL_ATTACH' to the vehicle interface and run the integrated thermal models in a simulated mission.

Inputs required from and outputs delivered to the customer are listed below.

Inputs Required from Customer

1. Completed customer Thermal Model Requirements Checklist outlined below
2. Thermal Desktop payload thermal model with geometry (coarsened if necessary) in accordance to the customer Thermal Model Requirements Checklist
3. Payload temperature requirements (by node) using the SpaceX template Excel file
4. Instructions for payload thermal model integration and running

Output Delivered to Customer

1. Microsoft PowerPoint slides summarizing analysis performed, including:
    a. Model validation
    b. Input summary (i.e. launch date/time, mission timeline, ECS set points)
    c. Free Molecular Heating (FMH) profile as well as trajectory visualization
    d. Nodal exceedances and transient plots of nodal exceedances
2. Excel summary of min and max temperature predictions compared to customer-supplied limits

Customer Thermal Model Requirements Checklist

- Each payload will be assigned a short, unique spacecraft name which will be used to differentiate that payload from others. The identifier will be inserted wherever [NAME] appears below. If there are expected to be more than one payload for a mission, the [NAME] shall correspond to a designated name of the individual payload, otherwise, the [NAME] shall correspond to the designated mission name of which the payload is part. For missions with identical/duplicate payloads in a single analysis, there shall at least exist one payload thermal model file per payload with unique filenames that properly identify each unique payload (e.g. [NAME_1], [NAME_2], [NAME_3]).
  - Thermal Desktop "External References" (a.k.a. "XREFs") are not permitted within the payload model(s).
  - Missions with identical/duplicate payloads shall also have unique:
    - Submodels names
    - Heater registers
    - Domain tag set names
- All sub-model names shall begin with PL_[NAME]_
  - The total number of submodels across all payloads shall not exceed 800
- All optical and thermophysical properties shall begin with PL_[NAME]_
  - Optical and thermal property files containing the respective properties shall be named PL_[NAME].rco and PL_[NAME].tdp, respectively
  - Optical and thermal property aliases shall have names that begin with PL_[NAME]_
  - All Thermal Desktop stack names in the Material Stack Manager shall begin with PL_[NAME]_

- All Thermal Desktop *Symbols* shall begin with PL_[NAME]_ and be in a symbol group named "Payload"
  - The total number of symbols in the payload model shall not exceed 2,000
- All Thermal Desktop *Layers* shall begin with _PL_[NAME]_

- All surfaces that should radiate to surroundings shall be in a Thermal Desktop *Radiation Analysis Group* named "Payload," and any other radiation analysis groups shall be named PL_INT_RAD1, PL_INT_RAD2, …
  - The total number of radiation analysis groups across all payloads shall not exceed 15
- All surfaces that should be subject to convection with fairing air shall be in a Thermal Desktop *tag set* named "PL_CONVECT" of object type Face Set
- All surfaces that should be mechanically connected to the launch vehicle (e.g. payload adapter or separation ring) shall be in a Thermal Desktop *tag set* named "PL_ATTACH" of object type Face Set
  - For customer-owned separation systems, customer shall provide a conductance value between the payload adapter and payload
  - The total number of domain tag-sets across all payloads shall not exceed 1,000

- Customer may additionally provide one SINDA/FLUINT include file named "Payload_[NAME].inc" or one Thermal Desktop *logic object* that will be included in the integrated Thermal Desktop model. All manually coded thermal submodel logic must be contained within the include file or logic object. The file or logic object may not contain a HEADER OPERATIONS block, and it must be included in the test *Case Set* (see below) for validation. Units within this file or logic object must be Joules, seconds, inches, lb, °C.
  - "User Written Build Statements" or "User Defined" build statements within the SINDA tab of the Case Set(s) are not permitted

- Ensure payload propellant tank(s) and payload mass are accurately captured in the Thermal Desktop model
- The payload model shall contain Thermal Desktop *symbols* named:

  - PL_OnPad that will drive any changes to the payload model that depend on the positional status of the launch vehicle. During integrated analysis, PL_OnPad will be set to 1 prior to liftoff and to 0 after liftoff. This symbol is commonly used to enable (ground)/disable (ascent) convection.
  - PL_[NAME]_HeatersOn that will drive any changes to the payload model that depend on whether the payload's heaters are operational. During integrated analysis, PL_[NAME]_HeatersOn will be set to 1 when the payload heaters are in the ON state (i.e. enabled); it will be set to 0 when the payload heaters are in the OFF state (i.e. disabled). This symbol is commonly used to enable/disable heaters.
  - PL_[NAME]_AvPower that will drive any changes to the payload model that depend on whether the payload is in the powered ON or OFF state. During integrated analysis, PL_[NAME]_AvPower will be set to 1 when the payload is in the powered ON state; it will be set to 0 when the payload is in the powered OFF state. This symbol is commonly used to enable/disable heat load dissipations.
    - For clarity, customer shall provide a table of how these symbols, and others, if included in the model file(s), are to be handled by SpaceX in the analysis (note: separate hot and cold case values are permitted). Unless otherwise specified by customer, SpaceX will assume symbol values as displayed in the table below:

Sample Table of Symbol Value for Analyzed Phases			
Analysis Phase	**PL_OnPad**	**PL_[NAME]_HeatersOn**	**PL_[Name]_AvPower**
In Hangar (Steady)	1	0	0
Rollout (Transient)	1	0	0
On Pad (Trans...)	1	1	1
Liftoff to SES1 (...)	0	1	1
SES1 to Fairing Deploy (...)	0	1	1
Fairing Deploy to SECO1 (...)	0	1	1
SECO1 to Payload Deploy (...)	0	1	1

- Customer shall provide a MS Word document, MS PowerPoint presentation, or PDF containing a general summary of the payload thermal model. Within this document, there shall be a dedicated section clearly summarizing/outlining details for running and integrating the payload model, noting the following (if included/necessary):
  - Include file(s)
  - Logic object(s)
  - Node conductor blocks
  - Node correspondence
  - Optical/Thermal property files (e.g. which is to be used: beginning of life or end of life)
  - Property aliases
  - Material stacks
  - Payload/Payload adapter conductance
  - Thermal Desktop symbols (see table above)

- The payload model shall include a test case in the Thermal Desktop *Case Set Manager*, including (at a minimum) a steady-state run followed by a 1-hour transient run. The test case shall demonstrate that the model's SINDA run time is less than 1 hour of clock time per hour of transient model time as measured by the ASTAP execution time output by SINDA in the case set's *.out* file (i.e. the model must run at faster than real time). The submitted model shall include the results of that test case in a SINDA *.sav* format file. SpaceX will run the prescribed case set in Thermal Desktop and confirm that it produces identical results prior to integration with the SpaceX launch vehicle thermal model (i.e. validation). All aspects of the payload model shall be exercised in the Thermal Desktop test case, or multiple test cases may be supplied if this cannot be accomplished in a single test case. Integrated analysis will only proceed once this requirement is met or mutually agreed upon.

  - Ensure test case node names and numbering are consistent with results of test case node names and numbering
  - Ensure the as built test case set in Thermal Desktop corresponds to the provided test case results

- Customer shall fill out a table of temperature requirements using a SpaceX template Excel file. Temperature requirements embedded inside the summary documentation (i.e. docx, pptx, or pdf) will need to be included in a separate xlsx file. This file must follow the exact same format as in the provided template. Customer-supplied temperature limits shall include all uncertainty and margin. Thus, model results will be compared directly to customer-supplied limits.
  - Prior to sending the table of temperature requirements to SpaceX, ensure temperature requirements are correct and up to date.

APPENDIX H: DELIVERY FORMAT OF SEPARATION STATE VECTOR

SpaceX OPM output (generated YYYY-MM-DD-Day-HH-MM-SS):

All orbital elements are defined as osculating at the instant of the printed state.

Orbital elements are computed in an inertial frame realized by inertially freezing the WGS84 ECEF frame at time of current state. This OPM is provided based on flight telemetry from the second stage, and therefore represents the state of the second stage and not the state of any other body. Any position, velocity, attitude, or attitude-rate differences between the second stage and any other body need to be accounted for by the recipient of this OPM.

UTC time at liftoff:	DOY:HH:MM:SS.SS
UTC time of current state:	DOY:HH:MM:SS.SS
Mission elapsed time (s):	+XX.XX
ECEF (X,Y,Z) Position (m):	+XXXXXX.XXX, +XXXXXXXX.XXX, +XXXXXXX.XXX
ECEF (X,Y,Z) Velocity* (m/s):	+XXXX.XXX, +XXXX.XXX, +XXXX.XXX
LVLH to BODY quaternion (S,X,Y,Z):	+X.XXXXXXX, +X.XXXXXXX, +X.XXXXXXX, +X.XXXXXXX
Inertial body rates (X,Y,Z) (deg/s):	+X.XXXXXXX, +X.XXXXXXX, +X.XXXXXXX
Apogee Altitude** (km):	+XXXXX.XXX
Perigee Altitude** (km):	+XXX.XXX
Inclination (deg):	+XX.XXX
Argument of Perigee (deg):	+XXX.XXX
Longitude of the Asc. Node*** (deg):	+XXX.XXX
True Anomaly (deg):	+XX.XXX

Notes:

* ECEF velocity is Earth-relative

** Apogee/Perigee altitude assumes a spherical Earth, 6378.137 km radius

*** LAN is defined as the angle between Greenwich Meridian (Earth longitude 0) and the ascending node

APPENDIX I: TEST SCHEDULE FOR CONSTELLATIONS

Table I-1 shows the minimum required planned test schedule for a constellation consisting of 20 identical payloads following a protoqualification approach (total number of payloads and use of protoqualification shown as an example). The first five flight unit serial numbers, then flight units every fifth serial number are fully tested at integrated level. Constellations following a fleet qualification with a dedicated qualification unit (not flown) may use acceptance levels on the first flight unit instead.

Table I-1: Example Test Schedule for a Constellation of 20 Identical Payloads

SV SN#	SN 1	SN 2	SN 3	SN 4	SN 5	SN 6	SN 7	SN 8	SN 9	SN 10	SN 11	SN 12	SN 13	SN 14	SN 15	SN 16	SN 17	SN 18	SN 19	SN 20
Quasi static load[1]	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*					R *(AT)*					R *(AT)*
Sine vibration	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*					R *(AT)*					R *(AT)*
Shock	A																			
Random vibration or acoustics[2]	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*					R *(AT)*					R *(AT)*
Power inhibits	R	R	R	R	R					R					R					R
EMI/EMC	R																			
Thermal cycling/vacuum	A																			
Leak test	R	R	R	R	R					R					R					R

R = Required. A = Advised; PT = Protoqualification test (if following Protoqualification approach); AT = Acceptance test. Refer to Section 7.2 for test factors and levels. All tests, if required, must be conducted per levels, number of axes, and guidance as specified in Section 7.2.

[1] Verification of quasi-static load may be combined with sine vibration testing. Refer to Section 7.2.

[2] Follow guidance in Section 7.2 to determine the appropriate test.

The following table shows an example modified test schedule for the same constellation in Table I-1, where a Type 2 retest was triggered for SN12 (as an example), due to one of the factors listed in Section 7.3 for retest. SN12 and SN13 are fully tested at integrated level to re-establish test baseline, then the original lot test sampling approach is resumed.

Table I-2: Test Schedule for a Constellation of 20 Identical Payloads (with Retest Trigger Type 2 Example)

Retest Trigger (Type 2)

SV SN#	SN 1	SN 2	SN 3	SN 4	SN 5	SN 6	SN 7	SN 8	SN 9	SN 10	SN 11	SN 12	SN 13	SN 14	SN 15	SN 16	SN 17	SN 18	SN 19	SN 20
Quasi static load	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*		R *(PT)*	R *(AT)*		R *(AT)*					R *(AT)*
Sine vibration	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*		R *(PT)*	R *(AT)*		R *(AT)*					R *(AT)*
Shock	A																			
Random vibration or acoustics	R *(PT)*	R *(AT)*	R *(AT)*	R *(AT)*	R *(AT)*					R *(AT)*		R *(PT)*	R *(AT)*		R *(AT)*					R *(AT)*
Power inhibits	R	R	R	R	R					R		R[1]	R[1]		R					R
EMI/EMC	R											R[1]								
Thermal cycling/vacuum	A																			
Leak test	R	R	R	R	R					R		R[1]	R[1]		R					R

[1] Power inhibit, EMI/EMC, and/or leak tests may be waived if changes leading to retest trigger are structural in nature