Cake Topper Payload User's Guide

January 2023

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ACRONYMS

CCSFS .... Cape Canaveral Space Force Station
CG .... center of gravity
CLA .... coupled loads analysis
CVCM .... collected volatile condensable mass
EGSE .... electrical ground support equipment
EMI .... electromagnetic interference
FCC .... Federal Communications Commission
GRMS .... foot-mean-square acceleration
GSE .... ground support equipment
HVAC .... heating, ventilation, and air conditioning
HPF .... hazardous processing facility
ICD .... interface control document
IRIG .... inter-range instrumentation group
KSC .... Kennedy Space Center
LTAN .... local time ascending node
LTDN .... local time descending node
LV .... launch vehicle
MEOP .... maximum expected operating pressure
MPE .... maximum predicted environment
NASA .... National Aeronautics and Space Administration
NTE .... not-to-exceed
OPM .... orbital parameter message
PL .... payload
PLA .... payload adapter
PPF .... payload processing facility
QSL .... quasi-static loads
RF .... radio frequency
RTV .... room-temperature vulcanizing
SC .... spacecraft
SCAPE .... self-contained atmospheric protective ensemble
SPCS .... space control squadron
SPL .... sound pressure level
SSO .... sun-synchronous orbit
TBD .... to be defined
USSPACECOM .... United States Space Command
VSFB .... Vandenberg Space Force Base

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CHANGE LOG

Date	Update
January 2023	Original Release

1 INTRODUCTION

1.1 CAKE TOPPER USER'S GUIDE PURPOSE

Space Exploration Technologies Corp. (SpaceX) is pleased to offer a unique solution for medium-class spacecraft (500 kg – 2500 kg), which combines the schedule assurances of the Rideshare Program with many of the capabilities and offerings of primary, dedicated missions. For spacecraft under 500 kg that need to ride as a Cake Topper instead of standard side-port rideshare, please contact SpaceX for more details.

The Cake Topper Payload User's Guide is a planning document provided for medium-sized satellite Customers of SpaceX. This document is intended to help Customers understand SpaceX's standard services for pre-contract mission planning and to delineate Customer requirements for contracted Cake Topper Launch Services. This User's Guide provides environmental, interface, and preliminary launch operations information for medium-class payloads utilizing the "Cake Topper" location, a top-mount interface on the forward end of a rideshare hardware "stack". This document outlines the standard services provided for these payloads. Please contact SpaceX for availability and pricing if non-standard services are required.

SpaceX reserves the right to update this guide as required. Future revisions are likely as SpaceX continues to gather additional data and works to improve the Cake Topper product offering.

1.2 CAKE TOPPER DESCRIPTION AND REQUIREMENTS

The Cake Topper Payload (referred to as "Payload," or "Cake Topper" in this document) is a payload mounting location on the forward end of a rideshare hardware stack, as shown below in Figure 1-1.

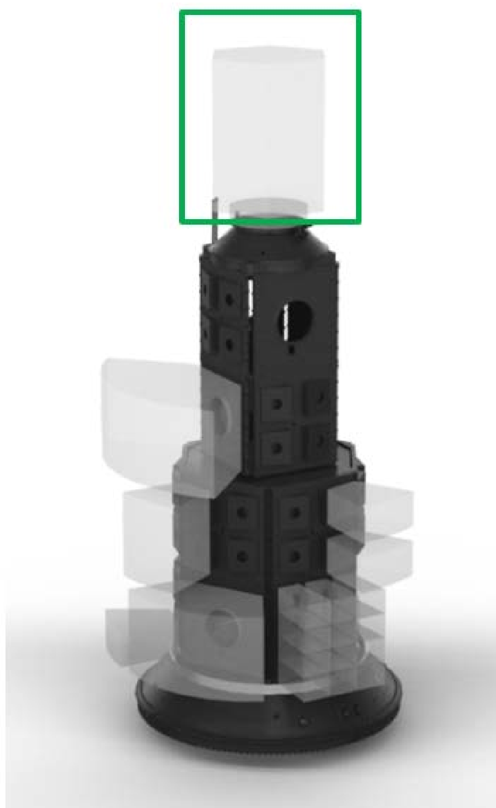


Figure 1-1: Cake Topper Location (green)*

*Example hardware configuration shown above for Payload mounted on Rideshare Plates; configuration is subject to change.

Up to two side-by-side mounting interfaces are available in this location; please contact SpaceX for more details if a dual-configuration is desired. A single interface is able to support a payload up to 2500 kg in size. Because of the Cake Topper Payload's unique location, it has a distinct set of environmental and interface requirements.

1.3 CAKE TOPPER PROGRAM OVERVIEW

The timeline of a typical Cake Topper contract is shown in Figure 1-2. Contract signature to launch is typically 1-2 years depending on spacecraft readiness and Launch Vehicle (LV) availability.

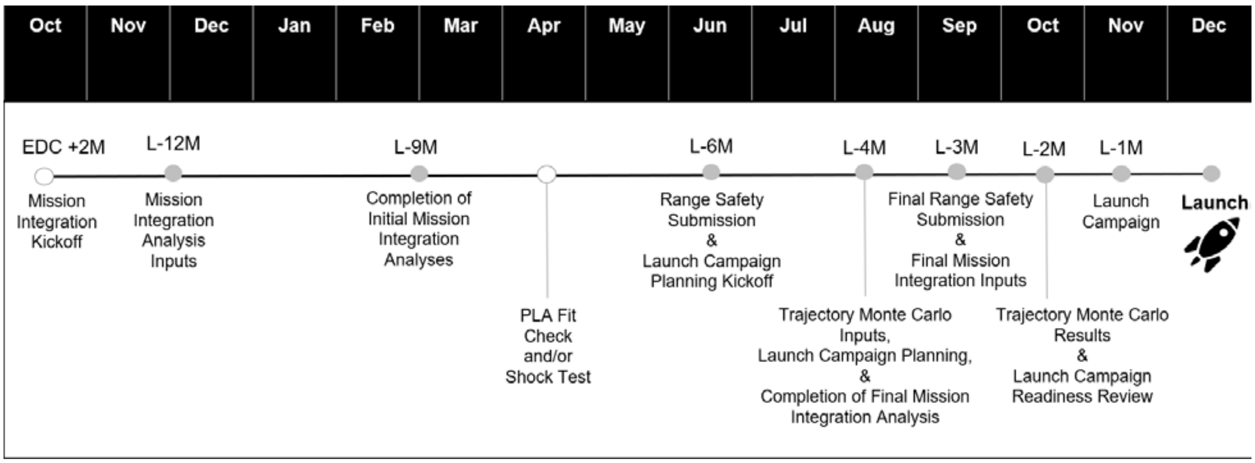


Figure 1-2: Cake Topper Typical Mission Integration Timeline

SpaceX will provide kickoff materials shortly after the launch services contract is signed. To aid in communication, SpaceX will send document templates for the Customer to complete. A description of the documents associated with each milestone can be found in Appendix A: Deliverable Descriptions.

To ensure a smooth Launch Campaign and a successful mission for all Customers, SpaceX will maintain an Interface Control Document (ICD) for the Payload. Requirements in the ICD are designed to ensure the safety of all Co-Payloads and the Launch Vehicle. SpaceX and the Customer will periodically review and update the ICD throughout the mission integration process.

Approximately six months before Launch, the Customer and SpaceX begin planning Range Safety and Launch Campaign operations.

Detailed mission analysis deliveries that rely on a known rideshare stack configuration are not available until approximately L-2 months. Before the Payload is delivered to the Launch Site, the ICD is signed and a review is held to confirm Launch Campaign readiness as well as the Payload-specific schedule. The Payload is then shipped to the Launch Site, where it is integrated to the Launch Vehicle.

SpaceX will provide a best-estimate Payload separation state vector, or Orbital Parameter Message (OPM) to the Customer shortly after Payload separation, as described in Appendix E: Delivery Format of Separation State Vector. Customer is responsible for tracking and contacting the Payload after separation from the Launch Vehicle.

1.4 FALCON 9 PROGRAM

Please refer to the SpaceX Falcon User's Guide latest revision, available on www.spacex.com/vehicles/falcon-9/, for detailed information regarding the Falcon program, including Operations and Launch Vehicle safety and reliability.

1.5 RIDESHARE PROGRAM

Please refer to the SpaceX Rideshare Payload User's Guide latest revision, available on https://www.spacex.com/rideshare/, for more information about flying small satellites on side-mounted ports.

2 PERFORMANCE

2.1 MASS PROPERTIES

Cake Topper Payloads must comply with the mass and center-of-gravity limitations given in Figure 2-1. The center of gravity is relative to the Cake Topper origin, with the origin defined at the separation plane. The Launch Vehicle may be able to accommodate Cake Topper Payloads with characteristics in excess of these limits; for example, with a reduced Rideshare capacity. Please contact SpaceX with your mission-unique requirements.

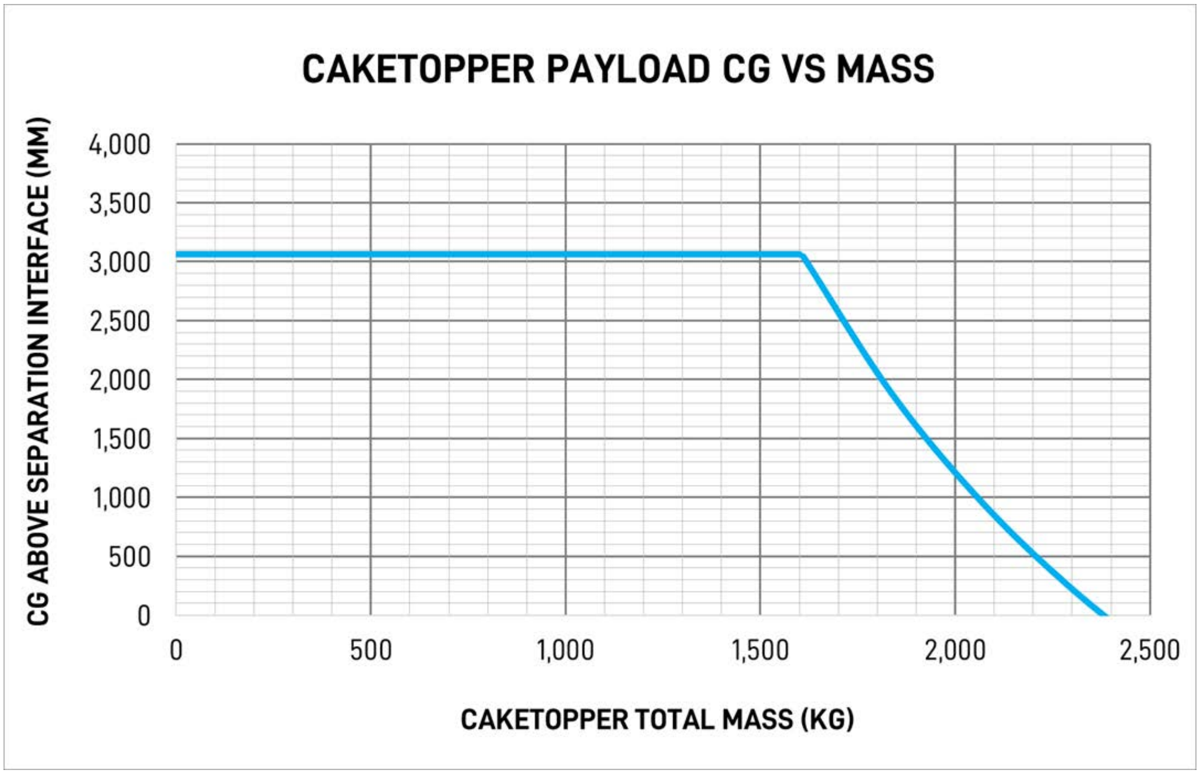


Figure 2-1: Cake Topper Center of Gravity Restrictions

2.2 SEPARATION ORBIT

Cake Topper Payloads may be part of a two-orbit drop-off mission, to ensure Co-Payloads can be deployed within standard Rideshare Program mission altitudes. Orbit parameters are defined in terms of semi-major axis altitude and eccentricity (as opposed to apogee and perigee). Standard dispersions of orbital parameters are as follows:

Table 2-1: Typical Orbital Dispersions

Parameter	Example Transporter Values	Allowable Dispersion
Mean Semi-Major Axis Altitude	500–700 km (*typical*)	+/- 20 km
Mean Inclination	SSO (*typical*)	+/- 0.1 deg
Mean Eccentricity	Circular (*typical*)	<0.004
Mean LTAN or Mean LTDN	Customer-defined	Customer-defined

SpaceX may be able to provide reduced dispersions on a mission-specific basis. Please contact SpaceX for more details. Note that all missions fly south out of SpaceX launch sites that are north of the equator, so Local Time Ascending Node (LTAN) will be approximately 12 hours after launch time for sun-synchronous orbits (SSO). Osculating elements are available, upon request.

2.3 POST-SEPARATION RATES AND VELOCITY

Cake Topper Payloads should be designed to meet a separation velocity typically between 0.3 m/s and 1.5 m/s, which is determined by both the payload mass and the Payload separation system characteristics. Post-separation rates will also depend on spacecraft mass properties and the separation mechanism but typically target < 2.5 deg/s in all axes. Please contact SpaceX for any mission-specific requests. Note that post-separation rates are inclusive of the pre-separation rates, as defined below in Table 2-2.

Table 2-2: Launch Vehicle Rates Before Payload Separation

Axis	Rate
Launch Vehicle Roll (W_X)	± 2.0 deg/s
Launch Vehicle Pitch (W_Y)	± 1.0 deg/s
Launch Vehicle Yaw (W_Z)	± 1.0 deg/s

2.4 SUN ANGLE EXPOSURE

Sun angle exclusion requirements during ascent may affect performance or launch availability. However, most sun-angle exclusion requirements are driven by component thermal limits, which is a more easily solved and less performance-restrictive requirement. Therefore, Cake Topper Payloads are encouraged to evaluate sun angle exclusion requirements as thermal requirements (see Section 3.3.8 for more details). Please contact SpaceX for details and pricing if sun angle exclusions are still required, as these can be evaluated on a mission-specific basis.

3 ENVIRONMENTS

The Launch Vehicle has been designed to provide a benign Payload environment. The environments presented below reflect typical mission maximum predicted environments (MPE) for Cake Topper Payloads.

3.1 TRANSPORTATION ENVIRONMENTS

Transportation environments at launch site facilities will be enveloped by the flight environments in Section 3.3.

3.2 CLEANROOM ENVIRONMENTS

The standard service temperature, humidity, and cleanliness environments during various processing phases are provided in Table 3-1.

Conditioned air will only be disconnected for short durations (generally between 30 and 60 minutes) during pre-determined operations such as movements, lifts, and rollout to the pad. Payload environmental temperatures will be maintained above the dew point of the supply air at all times. The SpaceX-supplied mechanical interface and fairing surface are cleaned to Visibly Clean, Highly Sensitive (VC-HS) level.

Table 3-1: Temperature and Cleanliness Environments

<table>
<tr><th>Phase</th><th>Control System</th><th>Temp °C (°F)</th><th>Humidity</th><th>Cleanliness (Class)</th></tr>
<tr><td>Payload Processing</td><td>PPF HVAC</td><td rowspan="4">21 ± 3 (70 ± 5)</td><td rowspan="2">CCSFS/KSC: 45% ± 15%
VSFB: 50% ± 15%</td><td rowspan="6">100,000
(Class 8) or better</td></tr>
<tr><td>Propellant Conditioning and Loading</td><td>PPF HVAC</td></tr>
<tr><td>Transport to Hangar (CCSFS/KSC only)</td><td>Transport trailer unit</td><td>25% to 60%</td></tr>
<tr><td>Encapsulated in Hangar</td><td>Ducted supply from standalone HVAC unit or transport trailer unit (if required)</td><td>CCSFS/KSC: 45% ± 15%
VSFB: 50% ± 15%</td></tr>
<tr><td>Encapsulated Roll-Out to Pad</td><td>None (transport trailer unit if required)</td><td>No Control System</td><td>No Control System</td></tr>
<tr><td>Encapsulated on Pad (Vertical or Horizontal)</td><td>Pad air conditioning</td><td>Bulk air temperature will remain between 10 and 32 (50 to 90), targeting 21 (70)</td><td>0% [1] to 65%</td></tr>
</table>

Note:

1. Supply air is switched to GN2 during the Launch Countdown sequence.

3.3 FLIGHT ENVIRONMENTS

This section describes the MPE the Cake Topper Payload will experience from liftoff through separation. Environments are defined at the Payload interface.

Payloads must show compliance to all environments in Table 3-14 (i.e., if an acoustic test is done but not a random vibe test, acoustic levels must be shown to envelope random vibe required levels), as well as contamination requirements. Other environments are given for informational purposes only.

3.3.1 LOADS

Purpose: To ensure structural integrity of the Payload to LV interface.

Cake Topper Payload design load factors are listed in Table 3-2. These load factors are valid for Payloads with a primary lateral fundamental frequency greater than 15 Hz, and primary axial frequency greater than 25 Hz. Payloads with fundamental frequencies at or below these values will require SpaceX approval, and may be subject to increased load factors.

Verification: Testing is REQUIRED to the static load test levels and durations defined in Table 3-2 in accordance with the MPE defined in this section. Static load test requirements can be achieved through sine burst, sine sweep (sine vibe), random vibration, or static load testing. Customer is responsible for providing test data (via accelerometer readings or force gauges) to show that the chosen test has achieved the appropriate interface force, as well as documentation for any planned notching or adjustment of the provided levels.

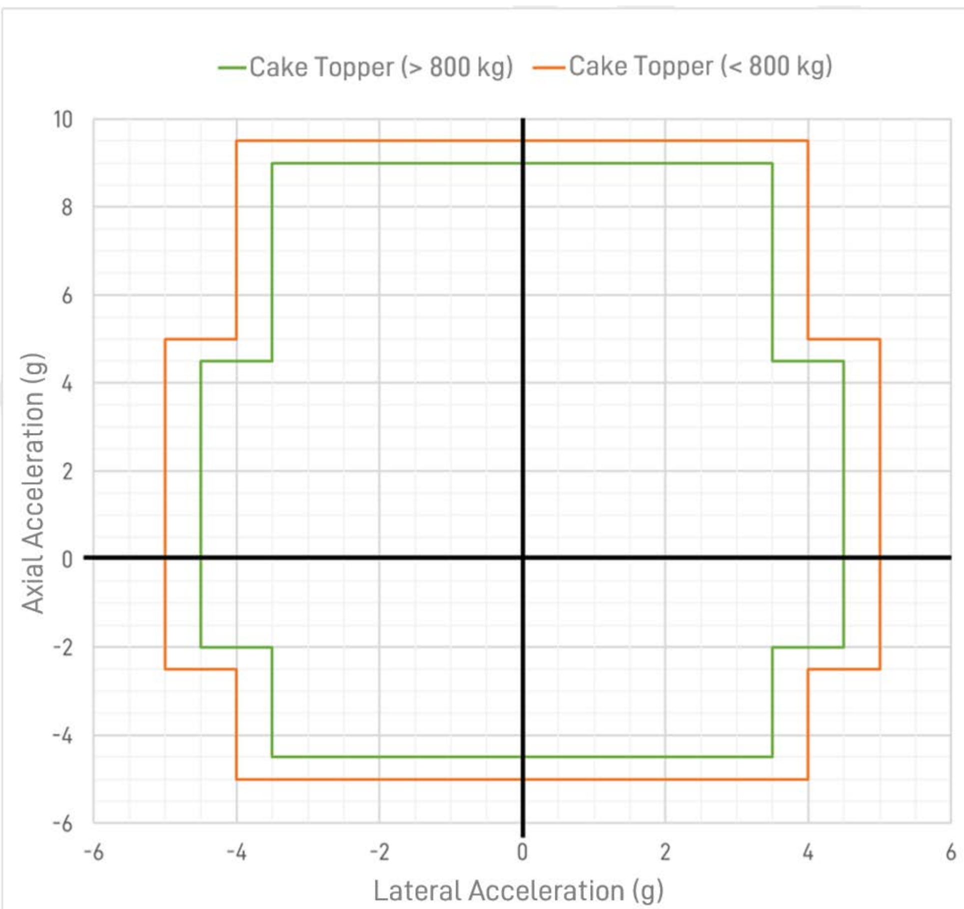


Figure 3-1: Cake Topper Axial and Lateral Load Factors (MPE)

Table 3-2: Cake Topper Payload Design Load Factors

> 800 kg		< 800 kg	
Axial (g)	Lateral (g)	Axial (g)	Lateral (g)
9	3.5	9.5	4
4.5	3.5	5	4
4.5	4.5	5	5
-2	4.5	-2.5	5
-2	3.5	-2.5	4
-4.5	3.5	-5	4
-4.5	-3.5	-5	-4
-2	-3.5	-2.5	-4
-2	-4.5	-2.5	-5
4.5	-4.5	5	-5
4.5	-3.5	5	-4
9	-3.5	9.5	-4
9	3.5	9.5	4

3.3.2 SINE VIBRATION

Purpose: To ensure Payloads are compatible with loads imparted on primary and secondary structures with modes < 100 Hz, the maximum predicted sine vibration environment is defined below in Figure 3-2 andTable 3-3. This environment is defined for Payloads with Q ≥ 10, and may be notched at primary mode(s) to stay within the design load factors defined in Section 3.3.1. Notching profiles are due at Mission Integration Kickoff and may not be reviewed if delivered later than two weeks before spacecraft testing begins.

IMPORTANT NOTE: Mission-specific sine vibration levels, including Output Transfer Matrices (OTMs) from Coupled Loads Analysis (CLA) are not available until L-2 months due to the Rideshare Program configuration timeline. Therefore, Cake Topper Payloads are expected to test, with appropriate test factors, to the enveloping values as described in this section. Final CLA results will only validate test levels of all hardware and spacecraft on the mission, and will not be available prior to SC testing.

Dynamic models are required to be submitted per Appendix B: Dynamic Model Requirements.

Verification: Testing is REQUIRED to the sine vibration test levels and durations defined in Table 3-3 in accordance with the MPE defined in this section.

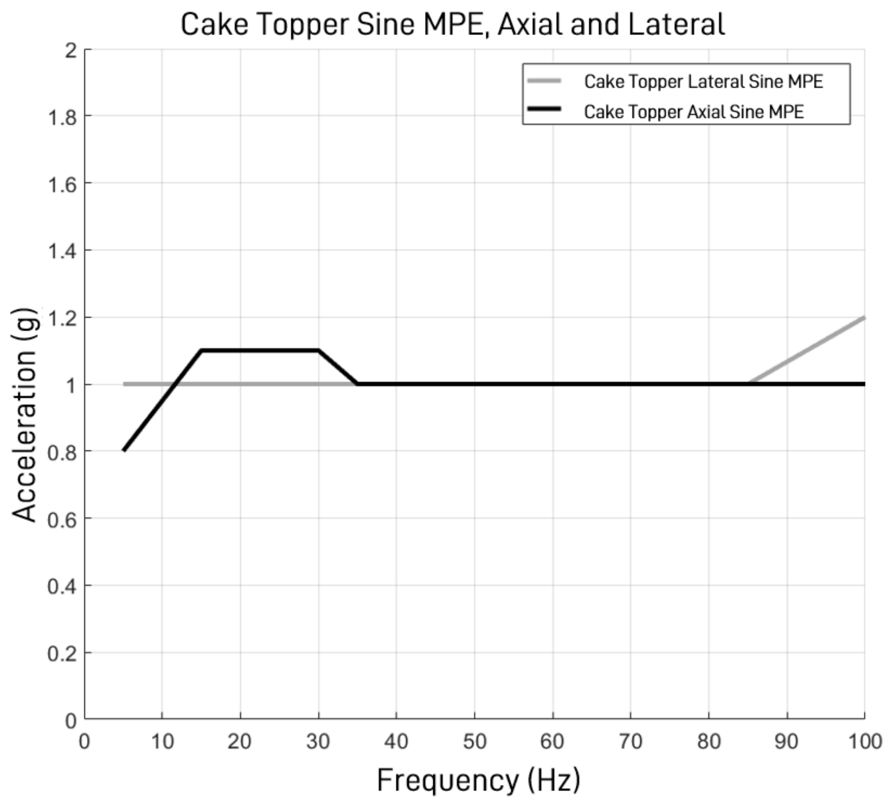


Figure 3-2: Axial and Lateral Sine Vibration MPE

Table 3-3: Cake Topper Axial and Lateral Accelerations

Frequency (Hz)	Axial Acceleration (g) (Q ≥10)	Lateral Acceleration (g) (Q ≥10)
5	0.8	1.0
15	1.1	1.0
30	1.1	1.0
35	1.0	1.0
85	1.0	1.0
100	1.0	1.2

3.3.3 ACOUSTIC

Purpose: To ensure Payloads are compatible with acoustic environments inside the LV fairing.

Acoustic levels for Cake Topper Payloads are shown in Figure 3-2, Table 3-4, and Table 3-5. Acoustic mitigations may be available as an optional service. Please contact SpaceX for assessment of mission-specific acoustic requirements and pricing for mitigations.

Verification: Testing is REQUIRED to the acoustic test levels and durations defined in Table 3-4 (1/3 octave) or Table 3-5 (full octave) in accordance with the MPE defined in this section.

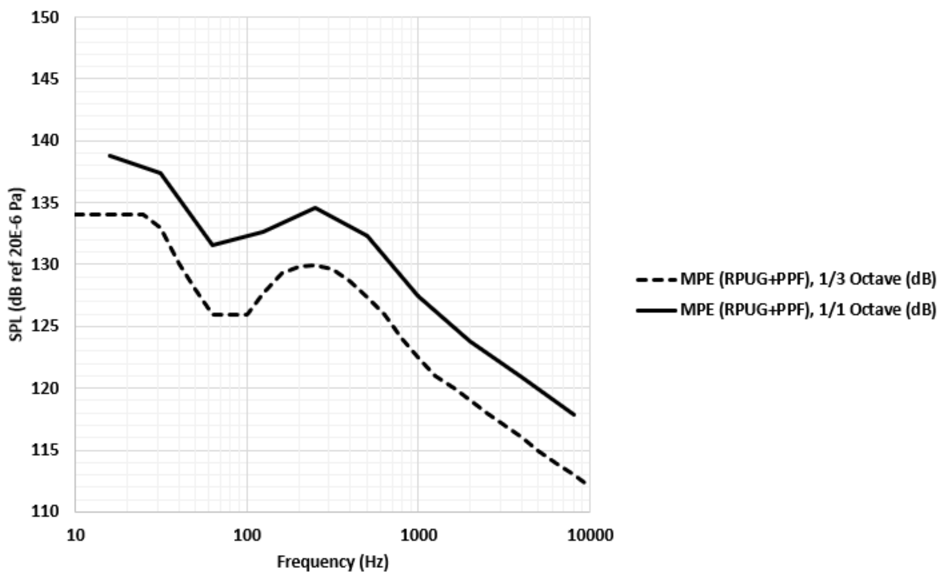


Figure 3-3: Maximum Predicted Acoustic Environment

Table 3-4: Third Octave Acoustic MPE

Frequency (Hz)	Acoustic MPE 1/3 Octave (dB)
10	134
12.5	134
16	134
20	134
25	134
31.5	133
40	130
50	128
63	126
80	126
100	126
125	127.7
160	129.3
200	129.8
250	129.9
315	129.6
400	128.7
500	127.4
630	126
800	124
1000	122.5
1250	121
1600	120
2000	119
2500	118
3150	117
4000	116
5000	115
6300	114
8000	113
10000	112
OASPL	143.9

Table 3-5: Full Octave Acoustic MPE

Frequency (Hz)	Acoustic MPE Full Octave (dB)
16	138.8
31.5	137.4
63	131.5
125	132.6
250	134.5
500	132.3
1000	127.4
2000	123.8
4000	120.8
8000	117.8
OASPL	143.4

3.3.4 SHOCK

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

The shock response spectrum MPE, for Q=10, at the Payload mechanical interface for fairing deployment and Co-Payload separation(s), as well as the maximum allowable shock for a single separation system are defined in Table 3-6 and Figure 3-4. These levels are defined assuming a minimum of 3 bolted joints between Co-Payloads.

Customers may opt for a spacecraft shock test with the flight Payload Adapter (PLA), which takes place at the Customer facility. However, for low-shock separation systems that provide shock levels lower than those defined below in this section, the Table 3-6 shock levels must be evaluated in order to account for co-payload and fairing shock levels. Customer-defined shock requirements lower than Table 3-6 are not permitted.

Verification: Testing is REQUIRED to the shock test levels defined in this section. Alternatively, Customers may show compliance via analysis of all shock-critical components to the shock levels defined in this section.

Table 3-6: Payload Mechanical Interface Shock

Frequency (Hz)	MPE Induced by Launch Vehicle and Co-Payload(s) SRS (g)	Maximum Allowable Induced by Payload Separation System SRS (g)
100	30	30
1000	1000	--
1950	--	2850
10000	1000	2850

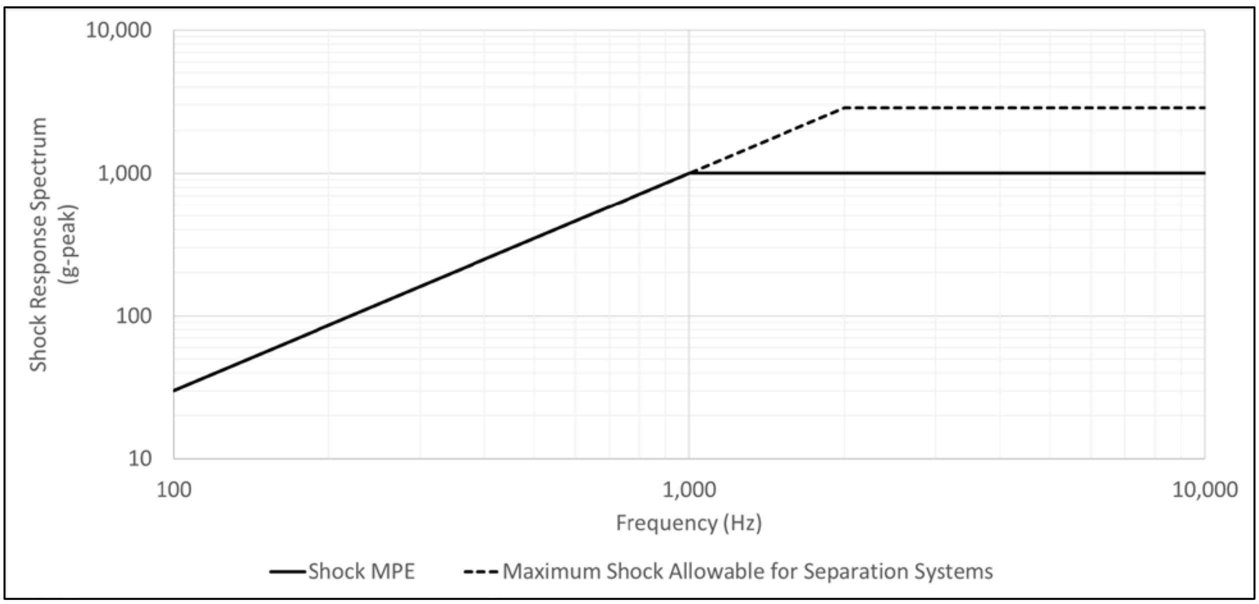


Figure 3-4: Payload Mechanical Interface Shock

3.3.5 RANDOM VIBRATION

Purpose: To ensure structural integrity of the Payload during flight dynamic events. Exposure to the random vibration environment ensures that primary structures, secondary structures, and smaller components are exposed to flight loads plus margin. This exposure is required for mission safety and Co-Payload safety.

Verification: Testing is REQUIRED to the random vibration test levels and durations defined in Table 3-14 in accordance with the MPE defined in this section.

Table 3-7: Random Vibration MPE

Frequency (Hz)	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

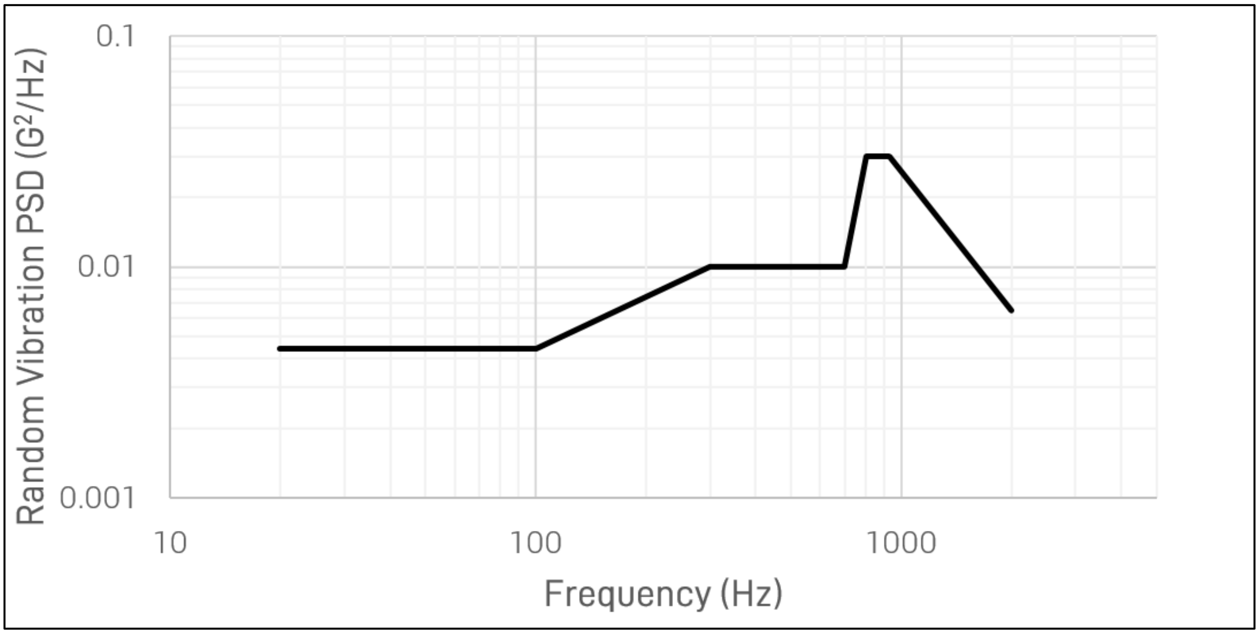


Figure 3-5: Random Vibration MPE

3.3.6 ELECTROMAGNETIC

Purpose: To ensure that LV and Launch Site radiated emissions do not compromise electrical integrity of the Payload, and to ensure that Payload emissions do not compromise safety of the LV or of Co-Payloads during the mission.

The Payload must show compliance with the electromagnetic environments in the following sections. Payload electromagnetic specifications will be captured in the Payload-specific ICD.

Verification: Testing or verification by analysis is REQUIRED to the electromagnetic compatibility test levels and durations defined in Table 3-14 in accordance with the environments defined in this section. If the Payload is powered off during ascent, see Note 2 of Table 3-14.

3.3.6.1 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 3-6. LV, including Co-Payloads, and Launch Site radiated emissions, are shown in Table 3-8 and Table 3-9 respectively. EMI margin is not included.

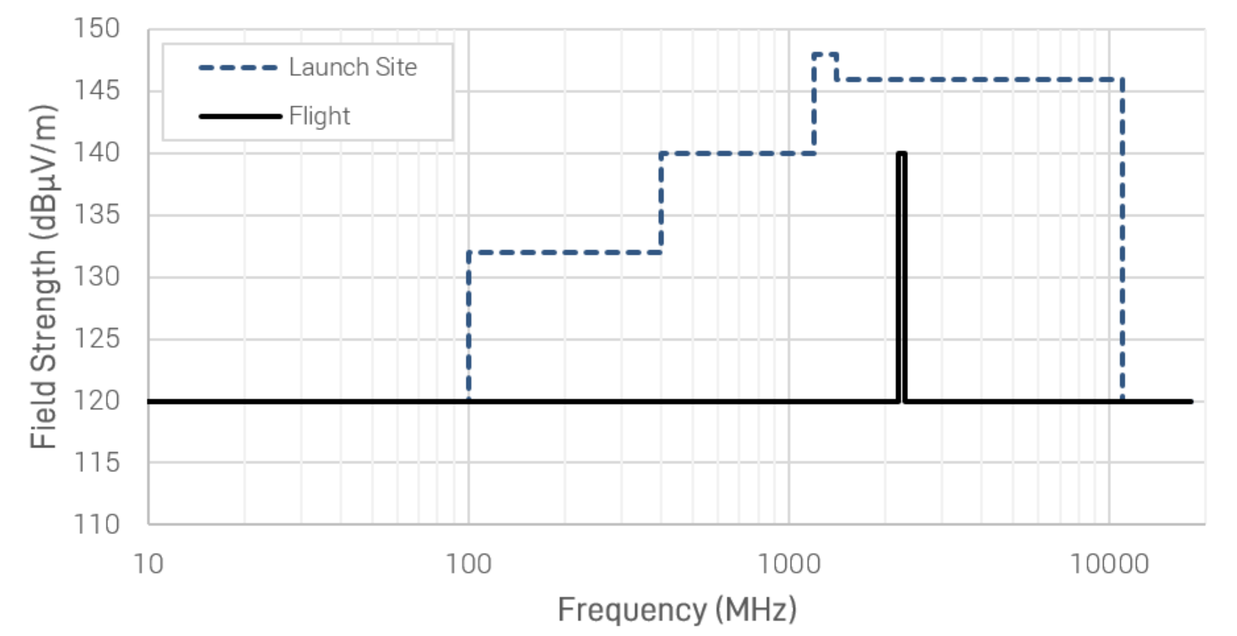


Figure 3-6: In-Flight & Environmental Radiated Emissions / Payload Radiated Susceptibility Limit

Table 3-8: Launch Vehicle Radiated Emissions

Frequency Range (MHz)	E-Field Limit (dBµV/m)
1.00–2200.0	120
2200.0–2300.0	140
2300.0–18000.0	120

Table 3-9: Launch Site Radiated Emissions

Frequency Range (MHz)	E-Field Limit (dBµV/m)
1.00–100	120
100–400	132
400–1200	140
1200–1400	148
1400–11000	146
11000–18000	120

These limits envelope the expected emissions from the LV, Co-Payloads, and Launch Site radar transmitters. The Customer should assume 26 dB of shielding from Launch Site sources when testing and integrating the Payload in either the PPF or the Hangar Annex.

3.3.6.2 MAXIMUM SPACECRAFT EMISSIONS

The emission envelope for Cake Topper missions, including 6 dB of EMI safety margin by test, or 12 dB of EMI safety margin by analysis, is shown in Table 3-10.

Table 3-10: Maximum Payload Emissions

Frequency Range (MHz)	by Test (dBµV/m)	by Analysis (dBµV/m)
30.0–1555.42	90	84
1555.42–1595.42	48	42
30.0–18000.0	90	84

Standard Launch Services do not permit use of Payload transmitters while integrated to the LV hardware. Payload transmitters may be enabled after the time interpolated using the information found in Table 3-11.

Additionally, any transmitter centered in the 2227.5–2237.5 MHz, 2267.5–2277.5 MHz, and 2206–2216 MHz bands must wait to enable these transmitters until "End of Mission," as defined by the mission-specific second stage re-entry time (usually a maximum of 1 hour, or 3600 seconds, after the last deployment from the LV).

Table 3-11: Payload Transmitter Delay Time (seconds)

	EIRP (Watts)	0.00001	0.0001	0.001	0.01	0.1	1	10	19.95	100	1000
	EIRP (dBm)	-20	-10	0	10	20	30	40	43	50	60
Separation Velocity (m/s)	0.1	0.260	0.822	2.599	8.216	26.0	82.2	260	367	822	2599
	0.2	0.130	0.411	1.30	4.108	13.0	41.1	130	184	411	1300
	0.5	0.052	0.165	0.52	1.644	5.197	16.5	52.0	73.4	165	520
	1.0	0.026	0.083	0.26	0.822	2.599	8.216	26.0	36.7	82.2	260
	2.0	0.013	0.042	0.13	0.411	1.30	4.108	13.0	18.4	41.1	130
	5.0	0.006	0.017	0.052	0.165	0.52	1.644	5.197	7.34	16.5	52.0

Payload electromagnetic specifications will be captured in the Payload-specific ICD. Customers with Cake Topper Payloads transmitting in the 2227.5–2237.5 MHz, 2267.5–2277.5 MHz, and 2206–2216 MHz frequency bands must inform SpaceX prior to launch services agreement (LSA) finalization.

3.3.7 FAIRING INTERNAL PRESSURE

Fairing internal pressure will decay at a rate no larger than 0.40 psi/sec (2.8 kPa/sec) from liftoff through immediately prior to fairing separation, except for brief periods during flight, where the fairing internal pressure will decay at a rate no larger than 0.65 psi/sec (4.5 kPa/sec), for no more than 5 seconds. A mission-specific analysis will not be provided by SpaceX.

3.3.8 THERMAL

Customers may perform a Payload-specific thermal analysis for their Payload. Upon request, SpaceX will provide a representative description of thermal attitude parameters to the Customer once a target orbit has been identified in the Statement of Work (SOW).

Bounding hot and cold boundary temperatures and conductance values at the interface of the Payload and the SpaceX-provided mechanical interface are shown in Table 3-12 and Figure 3-7. The Customer may use these boundary conditions to run a Payload-specific thermal analysis. Note that these boundary conditions are only relevant after Liftoff at Time = 0, as they contain analysis uncertainty that is not appropriate on the ground. The convective environment in Table 3-1 fully defines the pre-launch environment. A mission-specific analysis will not be provided by SpaceX.

Verification: Testing is ADVISED to the combined thermal vacuum and thermal cycle test levels and durations defined in Table 3-14 in accordance with the environments defined in this section.

Table 3-12: Bounding Conductive Boundary Temperature and Conductance

Time (s)	Hot Temperature (°C)	Cold Temperature (°C)	Min Conductance (W/°C)	Max Conductance (W/°C)
0	40	-5	0	7.7
1000	42	-10	0	7.7
2000	52	-15	0	7.7
3000	52	-20	0	7.7
7200	52	-20	0	7.7

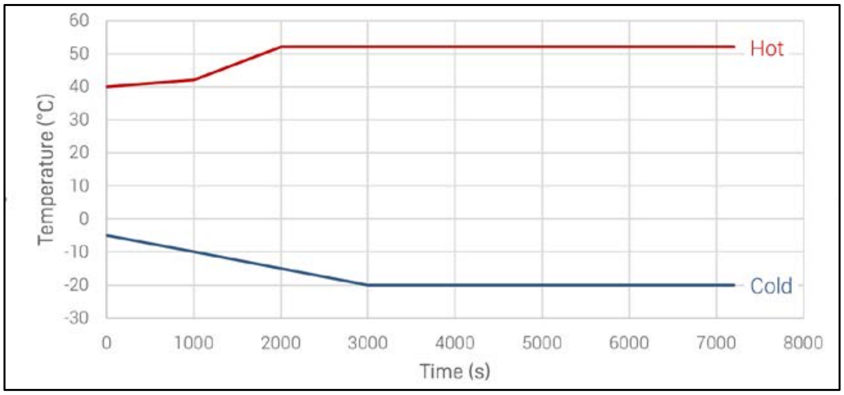


Figure 3-7: Bounding Conductive Boundary Temperature

3.3.9 PAYLOAD TEMPERATURE EXPOSURE DURING FLIGHT

The LV fairing is designed such that the temperature seen by the Payload never exceeds the temperature profile shown in Figure 3-8. The emissivity of the fairing is approximately 0.9.

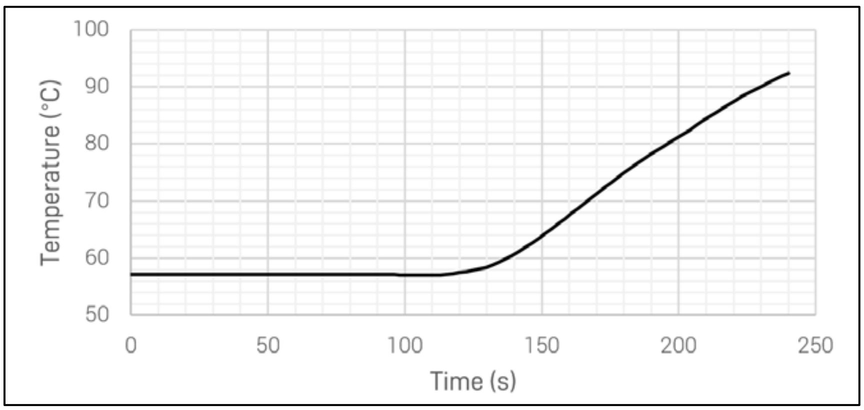


Figure 3-8: Maximum Fairing Spot Temperature Seen by Payload

3.3.10 FREE MOLECULAR HEATING

The maximum free molecular aero-thermal heating rate experienced by the Payload is less than 3,500 W/m2 at fairing separation. Free molecular aero-thermal heating declines significantly and becomes negligible over the next couple of minutes. The free molecular heating environment can be assessed on a mission-specific basis, if required. Please contact SpaceX for additional details.

3.3.11 CONTAMINATION

Purpose: To maintain a clean processing fairing environment for all hardware on the mission.

Cake Topper Payloads are mounted above other Co-Payloads, and cannot generate Foreign Object Debris (FOD), or contain prohibited materials. Cake Topper Payloads will be exposed to hardware inside the fairing that has been cleaned to VC-HS level.

The Customer is responsible for cleaning all Customer-provided equipment and hardware, including the Payload, to the appropriate SpaceX-designated contamination-control levels prior to entering SpaceX's cleanliness-controlled facilities at the Launch Site (e.g., the Payload Processing Facility cleanroom). Standard cleaning products (e.g., isopropyl alcohol and cleanroom wipes) are provided by SpaceX.

Payload contamination must meet the requirements in Table 3-13.

Verification: The Customer is responsible for verifying compliance to this requirement in the form of a Payload contamination report.

Table 3-13: Payload Contamination Requirements

Name	Description
Visual Cleanliness	Payloads must be cleaned to VC-HS standards per NASA-SN-C-005D prior to integration onto Launch Vehicle hardware.
Non-Metallic Materials	Each individual non-metallic material used in the construction of the Payload that will be exposed to vacuum must not exceed a total mass loss of 1.0 and the volatile condensable matter must be less than 0.1% when tested per ASTM E595. This would include avoiding the use of markers, pens, and paint pens to mark Payload hardware. A complete vacuum-exposed non-metallic materials list including quantities (surface area or mass) will be delivered to SpaceX for review via the Environmental Test Report Template. Exceptions to this requirement are allowed using the rationale codes found in the Environmental Test Report Template. Rationale codes will be evaluated by SpaceX.
Metallic Materials	The selection of metallic materials by the Customer will include consideration of corrosion, wear products, shedding, and flaking in order to reduce particulate contamination. Dissimilar metals in contact will be avoided unless adequately protected against galvanic corrosion.
Payload Particulate Generation	The Payload will not create particulate during the vibroacoustic ascent environment. Actuation of any Payload mechanisms nearby any Co-Payload(s) or Launch Vehicle Hardware must not create particulate.
Payload Deployment	The Payload deployment system will not include the use of uncontained pyrotechnics (e.g., frangible nuts).
Payload Propulsion	Payload propulsion systems will not be operated in close proximity (within 1 km) of Co-Payload(s).
Prohibited Materials	The following materials are not to be used on Payload hardware: • Cadmium parts • Cadmium-plated parts • Zinc plating • Mercury, compounds containing mercury • Pure tin or tin electroplate (except when alloyed with lead, antimony, or bismuth)
Silicone Sensitivity	All silicone rubber or Room-Temperature Vulcanizing (RTV) silicones with probability of transfer to Co-Payload(s) or Launch Vehicle hardware will require SpaceX approval, coordination, and notification prior to use. Use of Silicone may limit launch availability, as not all missions allow Silicone.

3.4 ENVIRONMENTAL VERIFICATION TESTING

Customers must verify the compatibility of the Payload with the MPEs in Section 3.3. SpaceX will review verification plans and results during mission integration analysis to ensure mission safety.

The environments verification approach in this section is designed to ensure the safety of Co-Payloads and the Launch Vehicle. Deviations from these parameters may be acceptable but must be reviewed and approved by SpaceX early in the mission design process. Tests that are "Advised" are designed to ensure on-orbit health and functionality of the Payload but are not required in order to fly on a SpaceX Mission. Tests that are "Required" must be completed by the Customer. The intent of the following test matrices is to both qualify and preflight-screen flight hardware (including bolted joint interfaces and fastener retention methods) to ensure mission safety.

3.4.1 VERIFICATION APPROACH

SpaceX allows two approaches to environmental verification testing: Fleet Qualification and Flight Unit Protoqualification.

- Fleet Qualification: A qualification 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. Qualification can be performed at the component level with prior approval from SpaceX. With this approach, the qualification test validates the structural design while the acceptance test(s) validate workmanship.
- Flight Unit Protoqualification: Each Payload flight unit is subjected to protoqualification test levels. Testing must be performed at the fully integrated Payload assembly level. With this approach, the protoqualification test validates both structural design and workmanship.

Every Payload flying on a SpaceX mission must undergo either fleet qualification or flight unit protoqualification environmental verification testing. Payloads using a fleet qualification approach must submit evidence that the qualification unit is sufficiently similar to the flight unit. The environments verification approach in this section is designed to ensure the safety of Co-Payloads and the LV.

3.4.2 TEST-LIKE-YOU-FLY EXCEPTIONS

For acceptance and protoqualification tests performed on the flight Payload units, test-like-you-fly exceptions must be approved by SpaceX. Test-like-you-fly exceptions include all changes from the flight configuration to the test configuration. Rationale for the deviation must be provided to SpaceX. Common examples include:

- Not testing propulsion systems at flight pressure during the test
- Not filling propulsion tanks with propellants during the test
- Mass models or engineering models used in place of flight hardware

3.4.3 POST-INTEGRATED TEST MODIFICATIONS

Limited disassembly of the Payload for functional checkouts after the integrated test is allowed, as long as the following criteria are met:

- Fastened joints that meet the criteria in Section 4.1.2 are eligible for disassembly after test. Workmanship sensitive joints (adhesive, epoxy, brazed, welded, etc.) require a retest if they are modified after testing. Re-assembly after test must follow the fastener installation requirements in Section 4.1.2.
- (If applicable) Secondary deployment mechanisms that are re-assembled after testing must demonstrate similar workmanship insensitivity, redundant workmanship controls, post-reassembly proof testing, or retest of random vibration acceptance levels for 30 seconds in the most stressing single axis.

3.4.4 DOCUMENTATION REQUIREMENTS

Customers must deliver to SpaceX an environmental test approach summary, including test-like-you-fly exceptions and notching profiles, for review by SpaceX prior to Payload testing as defined in the Payload contract's SOW. Test Plans may not be reviewed if delivered later than two weeks before spacecraft testing begins, as SpaceX requires adequate time to evaluate and provide feedback on test plans.

A summary of the verification test results for the completed testing is due before the Launch Campaign Readiness Review as defined in the SOW. The summary report must include all 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 setup 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 within the summary report.

3.4.5 PAYLOAD UNIT TEST LEVELS

Payload unit testing must conform to the parameters shown in Table 3-14.

Table 3-14: Payload Unit Test Levels and Durations

Test	Required/Advised	Fleet Qualification		Flight Unit [1]
		Qualification	Acceptance Must be performed on fully integrated Payload assembly	Protoqualification Must be performed on fully integrated Payload assembly
Static Load [1]	REQUIRED	1.25 times the limit load	1.1 times the limit load	1.25 times the limit load
Sine Vibration	REQUIRED	1.25 times limit levels, two octave/minute sweep rate in each of 3 axes	1.0 times limit levels, four octave/minute sweep rate in each of 3 axes	1.25 times limit levels, two octave/minute sweep rate in each of 3 axes
Acoustic	REQUIRED	6 dB above acceptance for 2 minutes	MPE spectrum for 1 minute	3 dB above acceptance for 1 minute
Shock[8]	REQUIRED	6 dB above MPE, 3 times in each of 3 orthogonal axes	Not Required	3 dB above MPE, 2 times in each of 3 orthogonal axes
Random Vibration[9]	CUSTOMER EVALUATION REQUIRED	6 dB above acceptance for 2 minutes in each of 3 axes	Envelope of MPE spectrum and SMC-016 Figure 6.3.5-1 for 1 minute in each of 3 axes	3 dB above acceptance for 1 minutes in each of 3 axes
Electromagnetic Compatibility [2,3]	REQUIRED	6 dB EMISM by Test or 12 dB EMISM by Analysis	Not Required	6 dB EMISM by Test or 12 dB EMISM by Analysis
Combined Thermal Vacuum and Thermal Cycle [4]	ADVISED	±10 °C beyond acceptance for 27 cycles total	Envelope of MPT and minimum range (-24 to 61 °C) for 14 cycles total	±5 °C beyond acceptance for 20 cycles total
Pressure System [5,6]	REQUIRED	Pressures as specified in Table 6.3.12-2 of SMC-S-016 following acceptance proof pressure test, duration sufficient to collect data. Minimum 2.0 times Maximum Expected Operating Pressure (MEOP)	1.5 times ground MEOP for Pressure Vessels and pressure components. Other metallic pressurized hardware items per References 4 and 5 from SMC-S-016	See Note 5
System-Level Pressure Leak Test [7]	REQUIRED	Not Required	Full Pressure System MEOP Leak Test per Section 4.1.5.1	Full Pressure System MEOP Leak Test per Section 4.1.5.1
Pressure Vessel Leak Test [7]	REQUIRED	Not Required	Pressure Vessel Level MEOP Leak Test per Section 4.1.4.2	Pressure Vessel Level MEOP Leak Test per Section 4.1.4.2

Notes:

1. Static load testing can be achieved through a sine-burst test. In some instances, either random vibration or sine vibration testing at the levels described in this table may surpass the static load factors. Please contact SpaceX for more information.
2. 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 (1) a mechanical battery isolation inhibit strategy verified in vibrational testing or (2) electromagnetic circuit and wiring emissions analysis. For Payloads with GPS receivers, verification by analysis may be achieved through demonstration of self-compatibility with on-board GPS navigation systems.
3. EMISM (6 dB by test, 12 dB by analysis) is already included in Table 3-10.
4. 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.
5. Pressure Systems cannot be protoqualified at the Payload level. Pressure Systems must therefore be qualified via the fleet qualification approach at the component level. Supplier qualification testing is acceptable in place of fleet level qualification testing if approved by SpaceX. Reference Section 4.1.4 and Section 4.1.5 for additional information.
6. For all Non United States Department of Transportation (US DOT) rated Pressure Vessels, please contact SpaceX for detailed qualification and testing requirements (reference Section 4.1.4).
7. Pressure Systems that do not meet material compatibility requirements specified in Section 4.1.5.2 must contact SpaceX for specific leak testing requirements.
8. Shock Test can be achieved as 3 activations of the separation system while attached to the payload, along with component shock qualification testing based on specified environment at launch vehicle interface levels. Shock attenuation based on current industry standard practice from launch vehicle interface to components is accepted and encouraged.
9. SpaceX designs its first stage to be reusable. This results in the Falcon 9 second stage having a proportionally more aggressive ascent, which leads to some second-stage, engine-driven high frequency vibration. While some launch vehicle environments are acoustic driven for frequencies >100 Hz for all but the smallest payloads, for Falcon 9 this is not representative, due to the above point. In order to make sure that the Payload is fully accounting for the flight vibration environment and its possible effect on the Payload, SpaceX requires an evaluation of the Falcon 9 random vibration environment. Random vibration shaker testing is often aggressive when it comes to larger spacecraft. Therefore, SpaceX allows spacecraft to be tested to only the acoustic test, provided an evaluation shows that the acoustic test is sufficiently enveloping of random vibration levels for main spacecraft responses.

4 PAYLOAD DESIGN AND INTERFACES

4.1 PAYLOAD DESIGN REQUIREMENTS

4.1.1 DESIGN FACTORS OF SAFETY

Typical factor of safety for lifting hardware is 3.0, but this may be reduced or increased based on the criticality of the lift and material ductility. Consult AFSPCMAN 91-710 Vol 3 for detailed requirements. Payload systems and structural components should hold a minimum design factor of safety of 1.25 for all combined loads seen in flight.

4.1.2 FASTENERS

Any fasteners used on the Payload primary structure or used to hold external components onto the Payload that are removed after acceptance testing must meet the following requirements:

- Fasteners have a diameter of .190 in. (#10 size, metric: 5 mm) or larger.
- Fasteners have a form of retention that is not reliant on preload to function (e.g., prevailing torque feature like distorted thread locking nut or patched fastener, lock wire/lock cable, cotter pin, thread locker with proper application process check, etc.)
- Fasteners are 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.)
- Fasteners have a minimum acceptable thread protrusion beyond the end of a nut or nut plate of one thread pitch width. This will ensure that all of the fully formed threads on the fastener can carry load and that the prevailing torque feature (if present) is engaged properly.

4.1.3 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. Please contact SpaceX for recommended part numbers.

4.1.4 PRESSURE VESSELS

A Pressure Vessel is any system containing more than 20,000 J of stored energy (pneumatic and chemical energy) or a MEOP greater than 100 PsiD (6.9 barD). Systems that contain pressure but do not meet the above are considered "pressure components" or "Pressure Systems".

Pressure Vessel classification and use:

- Type 1: All metallic. Conforms to AIAA-S-080 (current approved release).
- Type 2: Metallic liner with composite hoop. Conforms to AIAA-S-081 (current approved release).
- Type 3: Metallic liner with full, wound composite overwrap. Conforms to AIAA-S-081 (current approved release).
- Type 4: Non-metallic liner with full, wound composite overwrap. Conform to applicable sections of AIAA-S-081 until such a time as AIAA G-082 is fully released.
    - Use is not recommended.
    - Some restrictions on fluid eligibility apply. See 4.1.4.1.
- Type 5: All-Composite Pressure Vessels (liner-less)
    - Use is not recommended.
    - Some restrictions on fluid eligibility apply. See 4.1.4.1.

4.1.4.1 RESTRICTIONS ON PRESSURE VESSEL FLUID USAGE

All hypergolic propellants are ineligible for use in Type 4 and Type 5 Pressure Vessels. Contact SpaceX for more information.

4.1.4.2 PRESSURE VESSEL LEVEL LEAK TEST

Each individual Pressure Vessel must undergo leak testing to demonstrate a maximum leak rate of 10^{-6} sccs at MEOP.

For Pressure Vessels that meet material compatibility requirements stated in Section 4.1.5.2, leak testing can be validated using the following method. Documentation must be submitted to SpaceX in order to evaluate conformance. All non-conforming material compatibility Pressure Vessels must contact their SpaceX representative for special leak test requirements.

1. Fully submerge Pressure Vessel in water
2. Pressurize to MEOP
3. Test Fluid: Helium or 90% Nitrogen/10% Helium mix
4. Minimum Time duration: 1 hour
5. Deliverables:
    - Continuous video of full water surface
    - Close-up video of each fitting and connection individually
    - Close-up video of pressure gauge (or data trace)
6. Success Criteria: No bubbles

Pressure Vessel tests must take proper precautions to ensure safety.

4.1.4.3 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.

Verification for US DOT Pressure Vessels:

- A certificate of conformance from vendor stating vessel maximum design pressure (MDP), including any special permits on the bottle design from vendor.
- A visual of the bottle including the mounting, demonstrating a mounting scheme that does not induce significant loading into the bottle (i.e., bottle is not a primary load path for anything besides the bottle itself).

4.1.4.4 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, 5 pressurized-structure tanks (reference Section 4.1.4) are allowed 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 are allowed.
- Pressurization state of the tank must not change between the time that the Payload is mated to LV hardware and deployment from the Launch Vehicle, as part of the overall Payload inhibit strategy.
- Qualification must include all testing per applicable AIAA document listed in Section 4.1.4 based on Pressure Vessel type, and AFSPC 91-710 Section 12.
- Pressure Vessels must have a contingency pressure-relief valve to vent pressure above personnel safe MEOP while in ground operations.
- Pressure Vessels must hold burst factors of safety on pressure, per applicable AIAA document listed in Section 4.1.4, based on Pressure Vessel type; not below factors defined in Section 3.4.5 or overall design factors of safety defined in Section 4.1.1 on all combined loading cases. Pressure Vessels that carry significant loads beyond pressure (pressurized-structure tanks, secondary structure mounts) must include combined loading in qualification testing and demonstrate testing to the combined factors of safety defined in Section 4.1.1.

4.1.4.4.1 VERIFICATION FOR NON-US DOT VESSELS THAT MEET THE 15% RULE

Customers must provide the following:

- Pressure Vessel qualification testing including: burst, cycle testing, residual Pressure Vessel strength after cycle testing, and vibration testing.
- Acceptance testing strategy and per-vessel proof test.
- Combined structural loading analysis in SpaceX template for flight, including all loading and material assumptions, demonstrating that less than 15% of maximum flight stress is from mounting/external loads (to demonstrate that pressure-only testing is sufficient on the Pressure Vessel).
- Document detailing test-like-you-fly deviations between test and flight, including rationale for acceptance.

4.1.4.4.2 VERIFICATION FOR NON-US DOT VESSELS THAT DO NOT MEET THE 15% RULE

Customers must provide the following:

- Either: (Preferred) Static and random vibration qualification of the Pressure Vessel while pressurized to 1.25 times flight MEOP in flight-like mounting OR: analysis report demonstrating complete flight stress coverage between unpressurized vibration/static testing and pressure-only (burst) testing.
- Pressure Vessel qualification testing including: burst, cycle testing, residual vessel strength after pressure, and structural cycle testing.
- Acceptance testing strategy and per-vessel proof test.
- Document detailing test-like-you-fly deviations between test and flight, including rationale for acceptance.

4.1.5 FULLY INTEGRATED PRESSURE SYSTEMS

A "Pressure System" is any system that is intended to be pressurized beyond 0.5 atmospheres. This includes both Pressure Vessels and pressure components such as valves, fittings, and tubes that have potential to see internal pressure in the time between Customer delivery to the Launch Site and on-orbit deployment. For all pressurized systems, the following information must be provided to SpaceX:

1. Document detailing system design criteria, MEOP derivation for flight, 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. List of all single-point failures in the system.
4. Qualification and acceptance testing for each component of the Pressure System, and the overall system qualification strategy.
5. Document detailing combined system test-like-you-fly deviations between test and flight including rationale.

4.1.5.1 LEAK TEST REQUIREMENT: FULLY INTEGRATED PRESSURE SYSTEM LEVEL

The fully integrated Pressure System must be leak tested demonstrating a maximum leak rate of 10^{-4} sccs at MEOP. For Pressure Vessels that meet material compatibility requirements stated in Section 4.1.5.2, leak testing can be validated using the method below. Documentation must be submitted to SpaceX in order to evaluate conformance. All non-conforming material compatibility Pressure Vessels must contact their SpaceX representative for special leak test requirements. Pressure System tests must take proper precautions to ensure safety.

1. Pressurize fully integrated system to MEOP
2. Test Fluid: Helium or 90% Nitrogen/10% Helium mix
3. Coat all fittings/connections with Snoop (ask SpaceX representative to verify acceptable equivalents)
4. Deliverables:
   - Close up video of each fitting and connection individually
   - Close up video of pressure gauge (or data trace)
5. Success Criteria: No bubbles

4.1.5.2 MATERIAL COMPATIBILITY ASSESSMENT

All Customers must provide a comprehensive list of Pressure System materials for a compatibility assessment.

The list must include:

1. All Pressure System materials within the Pressure Vessel, and all other pressurized components
2. All working fluids, processing fluids, and expected/potential by-product fluids

Accepted material compatibility are per the following industry accepted design guide:

- "Material Compatibility with Space Storable Propellant. Design Guidebook," P.E. Uney, et al, Martin Marietta Corporation. March 1972.

Any material combinations that are outside of this specification require SpaceX approval and may require modifications to testing as stated herein.

4.2 MECHANICAL INTERFACES

For Customers with 937-mm or 1194-mm or 1666-mm (36.89-in. or 47.01-in. or 65.59-in.) clampband interface requirements, 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 has experience integrating numerous commercially available and internally developed adapters and separation systems.

4.2.1 AVAILABLE VOLUME

The Payload must be no larger than the available volume defined in the following section. Customers may request small dimension changes to this volume and SpaceX will reasonably consider whether the Launch Services can support such changes with minimal additional work or risks to the mission.

The Cake Topper Payload keep-in volume is shown in Figure 4-1. A CAD model of the payload volume is available upon request. Additional volume may also be available if required; please contact SpaceX for details.

Figure 4-1: Cake Topper Payload Keep-In Volume

4.3 ELECTRICAL INTERFACES

Falcon vehicles provide electrical connectivity between the Payload and Customer-provided Electrical Ground Support Equipment (EGSE) prior to launch, as well as in-flight separation device command and separation monitoring. Falcon launch vehicles do not provide either payload command or interleaved telemetry access during flight. Table 4-1 summarizes the standard electrical offering for Cake Topper Payloads.

Table 4-1: Electrical Interface Summary

Signal Type	Standard Offering
Ground-side Umbilical	2x 61-pin connectors
Separation command	4 redundant signals
LV-side breakwire	8 channels

4.3.1 ELECTRICAL CONNECTORS

As a standard service, Falcon launch vehicles provide up to two in-flight disconnect electrical interface points located at the payload separation plane. MIL-C-81703 connectors are strongly recommended to encourage schedule compatibility. A list of example in-flight disconnect connectors is shown below in Table 4-2. Falcon is compatible with many connectors outside of this list. Please contact SpaceX if you have questions regarding use of a specific connector.

Table 4-2: Example In-Flight Disconnect Connectors

Part Number (Payload-side)	Part Number (LV-side)	Number of Electrical Contacts
DBAS-70-61-0SN	DBAS-79-61G-0PN	61
DBAS-70-61-0SY	DBAS-79-61G-0PY	61
DBAS-70-37-0SN	DBAS-79G-37G-0PN	37
DBAS-70-37-0SY	DBAS-79G-37G-0PY	37

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

4.3.2 UMBILICAL CONNECTIVITY DURING PAYLOAD PROCESSING AND ON LAUNCH PAD

The Falcon systems accommodate electrical connectivity between Customer EGSE and the payload during most processing and integration activities. Table 4-3 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, LV integration, and rollout operations. However, between these steps the Customer will be able to interface with the Payload. Customers may supply separate EGSE for the PPF and pad operations, or may relocate EGSE from the PPF to the pad.

Table 4-3: Payload Electrical Interface Connectivity

Phase	Interface Connection
In PPF (payload processing)	Customer cables directly to payload
In PPF (adapter mate and encapsulation)	None – SpaceX is connecting the payload to the flight adapter harness; SpaceX will provide payload to PAF connection cables
In PPF (encapsulated)	Customer cables to PPF junction box adapter cable.
Transport to hangar	None – mobile
In hangar (pre-integration)	Customer cables to hangar junction box
In hangar (LV integration)	None – SpaceX is connecting the flight adapter harness to the second-stage flight harness
In hangar (on transporter-erector)	Customer cables to hangar junction box (J-box) adapter cable
Rollout	None – mobile
On pad (horizontal and vertical)	Customer cables to pad junction box (J-box) adapter cable
Flight	None – separation indication only

Pad EGSE provided by the Customer will be housed in an instrument bay beneath the launch pad deck. 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 LV 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 Rideshare hardware stack region and to the spacecraft separation plane.

The total cable lengths between the Payload EGSE and the spacecraft separation plane are listed in Table 4-4 and shown in Figure 4-2.

Table 4-4: Maximum Expected Cable Lengths between Payload Racks/EGSE and the Separation Plane

Launch Site	PPF	Hangar	Launch Pad
VSFB (SLC-4)	37 m (120 ft)	208.5 m (684 ft)	171.9 m (564 ft)
CCSFS (SLC-40)	24.5 m (80 ft)	197.8 m (649 ft)	171.9 m (564 ft)
KSC (LC-39A)	24.5 m (80 ft)	181.1 m (594 ft)	196.3 m (644 ft)

The minimum one-way resistance from EGSE to separation plane is 5 ohms.

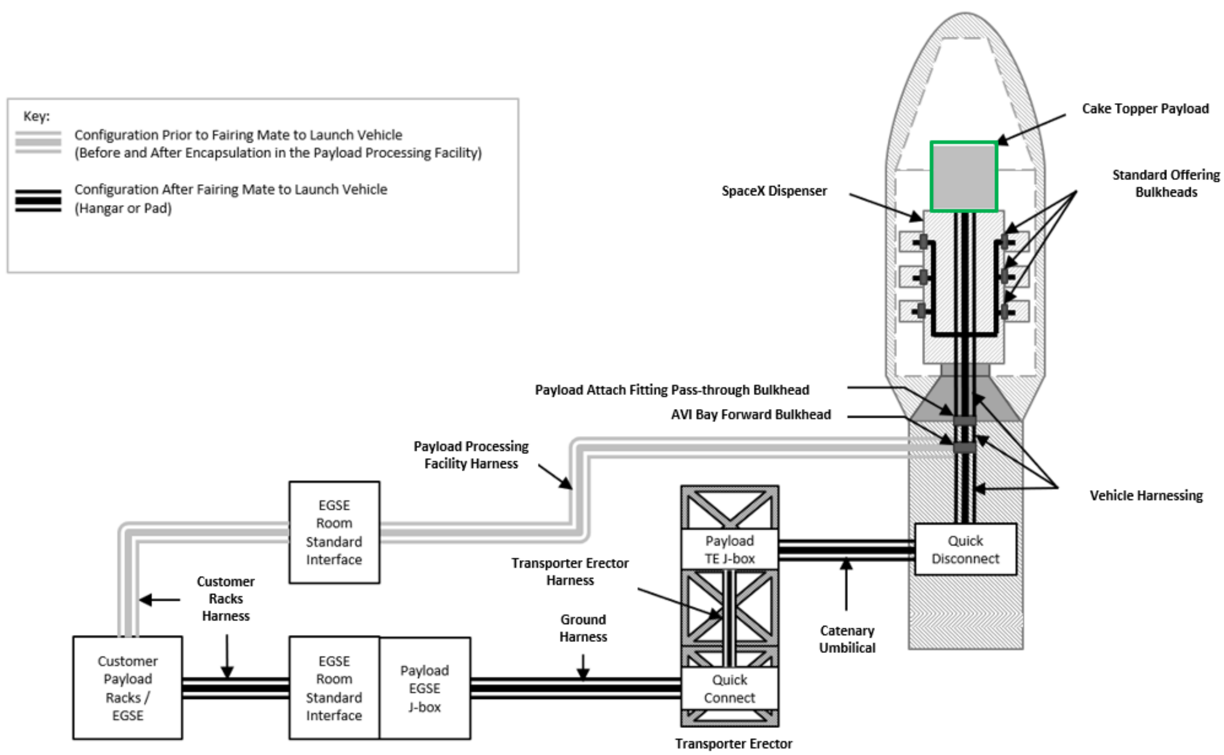


Figure 4-2: On-Pad Electrical Interfaces

4.3.3 FALCON-TO-PAYLOAD COMMAND INTERFACE

Separation device commands are used to initiate spacecraft separation from the second stage. Falcon LVs can provide up to 4 redundant separation device commands. Additional separation device command requests can be accommodated as a nonstandard service; please contact SpaceX for details.

Separation devices are typically procured by SpaceX for the Cake-Topper interface. For Customer-supplied separation devices, the following requirements apply.

4.3.3.1 CUSTOMER-SUPPLIED SEPARATION DEVICES (IF APPLICABLE)

(Only if applicable): For deployment/separation devices directly interfacing with LV electrical systems, these 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 LV 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 LV will be commanded by SpaceX. The use of Customer-provided sequencers for commanding more than one deployment from the LV within the Payload is prohibited. Each deployment command sent by the LV 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 specified 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 between 24–36 V with a maximum current draw of 6 A.

Specifics of the pulse duration will be specified 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. The deployment device timing delay from receipt of the LV deployment signal to physical release of the Payload is required to be characterized as < 2 seconds ± 0.5 second uncertainty.

4.3.4 BREAKWIRE INTERFACE

Breakwire channels are used to determine separation status of the Payload from the LV. Breakwires are organized into two categories: "PL-side breakwires", which are used by the LV to detect separation, and "LV-side breakwires", which are used by the Payload to detect separation. This is illustrated in Figure 4-3.

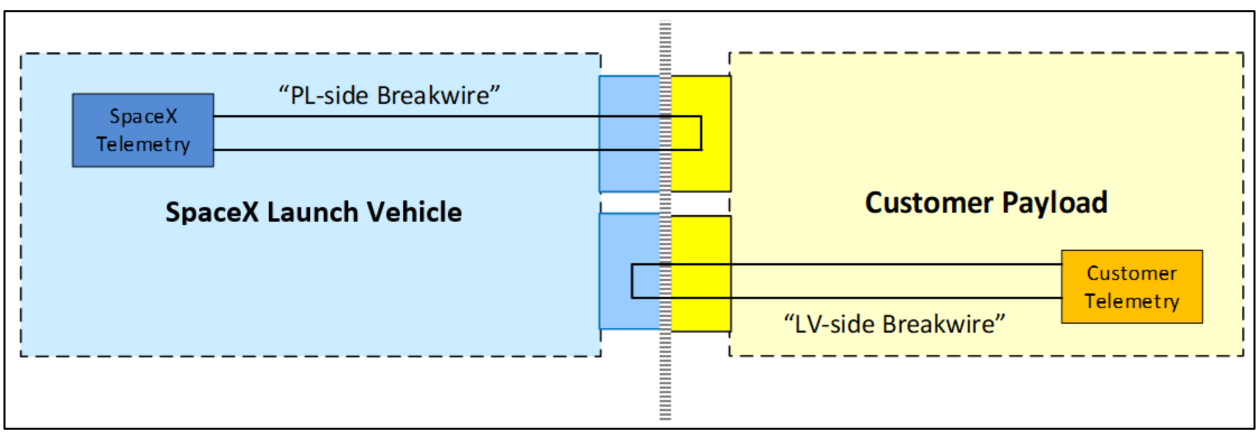


Figure 4-3: Illustration of Breakwire Channel Categories

A minimum of 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 4-5 defines the required properties of each state.

Table 4-5: 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 captured as part of the Payload-specific ICD.

The Falcon vehicle provides up to 8 PL-side breakwire channels for the Cake Topper region. Additional breakwire channels can be accommodated as a nonstandard service; please contact SpaceX for details. Customer may request any number of LV-side breakwire loops at a separation connector.

4.3.5 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.

4.4 INTERFACE COMPATIBILITY VERIFICATION REQUIREMENTS

SpaceX requires that Customers verify the compatibility of their systems with the Falcon mechanical and electrical 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. 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 MISSION INTEGRATION AND SERVICES

5.1 STANDARD SERVICES

As part of any Cake Topper Launch Service, SpaceX will:

- Provide personnel, services, hardware, equipment, documentation, analyses, and facilities to support mission planning, LV 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 Payload insurance at all times).
- Provide all Range Safety documents for the Customer to complete (per AFSPCMAN 91-710 and 14 CFR Part 400).
- Facilitate the Range Safety and integration process.
- Provide up to three sets of 37- or 61-pin satellite-to-launch vehicle in-flight disconnect electrical connectors, or integrate Customer-provided mission-unique connectors.
- Provide a 1575-mm bolted interface compatible with the 62.01-in. diameter Medium Payload Class mechanical interface defined in the EELV Standard Interface Specification, or a 2624-mm bolted interface as defined in section 5.1.1.
- Provide one 937-mm or 1194-mm or 1666-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.
- Provide an adapter and technical support for a mechanical interface compatibility verification test at a facility of the Customer's choosing.
- Provide transportation for the Customer's Payload container and all ground support equipment (GSE) from the Launch Site landing location 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 LV.
- Process the LV, 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 countdown dress rehearsal for Customer launch team members, supported by SpaceX mission management.
- Launch the Payload into the specified orbit within the specified environmental constraints.
- Perform 3-axis attitude control or spin-stabilized Payload separation.
- Perform a collision avoidance maneuver (as required).
- Verify Payload separation from the LV and provide an orbit injection report (OPM) as detailed in Appendix E: Delivery Format of Separation State Vector).

5.2 PROGRAM MANAGEMENT

5.2.1 LICENSING

Each Party is responsible for obtaining all Licenses to carry out its obligations under the Agreement and/or SOW. Failure to obtain a spacecraft on-orbit License or provide inputs for SpaceX's Launch License contributing to Launch delays is considered a Customer delay.

5.2.2 WEBCAST LOGO

Cake Topper Payloads may submit a logo and brief summary (typically around one-half of a page, summarized in bullet points) of the spacecraft mission for the SpaceX Launch webcast. A short video from the Customer is also acceptable, subject to SpaceX approval; please contact SpaceX for video requirements.

5.2.3 MISSION MANAGER

A mission manager is appointed by SpaceX to serve as the sole point of contact between SpaceX and the Customer. The SpaceX mission manager is responsible for all matters relating to the Agreement and SOW, including the assignment and availability of personnel, equipment, resources, and facilities necessary for the performance of the Launch Services.

The SpaceX mission manager:

- Functions as day-to-day SpaceX point of contact between SpaceX and the Customer.
- Coordinates efforts for meeting program milestones, technical requirements, and schedules.
- Confirms that LV production and testing activities are accomplished successfully.
- Coordinates LV integration functions to facilitate proper development of requirements and interfaces between SpaceX and the Customer throughout the integration process and launch campaign.
- Conducts programmatic and technical interchange meetings with Customer personnel, as applicable.

5.2.4 INTERFACE CONTROL DOCUMENT (ICD)

SpaceX creates and maintains the ICD in conjunction with Customer inputs. The ICD is negotiated in good faith between the Parties and, at a minimum, defines physical interfaces (mechanical and electrical), functional requirements (orbit, attitude, etc.), Payload MPEs, and Launch operations requirements. Following signature by SpaceX and the Customer, the ICD takes precedence (in the event of a conflict) over the SOW and any Payload interface requirements document. Prior to signature, the ICD is maintained in draft form. In accordance with the deliverables timeline in the SOW, SpaceX will deliver a draft ICD following the completion of the Initial Mission Integration Analyses milestone. Once delivered, the Parties will work in good faith to make required updates and promptly sign the ICD.

6 LAUNCH SITE FACILITIES

SpaceX operates Launch Sites at:

- Space Launch Complex 40 (SLC-40) at Cape Canaveral Space Force Station (CCSFS), Florida
- Launch Complex 39A (LC-39A) at John F. Kennedy Space Center (KSC), Florida
- Space Launch Complex 4 East (SLC-4E) at Vandenberg Space Force Base (VSFB), California

Details about these Launch Sites can be found in the SpaceX Falcon User's Guide, latest revision, available at www.spacex.com/vehicles/falcon-9/.

SpaceX will provide the Launch Site facilities, equipment, documentation, and procedures to receive Customer hardware, validate interfaces to Customer hardware, integrate the Payload with the LV, and perform a Launch of the Payload.

Customers should prepare to launch from both the Florida and California locations, as a Launch Site is not typically chosen until approximately L-4 months, and may be subject to change.

6.1 FACILITY ACCESS AND WORKING HOURS

SpaceX supports Customer personnel access to Launch Site facilities for two 8-hour working shifts per day, during those portions of the Launch Campaign when Customer's activities require use of a given facility.

SpaceX additionally supports 24 hours per day, 7 days per week (24/7) access to Launch Site facilities on an as-needed basis for Customer's scheduled activities throughout the campaign, provided such access is coordinated in advance and mutually agreed with SpaceX. SpaceX supports 24/7 access to Launch Site facilities for responding to emergency or off-nominal situations related to flight hardware.

During the Launch Campaign, SpaceX may provide short-term, controlled facility access to SpaceX personnel, SpaceX's contractors, or other third parties (e.g., other Customers, potential Customers, VIPs, SpaceX-hosted tours). SpaceX is not required to provide Customer advance notice for short-term, controlled access to areas free of Payload or Customer hardware. SpaceX will provide prior notice and request approval for physical or visual access to areas with Payload or Customer hardware. At all times, SpaceX will follow Customer proprietary information and security requirements; however, visual access to Co-Payloads is expected after mating to LV hardware.

6.2 CUSTOMER OFFICES

SpaceX provides an office area at the Launch Site during Payload processing. The office area could be shared with Co-Payload Customer(s) and could be located at the PPF or a nearby SpaceX facility. Office accommodations include 100-Mbps-class Internet connection, which may be common with other Customer Internet connections; air conditioning; and standard office equipment such as desks, chairs, and phones.

6.3 SPACEX PAYLOAD PROCESSING FACILITY (PPF)

SpaceX provides a PPF at the Launch Site for the Customer to perform Payload pre-Launch processing activities. Payload and Co-Payload(s) may be co-located in the processing area. The processing area will be defined in a mission-specific Launch Campaign Plan based on Payload and Co-Payload(s) space requirements. The Payload processing area will:

- Operate at ISO 14644-1 Class 8 (Class 100,000) cleanliness.
- Operate at 70 °F ± 5 °F air temperature (21 °C ± 3 °C).
- Operate at 45% ± 15% relative humidity.
- Include 30-ton capacity crane with 59 ft (18 m) hook height.
- Provide minimum floor dimensions of 30 ft x 20 ft (9 m x 6 m) for Payload processing activities.

The PPF includes an area for Payload EGSE adjacent to the Payload processing area. A 100-Mbps-class Internet connection is provided, which may be common with other Customer internet connections.

6.3.1 CLEANROOM

PPF Office spaces and EGSE rooms, and garment changing rooms are shared with Co-Payload Customers. Specific network/ethernet, power, and space requirements are detailed in the ICD. SpaceX provides a spacecraft processing area inside of the cleanroom of 9 m x 6 m. This area is sectioned off with standard-height welding screens in the PPF. Note that larger spacecraft may be visible above the screen height.

Customers are required to stay within their zones or the shared spaces of the PPF; however, physical locks in these areas are not standard. Customers may provide security teams, but must coordinate and obtain approval by SpaceX and cannot interfere with other Customer or SpaceX operations.

A Uninterrupted Power Supply (UPS) is available as an electrical power backup in all cleanrooms, as a standard facility service.

Hazardous operations must declare a clear-zone in the Range Safety documentation, and Customers must coordinate these operations with SpaceX mission management.

6.3.2 STORAGE

Unconditioned (outdoor) equipment storage is available outside the PPF.

Conditioned storage within the PPF is limited, and must be coordinated by the Launch Campaign Readiness Review at L-2 months.

Propellant conditioned storage inside of the PPF or PPF airlock is available starting up to 5 days before fueling activities, through completion of fueling activities. Hazardous fueling zones are defined in the facility user guides.

6.3.3 EQUIPMENT

PPF facility cranes, forklifts, and boom lifts are shared with Co-Payload Customers. Cake Topper Customers will get initial schedule priority, as declared in the hourly processing schedule; however, if delays occur, Co-Payload Customers on schedule will receive subsequent priority, and mission management will deconflict any further scheduling overlaps.

The Customer is responsible for providing all personal protective equipment, such as hard hats, goggles, gloves, fall protection harnesses, and grounding straps, for Customer personnel and Customer's Related Third Parties at the Launch Site, with the exception of the SCAPE materials identified in Section 6.4.1.

6.4 HAZARDOUS PROCESSING FACILITY AND ASSOCIATED SUPPORT

SpaceX provides unconditioned storage of Payload propellants at the Launch Site from arrival of Payload propellant (up to 30 days ahead of the start of Launch Campaign) through the start of Payload fueling, which may be at a non-SpaceX location. The unconditioned storage temperature is not regulated and propellants may be stored outside with partial sun exposure. Customers must arrange for pickup of unused propellants no later than 90 days after the Launch.

SpaceX provides for temporary conditioned storage of Payload propellants beginning several days prior to the start of Payload fueling through completion of fueling activities, as allowable by Range Safety and SpaceX safety regulations. When in use, the conditioned storage temperature is maintained within ± 5°F (± 3°C) of the average Payload fueling area temperature.

SpaceX transports the Payload propellants from unconditioned storage to a conditioned storage area prior to Payload fueling operations.

SpaceX provides access to a hazardous processing facility (HPF) for Payload fueling operations. The HPF is a sub-section of the PPF:

- Provides minimum floor dimensions of 30 ft x 20 ft.
- Operates at ISO 14644-1 Class 8 (Class 100,000) cleanliness.
- Operates at 70°F ± 5°F air temperature (21°C ± 3°C).

- Operates at 45% ± 15% relative humidity.
- Includes an exterior vent to accommodate propellant vapor in accordance with safety and environmental regulations.
- Includes a drain system to accommodate waste propellant and water in accordance with safety and environmental regulations.

6.4.1 SELF-CONTAINED ATMOPHERIC PROTECTIVE ENSEMBLE (SCAPE) OPERATIONS

Standard facility consumables are noted in the facility user guides. For hazardous fueling operations, SpaceX provides up to 600 gallons (2273 liters) of decontamination water, and up to 3 days (with two 4-hour shifts per day) of radio-equipped SCAPE suits and breathing air upon request. Customers must comply with NASA requirements for SCAPE training, and this training for personnel is coordinated by SpaceX.

Customer must arrange for and implement the disposal of hazardous waste generated during Payload processing activities, including during propellant loading and related activities, in accordance with Range Safety and facility regulations, with the exception of the decontamination water mentioned above.

6.5 LAUNCH COMPLEX

SpaceX provides a Launch Complex, including the Launch pad and related Launch Vehicle GSE. SpaceX provides conditioned air into the fairing, including environmental monitoring of the encapsulated Payload when at the Launch pad. In the event of a Launch Site power outage, conditioned air will be resumed on backup power systems within 10 minutes.

6.5.1 LAUNCH COUNTDOWN MONITORING

SpaceX may provide Customer personnel (determined on an as-needed basis) a space at the Launch Site for Launch countdown monitoring. Space will be shared between Payload and Co-Payload Customer(s), as documented in the mission-specific Launch Campaign Plan.

6.5.2 CUSTOMER CONTROL ROOM

SpaceX provides a control room at the Launch Site for use by Customer and Customer's Related Third Party personnel, determined on an as-needed basis. The control room may be shared between Payload Customer and other Co-Payload Customers.

The control room includes the mission-specific electrical interfaces as defined in the ICD, for Customer-provided EGSE for Payload monitoring and control activities on the day of Launch. Customer EGSE is limited in size to 1 m x 0.5 m x 1.5 m, unless otherwise mutually agreed and documented in the ICD.

SpaceX provides 2 payload-specific voice nets and 1 console for the Customer to view a limited subset of Launch Vehicle parameters during rehearsal and launch operations, consistent with US export control laws.

6.6 SECURITY

SpaceX provides security via a combination of locked facilities (security card access or cipher locks), closed-circuit video monitoring, and/or personnel presence 24 hours/day at the relevant Launch Site facilities when Customer flight hardware is present. During any hazardous operations for which the Range Safety authority requires non-essential personnel to evacuate, video monitoring will be the sole method of surveillance available. Customers will not be granted access to SpaceX's video footage due to proprietary and restrictions under US export control laws.

7 LAUNCH CAMPAIGN

7.1 SCHEDULING AND COORDINATION

SpaceX will prepare for and perform a Launch of the Payload. Starting upon Payload arrival at the Launch Site and throughout the Launch Campaign, the SpaceX mission manager provides the Customer a daily updated Launch Campaign schedule (including key milestones and joint operations), relevant Launch Range safety status and information, and LV integration status.

SpaceX maintains PPF management and scheduling responsibilities throughout the Payload processing and encapsulation phase. As facility manager, SpaceX will require some oversight of Payload activities.

SpaceX provides training for Customer personnel regarding the PPF (cranes, warning lights, etc.) and applicable Launch Range/facility safety and security procedures. Training will be provided in advance of spacecraft arrival and offloading or, for pre-coordinated groups, upon arrival at the Launch Site.

SpaceX supports and schedules the Range Safety-related operations conducted at the PPF.

The Customer will coordinate activities with SpaceX to create an integrated schedule and procedures. Where necessary, SpaceX coordinates with Range Safety directly on system safety, scheduling, meteorology, hazardous operations, usage of spacecraft, and GSE consumables.

7.2 LAUNCH CAMPAIGN DURATION

SpaceX provides Customer personnel access to the Launch Site facilities identified in Section 6 beginning a maximum of 15 calendar days prior to the start of combined operations and extending until 3 calendar days after Launch (for the purpose of GSE packing and shipment). The 7 days prior to Launch are reserved for combined operations, and the 15 days before the start of combined operations are for Customer's hardware preparation activities.

7.3 LAUNCH VEHICLE ELECTRICAL CONNECTIVITY AT LAUNCH PAD

If coordinated in advance, SpaceX can provide the Customer up to 8 hours with the LV electrically mated to the Launch pad, for final electrical Payload Launch preparations via the umbilical link (see Section 0).

7.4 PAYLOAD INTEGRATION

SpaceX leads the operations to physically integrate the Payload with the LV, and any operations after the Payload to LV mate. Payload-unique GSE is provided by the Customer, and SpaceX provides the standard encapsulation equipment and GSE to transport the encapsulated hardware stack to the Launch Complex.

7.5 CUSTOMS, VISAS, AND LICENSING

The Customer is responsible for obtaining any required permits, Licenses, or clearances for hardware import or export, as well as visas for non-US personnel, including Customer's Related Third Parties and guests. SpaceX can provide letters of invitation for Customer Launch Campaign personnel to support the issuance of US entry visas by the US Department of State.

The Customer is responsible for obtaining customs clearance of Customer's hardware and consumables, including the Payload.

7.6 TRANSPORTATION SERVICES

7.6.1 HARDWARE TRANSPORT

If the Customer ships via aircraft transport, the Customer delivers the Payload and GSE to the Launch Site airport designated by SpaceX, and SpaceX will transport the container from the launch site airport to the PPF. If Customer ships via road or sea transport, the Customer delivers the Payload and associated GSE to the PPF or other Launch Site facility designated by SpaceX. The Customer is responsible for environmental control of the Payload during Payload delivery, until the Payload is removed from its shipping container, including generators and fuel to maintain environmental control.

The Customer may also choose to ship the payload and GSE by ground directly to the PPF, or to the Launch Site airport designated by SpaceX, where SpaceX will then transport the Payload and GSE to the PPF. The Customer is responsible for all transportation to/from the Launch Site when shipping by sea or arriving at an airport not located at the Launch Site. Transport within SpaceX facilities, including safety and security coordination with the Launch Range, is arranged by SpaceX. The Customer must arrange and execute the shipment of the Payload shipping container and all Customer-furnished GSE from the Launch Site no later than 3 days after Launch.

The Customer can deliver propellants to the Launch Site no more than 30 days before Launch and must remove any unused propellant from the Launch Site no more than 90 days after Launch.

7.6.2 PERSONNEL TRANSPORT ON BASE

SpaceX provides transportation for the Customer's non-US personnel between the Launch Site entrance and SpaceX facilities, and between SpaceX facilities, on a reasonable schedule. US government regulations require that non-US personnel and US personnel representing non-US entities must be escorted while on a US government Launch Site.

7.7 PHOTOGRAPHY

Upon Customer request, SpaceX can provide still photography services during selected Payload processing, testing, and integration operations. This service does not include delivery or broadcast of photography in real-time or near-real-time. The Customer may use still photography that does not include video or sound. No phones or tablets are permitted in the cleanroom, and laptop cameras and microphones must be covered/off. Live meetings, including audio streaming, are not permitted in the cleanroom. All photos are subject to SpaceX review prior to leaving the facility, and may not include other Customer or SpaceX hardware or personnel.

All media intended for release is subject to Range Safety security procedures, US export control laws, and where applicable, the prior written approval of the US Government. Media that includes images of SpaceX hardware or facilities is also subject to SpaceX's prior written approval for release.

7.8 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, the Customer will cooperate with SpaceX, any insurers, and federal, state, and local government agencies in their respective investigations of the event. 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. The Customer and Customer's Related Third Parties may not make any public comment, announcement, or other disclosure regarding such event without SpaceX's review and approval.

7.9 PAYLOAD LICENSING AND REGISTRATION

The Customer will flow down its responsibilities relating to Payload licensing and registration under the Agreement (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. Customer will provide a letter in a format dictated by SpaceX, certifying that Customer has obtained all required Licenses and that all Payload information provided to SpaceX and/or any licensing agencies is complete and accurate.

7.10 COORDINATION WITH SPACE SITUATIONAL AWARENESS AGENCIES

The Customer is responsible for registering all deployed objects with the 18th Space Control Squadron (SPCS) to assist with the tracking and identification of all deployed objects. More 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.

To further aid in US Space Force satellite tracking, identification, cataloging, and collision avoidance screening, SpaceX strongly recommends Customers publish forward-predicted satellite ephemerides and covariance to https://www.space-track.org as quickly as possible post-Launch. If the Customer is unable to generate propagated ephemeris and covariance, SpaceX strongly recommends they work with a commercial provider (SpaceX can provide recommendations) to contract for this work. Publishing predicted ephemerides and covariance drastically improves and accelerates the cataloging process by the United States Space Command (USSPACECOM), as well as enhancing collision-avoidance screening. Furthermore, SpaceX 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.

APPENDIX A: DELIVERABLE DESCRIPTIONS

The deliverables described in this appendix correspond to SpaceX and Customer deliverables and corresponding due dates defined in Table 1 of the Payload contract's statement of work.

Table A-1: SpaceX Deliverables

Milestone	SpaceX Deliverables	Description
Agreement Signature	Signed Agreement	Copy of the Agreement signed by SpaceX.
	TAA questionnaire or Export Compliance Agreement template	Representations and certifications for Customer to complete for TAA application (if not already provided prior to Agreement signature) or Export Compliance Agreement between US parties and SpaceX.
	Payload questionnaire	Request for preliminary information on the Payload that SpaceX will use in support of early internal analyses and program deliverables.
Mission Integration Kickoff	Launch Range introduction	Introduction to the Launch Range, Launch Range processes, and how SpaceX/Customer/Launch Range will interface with each other during the campaign. Customer is also provided a copy of the safety regulations at the Launch Site.
	Payload Range Safety requirements	Summary of Range Safety submissions required for Rideshare Payloads.
	Range Safety submission document templates	Document templates for the Range Safety submission deliverables.
	Launch Site Facility User's Guide	User's Guides covering SpaceX Launch Site facilities for Vandenberg Space Force Base (VSFB) and Cape Canaveral Space Force Station (CCSFS).
	ICD template	Preliminary draft of the ICD containing placeholders for mission-specific requirements and other interface information to be developed and populated during the course of the launch campaign. The ICD defines the Mission requirements and interfaces between Customer and SpaceX systems.
	Dynamic model worksheet	A worksheet for the Customer to complete which serves as a companion document to accompany the Customer Payload dynamics model (reference Appendix B) delivery.
	Mass properties worksheet	A worksheet for the Customer to complete which describes the Payload mass properties, including its center of gravity, moments of inertia and products of inertia for the Payload, broken up into fly-away and stay-behind portions.
	Payload transmitter verification worksheet	A worksheet for Customer to use to verify Payload transmitter turn on times.
	Electrical interface pinout worksheet (AV2052)	A spreadsheet that describes the Launch Vehicle to Payload electrical harness properties and pin-outs.
	Payload EMI/EMC worksheet template (AV2054)	A spreadsheet template for the Customer to complete which describes the spacecraft radio frequency electromagnetic emissions and susceptibility.
	Payload environmental test approach worksheet	A worksheet for the Customer to complete which defines the test approach for the Payload including requested deviations to Section 3.4 and test schedule, which must be approved by SpaceX.
Completion of Initial Mission Integration Analyses	Initial trajectory analysis results	SpaceX will develop a nominal trajectory optimized for the Mission. This nominal trajectory will be used to determine the nominal injection state vector, develop the Launch Window (or assess the Customer provided Launch Window), and assess free molecular heating. This analysis also serves as an input to other SpaceX analyses such as Coupled Loads Analysis.
	Representative thermal attitude parameters	SpaceX will provide a file detailing the attitude information of a representative trajectory, as needed, for the Customer to perform a Payload thermal analysis.
	Contamination analysis results	SpaceX shall provide the Customer with a contamination analysis that shows compliance to a maximum particulate contamination level of 1% obscuration and maximum predicted organic contamination level of 4 mg/m2 onto any Payload surface, from the time period of encapsulation through collision avoidance maneuver. The presentation describes the inputs to these maximum levels and historical capabilities demonstrating compliance.
	Fairing air impingement analysis results	SpaceX provides a generic analysis that characterizes the maximum predicted air or GN2 impingement velocity on the exterior of the allowable fairing volume surfaces from the fairing air conditioning system.

Milestone	SpaceX Deliverables	Description
	Payload separation analysis results	Results of the separation analysis predicting the maximum linear and angular separation rates of the Payload upon separation from the Launch Vehicle.
	Spacecraft-to-LV Electrical interface details	Spreadsheet documenting the end-to-end pin-out of the Launch Vehicle umbilical, including electrical characteristics of each pin.
	Spacecraft-to-LV Mechanical interface details	Drawings (included in the ICD) capturing the mechanical interfaces of the Payload to the Launch Vehicle, including keep-out envelopes, relative clocking, electrical connectors, and fairing access door location(s).
	ICD - initial	Initial draft of the ICD to be reviewed by the Parties. Contains Mission requirements, interface information and mutually agreed TBDs for information to be populated prior to launch campaign.
Spacecraft to Payload Adapter Fit Check (if applicable)	Fit check plan jointly agreed with Customer	A document detailing the fit check operations, equipment, procedures and roles and responsibilities.
	Equipment packing list	A list of equipment which SpaceX will bring to the spacecraft facility in support of the fit check.
Launch Campaign Planning Kickoff	Launch campaign planning checklist (template)	Launch planning checklist template to track Launch campaign documentation, GSE shipment list, Customer personnel attendance, Payload details related to Launch Site operations, an OPM email distribution list, and Launch campaign action items.
	Launch campaign daily schedule (template)	Template for daily Launch Site activity planning for Customer to provide details such as stand-alone operations duration, SpaceX resource requirements, and hazardous operations.
	Licensing and insurance information template	A template for Customer to capture SpaceX licensing inputs such as hazardous materials and Customer crosswaiver inputs, as well as Payload insurer details, launch and in-orbit subrogation waiver accounting, and requests for additional parties to be included on SpaceX's third-party liability insurance policy.
	Payload and equipment delivery information	General information regarding the process and requirements for delivering the Payload and Customer GSE/EGSE to the Launch Site.
Launch Campaign Planning	Launch campaign planning checklist (preliminary)	Preliminary draft of Launch campaign planning checklist including preliminary Customer inputs.
	Launch integration schedule (preliminary)	Schedule of Launch Site operations identifying Payload stand-alone activities and combined Payload/Launch Vehicle operations for the Mission.
	Launch campaign plan (preliminary)	Plan for Payload integration and Launch, including the facilities to be used, Payload space allocation in those facilities, and the top-level operations to be performed for both Launch Vehicle and Payload processing.
Completion of Final Mission Integration Analyses	Predicted orbit injection report	Predicted state vector information, based on a nominal trajectory optimized for the Mission. This state vector will be provided in SpaceX-defined format (reference Appendix E).
	Coupled Loads Analysis (CLA) update (if applicable)	Updated coupled loads analysis results based on L-4 month mission configuration. Alternatively, SpaceX may provide confirmation that previously analyzed results are enveloping of final mission configuration.
	Payload clearance assessment results	Confirmation of positive clearance between Payload and Launch Vehicle hardware (or Co-Payloads) with worst case dynamic deflections. If necessary, identification of locations with minimal Payload to Launch Vehicle hardware (or Co-Payload) clearance, based on CAD modeling, will be provided.
	EMI/EMC analysis results	RF compatibility presented as described in Appendix E. Assesses whether the emissions and susceptibilities of the Payload, Launch Vehicle, and ground systems (including Co-Payloads during ground processing) are compatible with each other.
	ICD - update	Updated release of the ICD to be reviewed by the Parties and finalized for signature at Launch Campaign Readiness Review.
Trajectory Monte-Carlo Results	Trajectory analysis results, including monte carlo collision avoidance analysis and ascent telemetry coverage	SpaceX analyzes the Mission trajectory and delivers a chart-based presentation describing the analysis results. The presentation will include: a. A description of the tools used in the analysis b. The nominal flight timeline, profile, and ground track c. The free molecular heating environment at fairing jettison d. The predicted Launch Window, or assessment of the Launch Window (if Customer-provided) e. The Earth-Centered-Earth-Fixed (ECEF) Payload separation state vector f. Payload and Co-Payload(s) deploy timeline (provided at L-4 months)

Milestone	SpaceX Deliverables	Description
		g. Ascent telemetry coverage (provided at L-4 months) h. Orbit injection accuracy (Mission-unique Monte Carlo analysis results at L-2 months) i. A discussion of requirements compliance in all these areas SpaceX analyzes and implements a single Earth-referenced Launch trajectory, a single Earth-referenced ascent attitude profile, and a single Earth-referenced Payload separation attitude, which will be used for all dates and times throughout the Launch Period. SpaceX does not implement multiple trajectories for various dates/times within the Launch Period, and does not provide sun-referenced or inertially-referenced attitudes during ascent or for Payload separation. The trajectory will be analyzed using the maximum Payload mass, including worst-case Payload mass properties tolerances. SpaceX does not implement multiple trajectories for multiple masses and does not utilize nominal Payload mass in the analyses. SpaceX also performs an analysis to determine the need for a collision avoidance maneuver (CAM) following separation of all payloads. This analysis will characterize the relative separation distance between the second stage and the Payload and all Co-Payloads for one orbit after separation. The analysis will show that all combinations of any two bodies (Payload and all Co-Payloads and launch vehicle) result in long term growth in relative distance. This analysis will assume that no propulsive activities are executed by the Payload during the period analyzed. SpaceX does not perform additional analyses with respect to collision avoidance of potential debris or other space objects. SpaceX coordinates with applicable US regulatory authorities, such as the FAA and the North American Aerospace Defense Command (NORAD), to select a Launch Window that results in a sufficiently low risk of collision with another space object during the Mission.
Launch Campaign Readiness Review	Mission analysis updates, if applicable	Updated analyses performed by mutual agreement of the Parties (for example, revised trajectory results following a significant deviation of measured Payload mass properties from the predicted Payload mass properties, or revised CLA results following an exceedance of predicted Payload load limits after Payload testing). SpaceX does not provide analysis updates for minor changes to Customer models or inputs (for example, nominal reduction of Payload mass properties uncertainty due to Payload maturity).
	ICD revision for signature	Revision of the ICD signed by the Parties.
	ICD compliance matrix and status	Lists the ICD requirements and verification status/evidence in accordance with the approved verification matrix within the ICD.
	Launch integration schedule (update)	Approved schedule of Launch Site operations identifying Payload stand-alone activities and combined Payload/Launch Vehicle operations.
	Launch Campaign Plan (update)	Finalized plan for Payload arrival, integration and Launch, including the facilities to be used and the operations to be performed for both Launch Vehicle and Payload processing. The plan also defines SpaceX and Customer roles, communications, voice nets, mission constraints, and countdown steps.
	Launch Range readiness information	Confirmation that the Launch Range is prepared to receive the Payload and begin Launch Site activities.
Launch Campaign Kickoff	Launch Campaign Kickoff briefing	Briefing to the Customer providing information about working at the launch site, including contact information, security, SpaceX policies, transportation, medical, facility overview, hazardous operations and natural hazards (e.g. lightning), and personnel safety.
	Facility readiness letter	A letter to the Customer confirming that the payload processing facility is ready to receive the spacecraft.
Launch Campaign	Pre-arrival meeting (if arriving by air)	Briefing to the Customer providing information about spacecraft arrival timeline and operations ahead of the Payload aircraft offload.
	Electrical checkout results	Documents detailing the results of the SpaceX electrical checkouts performed on the harnessing which interfaces with the spacecraft.
	Facility environmental report	Reports of facility temperature, relative humidity and particle count are provided to the Customer point of contact.
	Daily launch campaign schedule	Daily updates to the Launch Campaign schedule as coordinated in real time with the Customer.
	Launch Vehicle readiness certificate	Signed confirmation from SpaceX to the Customer that the Launch Vehicle is ready for countdown and Launch.

Milestone	SpaceX Deliverables	Description
Insurance Mission Package	Insurance Mission Package	Slides provided to the Customer and their insurers including Mission Overview; Mission Timeline; Launch Vehicle Configuration; Significant Issues during Production, Test, and Launch Vehicle Integration; Significant Remove and Replace during Launch Campaign; Significant First Flight Items and Operations; Re-Flight Items; Other Items of Note; Responses to Written Questions from Underwriters; for Reused Boosters Only: "Life of the Booster".
Launch Readiness	Launch Vehicle Readiness Certificate	Signed confirmation from SpaceX to the Customer that the Launch Vehicle is ready for countdown and Launch, obtained after a Launch Readiness Review between SpaceX and the Range.
Launch	Orbit injection report	Provides operational state vector information, based on best available telemetry during the flight. This state vector will be provided in SpaceX-defined format (reference Appendix I); Customer is solely responsible for conversion, if necessary, of the data into a Customer-preferred format.

Table A-2: Customer Deliverables

Milestone	Customer Deliverables	Description
Agreement signature	Signed Agreement	Copy of the Agreement signed by Customer.
	Technical point(s) of contact	Identification for the Customer point of contact that will interface with the SpaceX mission manager.
Mission Integration Kickoff	Completed TAA questionnaire or Export Compliance Agreement (ECA)	Representations and certifications from Customer for Technical Assistance Agreement (TAA) application (if not already completed prior to the Kickoff) or signed Export Compliance Agreement.
	Completed Payload questionnaire	Preliminary information on the Payload provided by the Customer for SpaceX use in support of early internal analyses and program deliverables.
	Payload drawings and CAD models	Preliminary Payload CAD model, in accordance with Appendix C, and preliminary Payload interface drawings.
	Payload environmental test approach and schedule	Provide the test approach compared to Section 3.4 using the SpaceX provided worksheet, including additional rationale for any requests for deviation to the requirements found in Section 3.4, including notching.
	Propulsion system details	Customer provides SpaceX with propulsion system details for SpaceX evaluation in accordance Section 4.1.5 if applicable to the Payload.
Mission Integration Analysis Inputs	Payload inputs to ICD	Updated Payload interface information and system descriptions to be captured in the ICD, including electrical interface pin-out characteristics in a format provided by SpaceX.
	Payload CAD model update (if applicable)	Updated Payload CAD model, in accordance with Appendix C.
	Payload dynamic model and completed checkout worksheet	Payload dynamic model, in accordance with Appendix B.
	Payload mass properties	Current best estimate of the Payload mass properties (mass, CoG, MoI, PoI, all with tolerances).
	Payload transmitter verification	Customer verification that Payload transmitter turn on times are compatible with Launch Vehicle frequency restrictions using the SpaceX-provided worksheet.
	Completed Payload ICD pinout worksheet (AV2052)	A spreadsheet which describes the launch vehicle to spacecraft electrical harness properties and pin-outs.
	Completed Payload EMI/EMC worksheet template (AV2054)	A spreadsheet which describes the spacecraft radio frequency electromagnetic emissions and susceptibility.
Completion of Initial Mission Integration Analyses	Range Safety Program Introduction	A simplified and high-level overview of the Payload and its associated hazardous systems in a condensed format for Launch Range safety authorities (template provided by SpaceX). The PI provides quick reference on Payload appearance, size, mass, propellants, batteries, Pressure Vessels, heat pipes, and radiating sources. Detailed information about the Payload is provided in the MSPSP.
	Payload 91-710 tailoring, initial	Tailoring provides a means for formulating a Payload-specific edition of AFSPCMAN 91-710 (Volumes 1, 3, and 6) and documents whether or not the Customer will meet applicable safety requirements as written or achieve an equivalent level of safety through a requested and approved alternative approach. The Customer's tailoring requests must be prepared in accordance with 91-710 Vol 1, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval.
	Payload MSPSP, draft	Payload safety information providing the Launch Range safety authority with a description of hazardous and safety-critical support equipment and flight hardware associated with the Payload. The Customer's MSPSP must be prepared in accordance with 91-710 Vol 3, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval.
	Inputs to Launch Site activity planning / joint operations	Description of Customer Launch Site activities including Payload stand-alone processing, combined operations, Launch constraints, requested Launch Site services, and Launch Site interfaces.
Spacecraft to Payload Adapter Fit Check (if applicable)	Fit check plan jointly agreed with Customer	A document detailing the fit check operations, equipment, procedures and roles and responsibilities.

Milestone	Customer Deliverables	Description
Range Safety Submission	Payload 91-710 tailoring, final	Tailoring provides a means for formulating a Payload-specific edition of AFSPCMAN 91-710 (Volumes 1, 3, and 6) and documents whether or not the Customer will meet applicable safety requirements as written or achieve an equivalent level of safety through a requested and approved alternative approach. The Customer's tailoring requests must be prepared in accordance with 91-710 Vol 1, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval.
Launch Campaign Planning	List of emails for launch site badging access	Customer-provided list of emails for potential launch site personnel in order to fill out badge access paperwork online.
Range Safety Submission	Payload Ground Operations Plan, draft	The Payload Ground Operations Plan (GOP) provides a detailed description of the hazardous and safety critical operations associated with the Payload and its ground support equipment. The Payload GOP contains a description of planned operations and the hazard analysis of those operations. The Customer's GOP must be prepared in accordance with 91-710 Vol 6, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval.
	Certification Data for Payload Hazardous Systems	Certification data for Payload hazardous systems. A system is deemed hazardous if it includes any of the following: Pressure Vessels (over 250 psi), batteries, hazardous materials, non-ionizing and ionizing radiation systems, hazardous propulsion systems, or ordnance. Data must also be provided for ground support equipment (for example, lift slings).
Trajectory Monte Carlo Inputs	Updated mass properties	Customer to provide SpaceX refined Payload mass properties inputs for the Monte Carlo analysis of the nominal trajectory using the Payload mass properties template provided by SpaceX. Updates must fall within previously provided uncertainty bounds.
Payload Environmental Verification	Payload environmental verification reports	Customer to provide to SpaceX final environmental verification test and/or analysis results in order to show compliance to Section 3.3 and in accordance with the SpaceX approved Payload environmental test approach.
Final Range Safety Submission	Payload 91-710 Compliance Letter	Signed confirmation from Customer to SpaceX, in the form of the letter as specified in the SpaceX Range document templates that the Payload complies with all Range Safety requirements.
	Payload MSPSP, final	Payload safety information providing the Launch Range safety authority with a description of hazardous and safety-critical support equipment and flight hardware associated with the Payload. The Customer's MSPSP must be prepared in accordance with 91-710 Vol 3, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval. The final Payload MSPSP must include Customer's qualification data for hazardous systems and certification data for hazardous systems.
	Payload Ground Operations Plan, final	The Payload Ground Operations Plan (GOP) provides a detailed description of the hazardous and safety critical operations associated with the Payload and its ground support equipment. The Payload GOP contains a description of planned operations and the hazard analysis of those operations. The Customer's GOP must be prepared in accordance with 91-710 Vol 6, Attachment 1 for SpaceX to submit to the Launch Range safety authority for review and approval.
	GOP-defined Hazardous Procedures	Payload procedures provide detailed, step-by-step descriptions of the manner in which Customer's hazardous and safety critical operations will be accomplished at the Launch Site. These procedures are the basis from which approval to start hazardous or safety critical operations are obtained from the Launch Range safety authority. The Customer's hazardous procedures must be prepared in accordance with 91-710 Vol 6, Attachment 2 for SpaceX to submit to the Launch Range safety authority for review and approval. Customer is strongly encouraged to deliver procedures earlier than 45 days before hardware arrival at the Launch Site. Procedures must be in English.
	Medical Certificates for SCAPE/SCBA Personnel	Medical certificates of good health for personnel using SCAPE or SCBA (self-contained breathing apparatus) at the Launch Site. Medical certificates for SCAPE/SCBA must be valid throughout the expected duration of the campaign and contain all information required by NASA medical. Customer must provide Medical Exam information per KSC OCH-I-0106 and KSC Respirator Medical Evaluation questionnaire per KSC16-540V2.
	Propellant arrival information	The Payload propellant arrival plan describes the methods and logistics of Customer's propellant shipment to the Launch Site.
Launch Campaign	Final inputs to launch campaign checklist	Customer final inputs to the launch campaign checklist including status for launch campaign documentation, GSE shipment list, Customer personnel attendance, Payload details related to Launch Site operations, and OPM email distribution list.

Milestone	Customer Deliverables	Description
Readiness Review	Final inputs to launch campaign daily schedule	Customer final inputs describing Launch Site activities required in the launch campaign daily schedule for Payload stand-alone processing.
	Badging details filled out via Customer Portal	Customer details including personal information, and passport/visa scans and photos necessary for access to the Launch Site badging completed online.
	Completed licensing and insurance information template	Customer provides the Hazardous Materials list in support of SpaceX's application of an FAA license for the mission as well as crosswaiver inputs. If applicable, evidence of insurance for the Payload, including identification of insurer point of contact and if Customer has procured Payload insurance, Customer to provide evidence of express waivers of subrogation as to SpaceX and its Related Third Parties. If applicable, Customer identifies any parties that would like to be listed as additional insured on the SpaceX procured third party liability insurance.
	Hourly Schedule for Hazardous Operations	Launch Range safety scheduling information of hourly hazardous Payload operations. Required by the Launch Range safety authorities for awareness and oversight of hazardous Payload operations.
	Draft Dates and Times for EGSE Transfers	Schedule of Customer's expected EGSE transfers and movements between facilities at the Launch Site. SpaceX requires awareness of Customer's hardware transfer plans, to support the equipment movements and confirm personnel availability to assist with the transfer.
	Plan for Payload and GSE arrival at the Launch Site	The Payload and GSE arrival plan describes the methods and logistics of Customer's hardware arrival at the Launch Site.
	Payload insurance and cross-waivers	Evidence of insurance for the Payload, Customer property, equipment and personnel (with express waivers of subrogation as to SpaceX and its Related Third Parties). Evidence that the cross-waivers have been extended to (i) its Payload manufacturer(s); (ii) Related Third Parties with any ownership interest in the Payload; (iii) Customer's direct Customers for the Payload; and (iv) any other Related Third Parties, respective contractors, subcontractors and insurers, as requested by SpaceX. Each must waive (in writing) the right to sue or otherwise bring a claim against SpaceX or SpaceX's Related Third Parties, Co-Payload Customers or their Related Third Parties, or the US Government or its contractors or subcontractors for any injury, death, property loss or damage (including loss of or damage to the Payload, the Co- Payload(s), the Launch Vehicle, or other financial loss) sustained by them or any of their employees, officers, directors or agents, arising out of or related to activities relating to the performance of the Agreement.
	Launch and In-Orbit Insurer Subrogation Waiver	Customer to provide evidence that the insurer has waived subrogation rights.
Launch Campaign Kickoff	Launch site awareness training complete	All Customer personnel participating in the Launch Campaign complete online Launch Site awareness training prior to arrival at the Launch Site.
Launch Campaign	Payload mass properties - measured wet mass	Measured Payload mass, including adjustments for any non-flight items (e.g. remove-before-flight covers) which remained on the Payload during the final lift to Launch Vehicle hardware during join mating operations with SpaceX.
Launch Readiness	Payload Launch Readiness Certificate	Signed confirmation from Customer to SpaceX, in the form of the letter as determined by SpaceX, that the Payload is ready for countdown and Launch.
Flight Report	Coordination with the space situational agency	Customer coordination for space object identification as described in Section 7.10.
	Payload operations status	Brief summary of the current Payload status, as well as a launch and early operations informational summary.

APPENDIX B: 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 Customer to ensure the following requirements are met.

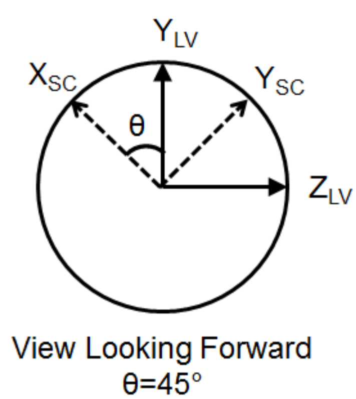
Payload Craig-Bampton Model Definition

Model Requirements:

- The units of the model shall be clearly defined (English or SI).
- The model may be a single or multi-point interface modal model.
- 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.
- Clampband and Lightband-style interfaces shall be reduced to a single centerline point with six degrees of freedom, unless a multi-point model is provided to assess peaking effects.
- Boundary node locations shall be clearly defined (see dynamic model summary template).
- 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.
- A single coordinate system, consistent with clocking definition and drawings, shall be used for the boundary degrees of freedom relative to the Launch Vehicle (payload clocking) and shall be defined in a clear manner (example 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

Matrix Requirements:

- 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 eigen values.
    - 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 $DRM1$ (single or multiple point interface models), or using both a $DRM1$ and a $DRM2$ (multiple point interface models only).
- 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 g's) 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 vibe 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 vibe curves is dependent on the coordinate system in which the grid points are defined. The available coordinate systems are:

For a single point interface:

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

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)

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's dynamic model be accompanied by documentation that includes:

- Definition of units used (SI or English).
- Definition of the Payload coordinate system relative to the Launch Vehicle.
- Location of all interface grids in Payload coordinate system
- 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
- A list of all frequencies.
- Pictures and/or descriptions and frequencies of the first few mode shapes (including the three fundamental modes in X, Y, and Z).
- Definition of damping.
- Definition of the model response (dynamic) uncertainty factor.
- 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.
- If internal Payload responses are requested, provide appropriate DRMs (ATMs, DTMs, and LTMs) as well as tables defining the rows of these matrices.

- 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.
- 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 the Customer is encouraged to provide additional information that will assist SpaceX in processing the Payload dynamic model for the coupled loads analysis.

APPENDIX C: CAD MODEL REQUIREMENTS

The Customer must provide SpaceX a CAD model of the Payload in NX parasolid, 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.

SpaceX uses Siemens NX for CAD processing and, upon mutual agreement of the Parties, can accept Customer CAD models in a Parasolid file, the native format of NX.

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). The 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 the 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 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:
  - Payload mechanical interface to Launch Vehicle
  - Separation connectors and associated brackets
  - Pusher pads
- Components subject to review for clearance analysis:
  - 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
- ☐ Simplified bodies fully envelope OML of actual payload
- ☐ All direct LV interface bodies are included
- ☐ File size is 50Mb or less
- ☐ Payload is properly configured: origin is at SpaceX standard interface, clocked correctly, and agrees with corresponding mass properties

APPENDIX D: EMI/EMC DESCRIPTIONS

SpaceX will perform analysis demonstrating radio frequency (RF) and electromagnetic interference (EMI) compatibility between the Payload and Launch Vehicle. This analysis will couple the emissions and susceptibility of the Launch Vehicle systems with the Payload emission and susceptibility provided by the Customer. The Customer shall provide SpaceX the Payload RF information described below in the form of the AV2054 worksheet.

Outputs to the Customer are predicted compatibility and/or interference areas across the megahertz (MHz) to gigahertz (GHz) frequency spectrum.

Inputs Required from Customer:

- Payload intentional radiated emissions in the range from 10MHz to 18GHz (Payload transmitters) including:
  - Frequency in MHz.
  - Bandwidth in MHz.
  - Electric field in dBµV/m at the separation plane.
  - Effective isotropically radiated power (EIRP)[1].
- Payload spurious radiated emissions in the range from 10MHz to 18GHz (all emission other than Payload transmitters).
  - Frequency in MHz.
  - Electric field in dBµV/m at the separation plane.
- Payload susceptibility to E-field emissions in the range from 10MHz to 18GHz (Payload receivers/notches).
  - Frequency in MHz.
  - Electric field in dBµV/m at the Payload receiver.
  - Threshold sensitivity receive power (of Payload receivers).
- Payload susceptibility to spurious E-field emissions in the range from 10MHz to 18GHz (other than receive notches).
  - Frequency in MHz.
  - Electric field in dBµV/m at the separation plane.

Notes:

[1] SpaceX can accept transmitter power and antenna gain in place of EIRP.

APPENDIX E: 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 F: DEFINITIONS

"Agreement" refers to the Launch Services Agreement between SpaceX and the Customer.

"Cake Topper Payload" refers to a medium-sized (500-2500 kg) Payload, forward mounted on a stack of rideshare hardware.

"CSLA" means the Commercial Space Launch Act of 1988, as amended, 51 U.S.C. §§ 50901-50923 and the regulations issued pursuant thereto, including the Commercial Space Transportation Regulations, 14 C.F.R. Parts 400-460.

"Co- Payload" means any payload of a Customer of SpaceX, other than Customer, that is manifested on the same Mission as Customer.

"Co-Payload Customer" means any Customer of SpaceX other than Customer that has a payload manifested on the same Mission as Customer.

"Customer" shall have the meaning set forth in the signature page of the Terms and Conditions.

"EAR" means the Export Administration Regulations administered by the Bureau of Industry and Security, US Department of Commerce, 15 C.F.R. Parts 730-744, pursuant to the Export Control Reform Act of 2018.

"End of Mission," is defined by the mission-specific second stage re-entry time (usually a maximum of 1 hour, or 3600 seconds, after the last deploy).

"Interface Control Document" means that document which shall be prepared by SpaceX with data to be supplied by Customer, negotiated in good faith, and mutually agreed upon in writing by both Parties prior to the beginning of the Launch Period. The Interface Control Document shall supersede any interface requirements document.

"ITAR" means the International Traffic in Arms Regulations administered by the Directorate of Defense Trade Controls, US Department of State, 22 C.F.R. Parts 120-130, pursuant to the Arms Export Control Act of 1976, as amended, 22 U.S.C. § 2778.

"L" means Launch Date and "L-xx" means the date xx months prior to the Launch Date (for example, if the Launch Date is currently July 1, 2018, L-6 means January 1, 2018).

"Launch" means Intentional Ignition followed by either: (a) Lift-Off or (b) the loss or destruction of the Payload or the Launch Vehicle (or both).

"Launch Activities" means the activities related to the performance of this Agreement following the arrival of the Payload or Launch Vehicle at the Launch Site, whichever comes first, including those prescribed by the CSLA and the terms of the launch license issued to SpaceX pursuant thereto for the Launch.

"Launch Campaign" means the activities and discussions leading up to and including Payload to Launch Vehicle integration at the Launch Site through Launch.

"Launch Complex" means the SpaceX-operated facility where the Launch Vehicle is integrated and from which the Launch Vehicle is launched.

"Launch Date" shall have the meaning set forth in the LSA. If the Launch Date has not yet been established (as determined solely by SpaceX), the Launch Date shall be deemed to be the first day of the Launch Period. Any delay shall not change the payment due dates in the Terms and Conditions.

"Launch Range" means the US Governmental authorities and office with jurisdiction over the Launch Site.

"Launch Services" means those services described in this SOW to be performed by SpaceX.

"Launch Site" means the SpaceX launch facility at Cape Canaveral Space Force Station or another SpaceX launch facility capable of supporting the Launch Services, as determined by SpaceX.

"Launch Vehicle" shall mean a launch vehicle capable of achieving Customer's orbital parameter requirements as set forth in Section 1 of the SOW.

"Launch Window" shall mean the time period established by SpaceX during which the Launch is scheduled to occur on the Launch Date.

"Licenses" shall mean all licenses, authorizations, clearances, approvals and permits necessary for each Party to carry out its respective obligations under the Agreement. Each Party agrees to provide reasonable assistance to the other Party as necessary to obtain such Licenses.

"Material Breach" means a breach in which the non-breaching party did not receive the "substantial benefit" of the bargain under the Agreement. To exercise its right to terminate for Material Breach, Customer shall notify SpaceX of this election to terminate in writing and within thirty (30) days following the conclusion of the ninety (90) day cure period. For the sake of clarity, neither (i) a delay nor ii) a Launch or Launch Activities resulting in the loss or destruction of the Payload, shall be deemed a Material Breach by SpaceX hereunder, and except as expressly stated in the Termination section of the Terms and Conditions, nothing in this Agreement shall be construed in any way as obligating SpaceX to refund any payment made in connection with any Launch Services performed hereunder.

"Parties" shall mean Customer and SpaceX.

"Party" shall mean Customer or SpaceX.

"Payload" shall mean the Customer spacecraft. The Payload shall not contain any hosted or auxiliary spacecraft provided by the Customer without the written mutual agreement of SpaceX.

"Pressure Vessel" is any system containing more than 20,000 J of stored energy (pneumatic and chemical energy) or a MEOP greater than 100 PsiD (6.9 barD).

"Pressure System" is any system that is intended to be pressurized beyond 0.5 atmospheres. This includes both Pressure Vessels and pressure components like valves, fittings, and tubes that have potential to see internal pressure in the time between Customer delivery and on-orbit deployment.

"Range Safety" refers to the specific safety branch of the Launch Range, the US Governmental authorities and office with jurisdiction over the Launch Site.

"Related Third Parties" means (a) the Parties' and Co- Payload Customer(s)' respective contractors and subcontractors involved in the performance of this Agreement and their respective directors, officers, employees, and agents; (b) the Parties' and Co- Payload Customer(s)' respective directors, officers, employees, and agents; and (c) any entity or person with any financial, property or other material interest in the Payload, Co- Payload(s), the Launch Vehicle or the ground support equipment.

"Rideshare" means in reference to the SpaceX Rideshare Program offering for small satellite launch services.

"Rideshare Program" is the SpaceX offering for small satellite launch services.

"Terms and Conditions" means the Terms and Conditions to which the SOW is attached.