COMMUNITY MULTI-MANIFEST DESIGN SPECIFICATION (MMDS)

Version 1.0a

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Preface

This document was developed by a collaborative effort of volunteers from within the small spacecraft community, including government organizations and contractors, commercial companies, and universities. **No new requirements were established by this effort.** The focus was on comparing validated requirements and attempting to establish a combined set that enveloped as many as practical to maximize rideshare acceptability and flight options. Additionally, all the requirements were converted to English units to permit clearer comparisons.

This material was based entirely on the validated, open source materials referenced throughout the MMDS. No single organization is responsible for the technical content of the MMDS and design decisions should be predicated on these individual, validated sources used in developing the MMDS materials.

Numerous organizations within the community graciously allowed their material to be incorporated into the document. References to the source materials have been intentionally included throughout but may have occasionally been missed. Please address any omissions or corrections to mmds@sprsa.org so that they can be corrected.

This document does not contain material restricted under the International Traffic in Arms Regulations (ITAR). All material contained within is unrestricted and includes no proprietary information.

The following organizations graciously allowed the use of their publicly available information and graphics throughout the MMDS:

SpaceX
Moog
Planetary Sciences Corporation
Sierra Space
Beyond Gravity (RUAG)
United Launch Alliance (ULA)
Blue Origin
Northrop Grumman
Rocket Lab
Virgin Orbit
Firefly
Relativity Space

The following organizations participated in the development or peer reviews of the MMDS.

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Aerospace	ALS	Applied Research Laboratory
Astranis	Atlantis Industries	AXA XL
Blue Origin	Cal Poly	Amazon Kuiper
John Hopkins Univ/APL	Sierra Space	Stellar Solutions
LeoStella	Malin Space Science.	Mantech
Maxar	Momentus	Moog
NASA	Northrop Grumman.	Naval Postgraduate School
Planetary Sciences Corporation	OmniTeq	Parsons
Relativity Space	SAIC	Schonedyne
Spaceflight Inc	TZero Consulting	United Launch Alliance
U.S. Space Force	Virgin Orbit/VOX	Xtenti
York Space Systems	VisSidius	SpaceX
Beyond Gravity (RUAG)		

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Multi-Manifest Design Specification (MMDS)

1.0. Introduction

1.1. Background

Hitchhiker or rideshare payloads have been part of the U.S. space program practically from the beginning. Numerous small payloads were flown on or deployed from the aft rack of the Agena stages from the 1960s and into the 1980s. Rideshare spacecraft have always taken advantage of excess performance capabilities as a cost-effective approach to achieving orbit. As launch capabilities increased, more modern rideshare adapters were developed and by the turn of the century spacer rings with multiple mounting ports became the newest small payload adapters.

As the popularity of rideshares increased, a standard mission approach developed. A primary spacecraft drove the acquisition or allocation of the launch vehicle, the launch schedule, and the flight trajectory for each mission. The “excess margin” presented the opportunity to manifest a secondary adapter carrying the smaller, rideshare spacecraft seen as secondary or auxiliary spacecraft. These secondary satellites have been seen as of secondary importance and efforts were focused on assuring that their inclusion on the flight posed no threat to the primary mission. If they failed to meet the standards established for their inclusion on the flight, they were dropped and replaced with mass simulators.

As technology advanced, smaller spacecraft became more capable and began to provide a significant contribution to a variety of mission areas. Consequently, a more efficient and flexible means of safely manifesting rideshare spacecraft became more important. This shift in focus has led elements of the small satellite community to adopt terminology that reflects this change in the value of the small satellite rideshare spacecraft.

While a “primary” or “anchor” spacecraft will continue to drive the acquisition of a launch vehicle, the launch date, and flight trajectory, smaller rideshare spacecraft should not be assumed to have a lower, "secondary" importance. The “primary” spacecraft may still be seen as first among equals on a multi-manifested flight, but the other multi-manifested spacecraft are becoming important assets demanding a more operational and flexible manifesting approach.

While some organizations (e.g. NASA) will continue to use heritage primary/secondary terminology to emphasize do no harm, the MMDS will use the following equivalent terms that do not imply relative value among the spacecraft or their missions.

The terms “mission spacecraft” or “anchor spacecraft” will be used as equivalent to the term “primary spacecraft”. “Multi-manifest spacecraft” will be used in place of “secondary spacecraft” to avoid the connotation of lesser importance or value. This paradigm implies mutual compatibility among all the manifested payloads. While the term “Do-No-Harm” doesn’t preclude this interpretation, its historical use has been with an emphasis on secondaries not posing a threat to the primary. This will remain a key aspect of the multi-manifesting approach but places the emphasis on flight safety and compatibility among all the manifested spacecraft. Table 1.1. provides a summary comparison of these terms.

MMDS Terms	Heritage Terms
Rideshare	Rideshare
Mission or Anchor spacecraft	Primary spacecraft
Multi-Manifested spacecraft	Secondary or Auxiliary Spacecraft
Small Payload Adapter	Secondary Payload Adapter
Mutual Do-No-Harm	Secondary Do-No-Harm

Table 1-1. Comparison of Terminology.

1.2. Multiple Requirements Documents

Despite the different perspectives, the rideshare portion of the U.S. space program has grown and matured admirably over the past twenty years but often along somewhat different lines. Various government offices have established requirements documents; the individual Launch Services Providers, large and small, have Rideshare User’s Guides delineating their specific requirements; several support services providers also have their Rideshare User’s Guides along with the individual component providers who list their capabilities and requirements in their respective product documents. Only open-source versions of these documents were used in developing the MMDS; these documents are listed in Section 2.2.

Many of the requirements found in open-source documents are identical, while others are similar, and some are contradictory. Usually, the requirements are developed under similar assumptions and standard methodologies. Occasionally they are not. Some use English units exclusively while others use metric units. Sometimes different units of measure are used in the same document. The scales on which the data is displayed are often different from one document to another. These conditions make all this wealth of information, while essential and valuable, difficult to understand and compare, let alone implement.

1.3. The Challenge and the Task

As multi-manifested spacecraft become more prevalent, the need for more flexible launch options will increase. Each spacecraft will likely be developed for a specific customer, complying with their specific requirements and a pre-determined launch opportunity. However, as schedules and conditions change, the ability to easily replace one spacecraft with another, often late in a launch campaign, will become a necessity for operational flexibility. It may even be desirable to move between multi-manifested flight options and small, dedicated launch vehicles. The more closely aligned or common the various requirements can be made, the easier and more flexible it will be to design and manifest ride share spacecraft.

The U.S. Space Force (USSF) Space Systems Command's (SSC) Mission Manifest Office (MMO) engaged the Small Payload Ride Share Association (SPRSA) to lead a community effort to collaboratively develop a Multi-Mission Design Specification (MMDS) to provide multi-mission spacecraft designers a single, open-source document that addressed the current, validated design requirements across the small spacecraft community.

Over one hundred people signed up for the project with volunteer representation from over forty government agencies, large and small launch services providers, spacecraft integrators and aggregators, universities, small spacecraft builders, and a variety of component and services providers. The MMDS represents the collaborative assessments of the current requirements documents by these individual volunteers.

1.4. The Objectives

The MMDS goal is to enhance the understanding of the individual, validated requirements documents and to assist in maximizing the potential launch options through increased compatibility with multiple requirements.

The MMDS has two objectives:

1. The ease of acceptance onto multi-manifested launch opportunities by consolidating essential design requirements for small multi-manifest spacecraft.
2. Enable rapid swapping between launch opportunities, to include larger multi-manifested missions and dedicated small launch vehicles.

The primary objective was to "envelope" as many of the existing multi-manifest requirements as practical so that compliance would enable acceptance by as many multi-manifesting organizations as possible. The approach adopted to satisfy this objective was to envelope the requirements and environments in the general government documents and the projected large launch service providers' multi-manifest User's Guides (ULA, SpaceX, and Blue Origin) and Moog's ESPA rings. These "Baseline Multi-Manifest Envelopes" would then represent the baseline for acceptance across the widest range of the multi-manifest community.

The second objective was to develop a set of criteria that would maximize the ability to readily move between available launch opportunities, whether on multi-manifested flights or small launch vehicles, thereby providing the most operationally flexible access to space for small payloads. With the "Baseline Multi-Manifest Envelopes" in hand, the small launch service providers' environments could then be compared to these baselines. Much of the small launch providers' environmental data was not yet publicly available for use in the MMDS. The intent would be to add this data as it becomes available.

1.5. Representations

The Multi-Manifest Design Specification (MMDS) was developed by participants from across the small spacecraft Community including representatives from government agencies, large and small launch services providers, integrators and aggregators, spacecraft builders, academia, and a variety of support services providers. This was a volunteer effort intended to provide a single document to assist small spacecraft designers in navigating through the several, validated sources of established design requirements. **No new requirements were developed by the MMDS development participants.** Rather current, validated source documents were collected, converted to common units of measurement, and portrayed on consistent scales. The community participants then discussed the feasibility and practicality of combining as many of these requirements within an “envelope” or set that would allow spacecraft designers to consider how many of the validated requirements within the envelope would be appropriate for their design. Enveloping increases flexibility and launch options, but flexibility is not a requirement. The MMDS should help designers determine the balance between increased flexibility and increased spacecraft design complexity, cost, and schedule impacts.

The MMDS does not address the totality of small spacecraft design requirements, but **only focuses on those affecting the inclusion on a multi-manifested flight**. This limited focus was judged to be acceptable since all spacecraft must satisfy all of the design requirements provided in the Range Safety User’s requirements Manual (AFSPCMAN) 91-710.

Actual design decisions must always be based on the individual requirements in the referenced source documents. The participants did not attempt to assess the validity or accuracy of any requirements stated in any of the source documents. Community judgement was simply used to determine if the stated requirement could be grouped with similar requirements from other sources. In many cases the assumptions and approaches used to develop the requirements in the various source documents were different or indeterminate. In these cases, a cautionary note was included to highlight these differences or uncertainties so that designers could contact the owners of the source documents for clarification. There are likely additional areas of ambiguity that escaped the attention of the community participants. As these areas come to light, they should be added to subsequent revisions.

Ultimately, there are two fundamental requirements underlying the MMDS:

1. All spacecraft designs must comply with Range Safety requirements
2. All spacecraft designs must comply with the specific requirements of any individual, validated source documents selected for use.

2.0. MMDS Baseline Material

This section addresses the baseline assumptions, definitions, coordinates systems, interfaces, launch systems, small payload adapters, and other material on which the subsequent requirements and specifications are predicated.

2.1. Baseline Assumptions

MMDS spacecraft are those uniquely designed for flight on small payload adapters (SPAs) and not based on an aggregation of CubeSat platforms and components.

English units are used throughout the MMDS with metric references included in parentheses when appropriate for clarity. Conversion accuracy between English/Metric systems will often be rounded for simplicity.

Only U.S. launch systems were considered in the development of the MMDS.

The MMDS does not address multi-manifested flights on human launch systems and their additional requirements.

The MMDS was not developed as a compliance document, but rather as a concise, specification-formatted, reference set of enveloped requirements that would facilitate easy access to multi-manifested launch options. This attempt at standardization through specific requirements allows, and even anticipates, deviations. When customized solutions are required, they should be seen as deviations from a "standard". All design requirements and customized deviations must be compliant with the specific source documentation that the MMDS attempts to summarize.

Three launch vehicles were assumed as baseline multi-manifest systems in developing the MMDS - SpaceX's Falcon 9, ULA's Vulcan Centaur, and Blue Origin's New Glenn.

SpaceX's Falcon 9 and ULA's Atlas V and Delta IV have established, mature rideshare capabilities. SpaceX's Falcon 9 has current flight data and heavily influenced the MMDS development.

ULA's new Vulcan Centaur will replace both Atlas and Delta which are being phased out. Vulcan is designed to carry small payload adapters and multi-manifested payloads. While publicly available data on Vulcan was limited, ULA advised that Atlas V data was representative of Vulcan and could be used in the development of the MMDS.

Blue Origin's New Glenn vehicle is also designed to provide a rideshare capability and estimated data for the New Glenn was provided for use in the MMDS.

While poised to enter the market, neither Vulcan nor New Glenn have flown as yet. As actual flight data for the new systems becomes available, the MMDS will be updated to ensure compatibility with each of the available multi-manifest systems.

Multi-manifest spacecraft are assumed to be powered off from integration through deployment with no services provided by the launch vehicle other than separation at the time of deployment.

Multi-manifested missions require a Small Payload Adapter (SPA) to mount the MMDS size (roughly 200 – 1,500 pound) spacecraft to the launch vehicle. Currently, there are two predominant providers of small payload adapters – Moog offers their ESPA ring in several configurations and SpaceX offers their adapter rings and Starlink platform mounts. These hardware adapters were adopted by the MMDS as baseline design interfaces and summary descriptions are provided in Appendix B.

Competitive small spacecraft separation systems exist that are compatible with these adapters and are also considered as baseline configurations for developing design specifications. The adapters are described in further detail in Appendix C and the separation systems are described in Appendix D.

Smaller launch vehicles that have already flown and those that are planned to be launched within the near future, were considered in the development of the MMDS to the extent possible where adequate technical performance and environmental data was available in the public domain.

2.2. Baseline Requirements Documents

There are several government and industry requirements documents that are either applicable to, or directly written for, rideshare spacecraft. These documents were reviewed as part of the MMDS development project, especially in the enveloping of the MMDS baseline flight environments. Collecting, converting to common units, displaying on consistent scales, and comparing these many requirements was a fundamental focus of the MMDS development. The "specification" terminology was chosen to ensure that the requirements were stated in specific detail and to avoid as much as possible the tendency to devolve into generalities that would be of little use to spacecraft designers.

The following source documents were used in creating the MMDS Baseline Enveloped Requirements (BER). Additional, small launch vehicle requirements documents were reviewed where available and these requirements compared to the MMDS Baseline Enveloped Environments. This effort remains a work in progress and will need updating as these systems mature and accumulate flight experience.

<u>Generic Requirements Documents:</u>

1) SMC-S-016, Space and Missile Systems Center Standard Test Requirements for Launch, Upper-Stage, and Space Vehicles, 5 September 2014

2) GSFC-STD-7000B, General Environmental Verification Standard for GSFC Flight programs and Projects, Approved: 28 April 2021
3) Evolved Expendable Launch Vehicle Rideshare User's Guide, May 2016
4) NASA Science Mission Directorate (SMD) Launch Vehicle Secondary Payload Adapter Rideshare User's Guide with Do-No-Harm, December 2021

Industry Requirements Documents:

5) SpaceX Rideshare Payload User's Guide, March 2022
6) United Launch Alliance Atlas V Launch Services User's Guide, March 2010
7) Blue Origin New Glenn Payload User's Guide, June 2021
8) Moog ESPA User's Guide, November 2018

Note: *Footnote numbers in the MMDS refer to these source documents from which the requirement was derived.*

A table with these Baseline documents is provided in each section identifying which were used in developing the MMDS "envelopes".

A complete list of reference documents is provided in Appendix A.

2.3. Specification Terminology

The enveloped requirements in the MMDS are intended to assist in:

- understanding the individual requirements in the multiple validated source documents, and
- demonstrating potential flexibility provided by multiple launch opportunities.

The following terms used throughout the MMDS reflect the compliance terminology generally used in source requirements documents.

"Shall" denotes requirements that must be met for maximum launch flexibility and will need formal verification. Failure to meet "shall" requirements may limit flexibility.

"Should" denotes a strong recommendation or a goal. In the context of the MMDS, "should" statements increase the probability of acceptance and maximize flight options.

"Will" indicates facts or explanations of situations that may happen regardless of inputs from the launch vehicle and/or spacecraft developer. "Will" statements serve to indicate events that the spacecraft developers should consider and be prepared for.

Since the MMDS enveloped requirements represent a combination of individual source requirements that would provide maximum acceptance and manifesting flexibility, a designer could elect to comply with a subset of these requirements, trading flexibility for spacecraft objectives. In this context, compliance with the enveloped MMDS requirements would be considered a “should” requirement. However, all the enveloped requirements might be “shall” requirements in the original source documents. All MMDS requirements must be understood in the context of the individual, validated source requirements.

Exceptions to established requirements are always a possibility, but such customization likely requires additional time, cost, and potentially additional testing and verification. Customization is opposite to the flexibility and standardization envisioned by the MMDS.

2.4. Baseline Launch Systems

The MMDS baseline launch systems were divided into two categories, the larger, multi-manifest launch systems, and the smaller, dedicated launch systems. The assignment of launch systems to these two categories was based on prevalent usage. Some smaller launch systems have adequate capability to support multi-manifest missions but are not currently used in a multi-manifest role.

The larger multi-manifest launch systems considered in the MMDS are:

Launch Vehicle	Source Document
SpaceX Falcon 9	SpaceX Rideshare Payload User’s Guide, March 2022
ULA Atlas V	ULA Atlas V Launch Services User’s Guide, March 2010
ULA Vulcan	{Atlas V data is representative per ULA}
Blue Origin New Glenn	Blue Origin New Glenn Payload User’s Guide, June 2021

Table 2.1. Larger launch systems.

The smaller, dedicated launch systems considered in the MMDS are:

Launch Vehicle	Source Document
Northrop Grumman Minotaur IV	Minotaur IV User’s Guide, v2.4, September 2020
Rocket Lab Electron	Launch: Payload User’s Guide, August 2020
Virgin Orbit LauncherOne	LauncherOne Service Guide, August 2020
Astra Rocket 4	TBD
Firefly Alpha	Alpha Payload User’s Guide 3.1, April 2021
Relativity Space Terran 1	Terran 1 Payload User’s Guide, August 2020
ABL Space RS-1	ABL Payload User’s Guide, 2022

Table 2.2. Smaller launch systems.

2.5. Baseline Small Payload Adapters

The most common Small Payload Adapters (SPAs) in use today were used as baseline hardware in the MMDS. Moog currently offers two standard versions of their Evolved Secondary Payload Adapter (ESPA); these were used in the MMDS. They also offer a variety of customized ESPAs that were not considered in the

MMDS since flexibility and standardization were fundamental to the MMDS development.

SpaceX offers two sizes of small payload adapter rings and two sizes of their Starlink shelf adapters. These MMDS baseline adapters are shown in Figure 2.1.

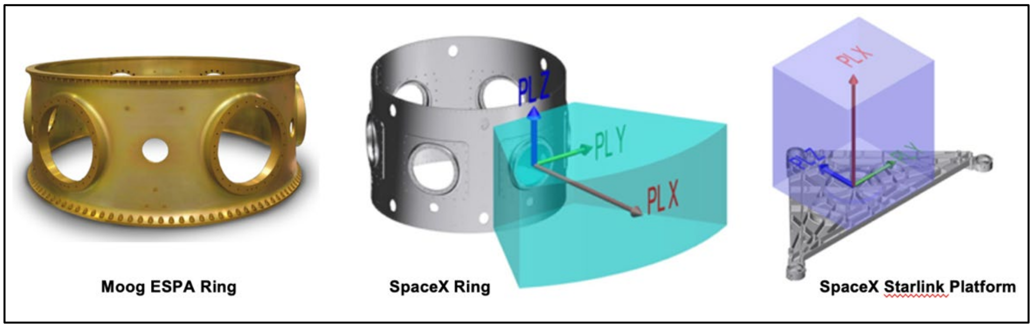
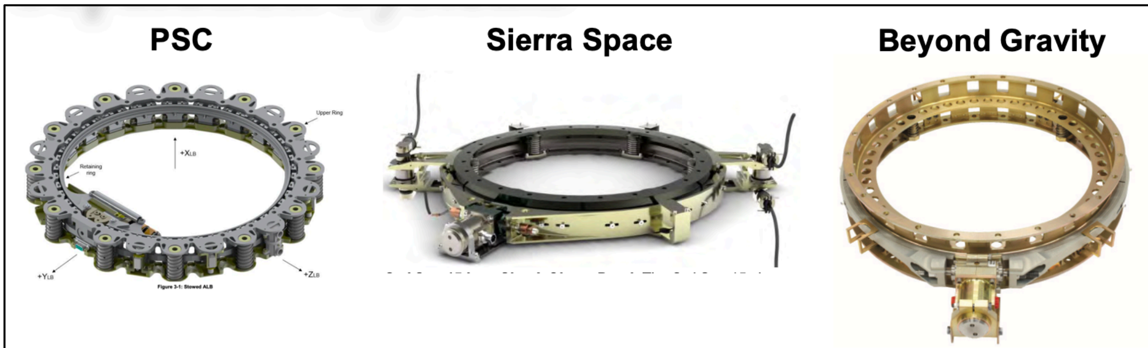


Figure 2.1. MMDS baseline Small Payload Adapters (SPAs)[6,9].

2.6. Baseline Separation Systems

Three currently available low-shock payload separation systems were included in the MMDS baseline hardware. The Planetary Systems Corporation's (PSC) 15" and 24" Advanced Light Bands, Sierra Space's 15" and 24" separation systems, and Beyond Gravity's (previously RUAG) 15" and 24" separation systems are summarized in Figure 2.2.



PSC	Sierra Space	Beyond Gravity
Services Connector +Z (39 pins)	**Services Connector** Zero-Extraction Force connector (200 pins)	**Services Connector** Deutsch DBAS 70 & 79 (12 pins)
Initiation Connector +Y (9 pins)	**Initiation Connector** MS3116P8-2S	**Initiation Connector** MS3116P8-2S
Separation Mechanism Motorized Light Band	**Separation Mechanism** Pyrotechnic	**Separation Mechanism** Pyrotechnic
Mounting Bolts 15" – 24 1/4" 28 24" – 36 1/4" 28	**Mounting Bolts** 15" – 24 1/4" 28 or 5/16" 24 24" – 36 1/4" 28 or 5/16" 24	**Mounting Bolts** 15" – 24 1/4" 28 24" – 36 1/4" 28
Compressed Height 15" - 2.1" 24" - 2.1"	**Compressed Height** 15" - 2.1" 24" - 2.1"	**Compressed Height** 15" - 3.1" 24" - 2.9"
Maximum Cantilevered Weight 15" - 600 pounds 24" - 1,800 pounds	**Maximum Cantilevered Weight** 15" - 1,000 pounds 24" - 1,600 pounds	**Maximum Cantilevered Weight** 15" - 460 pounds 24" - 1,230 pounds

Figure 2.2. MMDS baseline low-shock separation systems.

(Data courtesy of Planetary Systems Corporation, Sierra Space, and Beyond Gravity.)

2.7. Coordinate Systems

The spacecraft shall use a right-handed coordinate system, with the X-Axis being normal to the separation plane, as defined in Figure 2.3. The origin of the spacecraft coordinate system shall be located at the center of the Small Payload Adapter to spacecraft interface plane, with the X-axis as the separation axis.

The baseline coordinate system will be used to address the various flight configurations posed by the small payload adapters on both the multi-manifested flights and the small, dedicated launch vehicles. This standard coordinate system is required to ensure clarity across the launch options where the vehicle thrust vector may be aligned with the spacecraft X-axis (small launch vehicles and Starlink adapters) or is perpendicular with the X-axis (cantilevered mounts on the several ring adapters).

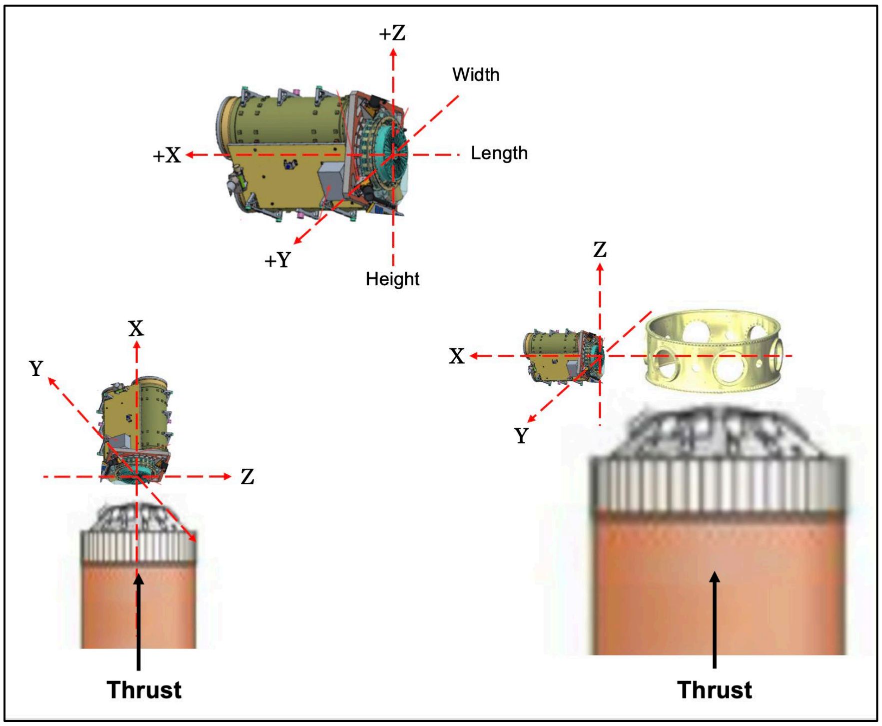


Figure 2.3. MMDS Spacecraft Coordinate Systems.

The adoption of these coordinates will allow for a clear transition between the launch vehicle thrust axis and the appropriate spacecraft axis depending on whether it is mounted horizontally (perpendicular to the traditional thrust axis) or vertically along the thrust of a vertically launched vehicle. Air launched systems represent a third set of conditions where the spacecraft is mounted and launched in a horizontal condition but is oriented along the thrust of the launch vehicle. These launch configurations must be taken into account in the spacecraft design when considering the enveloped launch environments listed within the MMDS.

2.8. MMDS Basic Interface Definitions

The interface between the multi-manifested payload and the small payload adapter is defined at the mounting surface of the payload adapter.

The multi-manifested spacecraft, its separation system, and any adapter plates are all components of the multi-manifested payload and must be included when addressing compliance with MMDS specifications. As an example, all associated hardware must be included in the "spacecraft" weight and volume when complying with these constraints defined in the MMDS. Figure 2.4 shows this interface graphically.

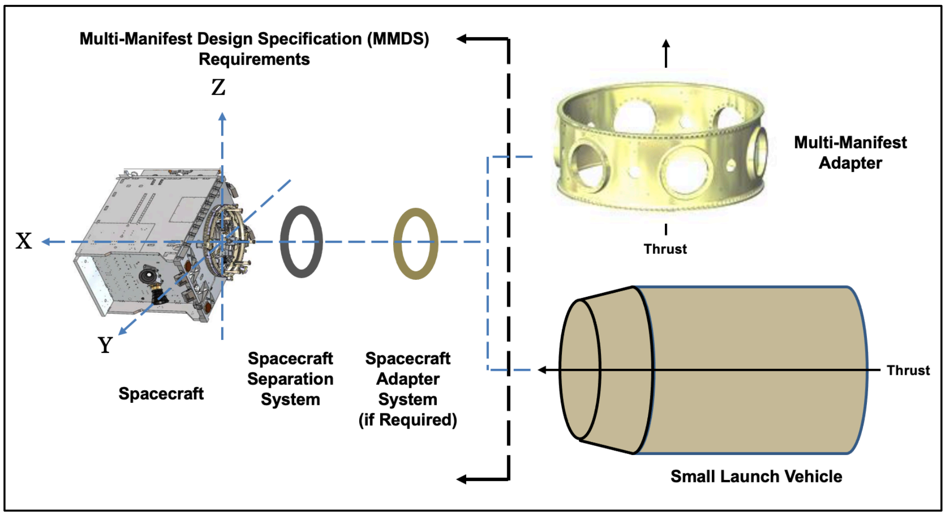


Figure 2.4. MMDS Primary Interface Definition.

All hardware to the left of the black dotted line is the responsibility of the spacecraft provider in that this hardware must be accounted for in the spacecraft mass and volume. All these components must fit within the mass and volume limits provided in Table 2.3. Whether they are purchased by the spacecraft developer, the integrator, or the launch service provider is a contractual decision rather than a technical consideration.

2.9. MMDS Small Spacecraft Class Definitions

Defining a set of spacecraft classes helps clarify the focus of the MMDS. Additionally, defining multi-manifest spacecraft classes is important to the MMDS objectives of interchangeability between multi-manifested flight opportunities and small launch vehicles. Interchangeability among spacecraft in the same class might prove to be a more realistic approach. The multiple spacecraft dimensions and masses, along with the available lift and volume capabilities of the launch systems, constrain these options. Any effort to enable this flexibility must consider the sizes and masses that could be accommodated on the most flight systems. This could result in slight reductions of potential dimensions and masses to maximize the possible flight options.

Table 2.3 shows the mass and volume capabilities of each of the baseline Small Payload Adapters where the center of gravity (CG) of the mass is 20" from the SPA mounting surface.

Adapter	# of S/C	S/C Mass (lbs)	Height (Z-in)	Width Y-in)	Length (X-in)	Shape
Moog Ring w/15" port	6	565	24	28	55.75	Rectangular*
SpaceX Ring w/15" port	6	465	34	32.6	55.75	Rectangular*
Moog Ring w/24" port	4	1,543	42	46	55.75	Rectangular*
SpaceX Ring w/24" port	4	1,230	48	58.8	55.75	Rectangular*
SpaceX 2 per Starlink shelf	2	465	28	28	40	Rectangular
SpaceX 1 per Starlink shelf	1	1,230	42	48	60	Rectangular

Table 2.3. Small Payload Adapters data based on CG 20" from mounting plane.

The rectangular shapes shown in Table 2.3 marked with an asterisk (*) are constrained from the actual pie shaped volumes allowed. Constraining the class volumes to a rectangular shape provides standardization with cylindrical fairings on the smaller launch vehicles. The values listed represent bounding cases to provide flexibility and interchangeability among launch options.

The pie shaped volumes permitted on the multi-manifested small payload adapters allows for additional non-rectangular shapes as shown in Figure 2.5. These expanded volumes would potentially limit options for flights on dedicated small launch systems.

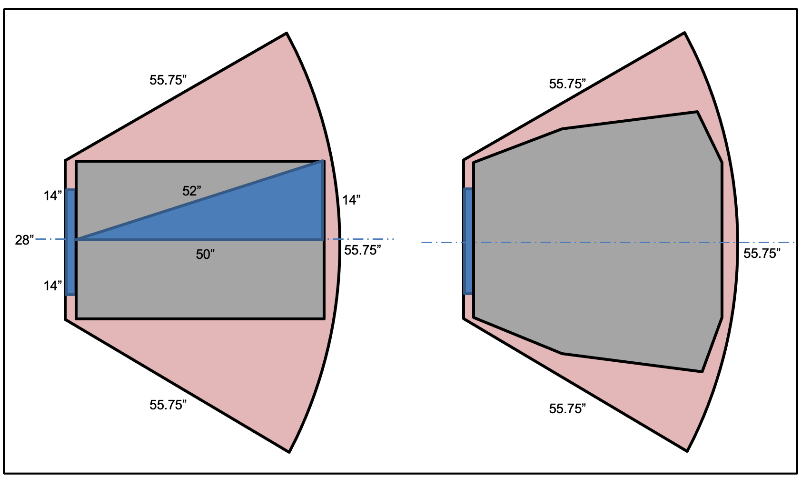


Figure 2.5. Example spacecraft shapes.

Since the limiting length imposed by the dynamic envelope of the payload fairing is a circular envelope, the spacecraft must fit within the pie shaped area shown in red in Figure 2.5. The actual rectangular shape is limited by the corners. The maximum dimension of the pie shape is 55.75". Allowing roughly 3" for the compressed separation system and 0.75" for additional clearance. The maximum spacecraft diagonal would be approximately 52”. Consequently, the maximum rectangular length would be reduced to about 50”.

Given these factors, three multi-manifest spacecraft classes, referred to as MMDS class spacecraft, were proposed.

> **Class 1** – spacecraft up to 24 high” by 24” wide by 24” long and between 100 and 220 pounds (100 kg).
>
> **Class 2** - spacecraft up to 24 high” by 28” wide by 50” long and less than 485 pounds (220 kg).
>
> **Class 3** - spacecraft up to 42” high by 46” wide by 48” long and less than 1,500 pounds (682 kg).

A review of the performance and fairing volumes of the smaller launch vehicles and the limitations of the small payload adapters helped to further refine the class definitions adopted for multi-manifest spacecraft specifically addressed by the MMDS. Table 1.3 provides a summary of these values based on data to specific reference orbits provided by each of these launch services providers and was used to propose three multi-manifesting spacecraft classes.

Class 1 spacecraft could fly on any of the systems shown in Table 2.2 and in some cases, multiple spacecraft could be flown. Class 2 spacecraft could be flown on all the systems except Electron (limited by mass) and the SpaceX Starlink 2 adapter (limited by length). Class 3 spacecraft could only be flown on ESPA Grande, Starlink 1 adapters, and SpaceX’s 24” ports on their rings. Data on the capabilities of the emerging small launch vehicles could indicate a need to change these definitions. This approach, once completely defined, would tend to maximize the number of potential launch options. However, spacecraft may choose to optimize for a larger set of conditions to take advantage of additional volume and/or mass at the expense of reducing the number of possible launch options.

Regardless of whether the separation systems and any necessary adapters are included with the spacecraft or the adapter, it is important to recognize that all this hardware associated with the spacecraft shall fit within the mass and volume constraints listed in Table 2.4. The small payload adapters are shown in blue along with their permissible masses and volumes. The smaller launch vehicles are shown in green along with their mass to 270nm, sun synchronous orbits and their available payload fairing volumes.

Table 2.4. MMDS Class spacecraft launch capabilities.

System	High Z (in)	Wide Y (in)	Long X (in)	Mass (lbs)*	Class 1 24 x 24 x 24 220 lbs	Class 2 24 x 28 x 50 465 lbs	Class 3 42 x 46 x 48 1,500 lbs
ESPA 15" Port	24	28	55.75	565	Two	One	No
Electron	29.7	29.7	> 74	330	One	No	No
Space X SL-2	28	28	40	465	One	No	No
SpaceX 15 Port"	34	32.6	55.75	465	Two	One	No
LauncherOne	49	49	83	660	Three	One	No
ESPA 24" Port	42	46	55.75	1,543	Two	One	One
SpaceX SL-1	42	48	60	1.230	Two	One	One
Firefly Alpha	79	79	> 98	1,639	Multiple	Two	One
SpaceX 24" Port	48	58.8	55.75	1,230	Two	One	One
Minotaur IV	81	81	>214	2,340	Multiple	Three	One
Astra Rocket 4	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ABL Space RS-1	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Relativity Terran-1	TBD	TBD	TBD	1,984	TBD	TBD	TBD

Rideshare adapters shown in blue and dedicated small launchers shown in green. Mass from Users Guides; Small LV Mass show performance to 270 nm (500 km) sun synchronous circular.

Carefully selected payload classes could also be important for multi-manifested flight selections as well. Replacing a satellite that failed to meet flight schedules with another spacecraft ready to fly, might be more feasible if the replacement satellite was in the same spacecraft class. This could ease or obviate the need for additional coupled loads analyses.

These classes represent upper bounds on masses and volumes and are not intended to recommend a precise size. These classes were defined for clarity and to ensure that the flight environments and other data presented were correct for the sizes of spacecraft addressed by the MMDS.

The number of variables in the design trade space for multi-manifest spacecraft complicates solutions. Constrained volumes, masses, centers of gravity (CG) limitations, and resonant frequencies, all factor into decisions. Figure 2.6. shows the mass limitations for the Small Payload Adapters (SPA) based on CG locations 20" from the SPA interface plane. The mass limitations of the three separation systems are shown as well. All these constraints must be considered when selecting spacecraft Class definitions and specific spacecraft designs.

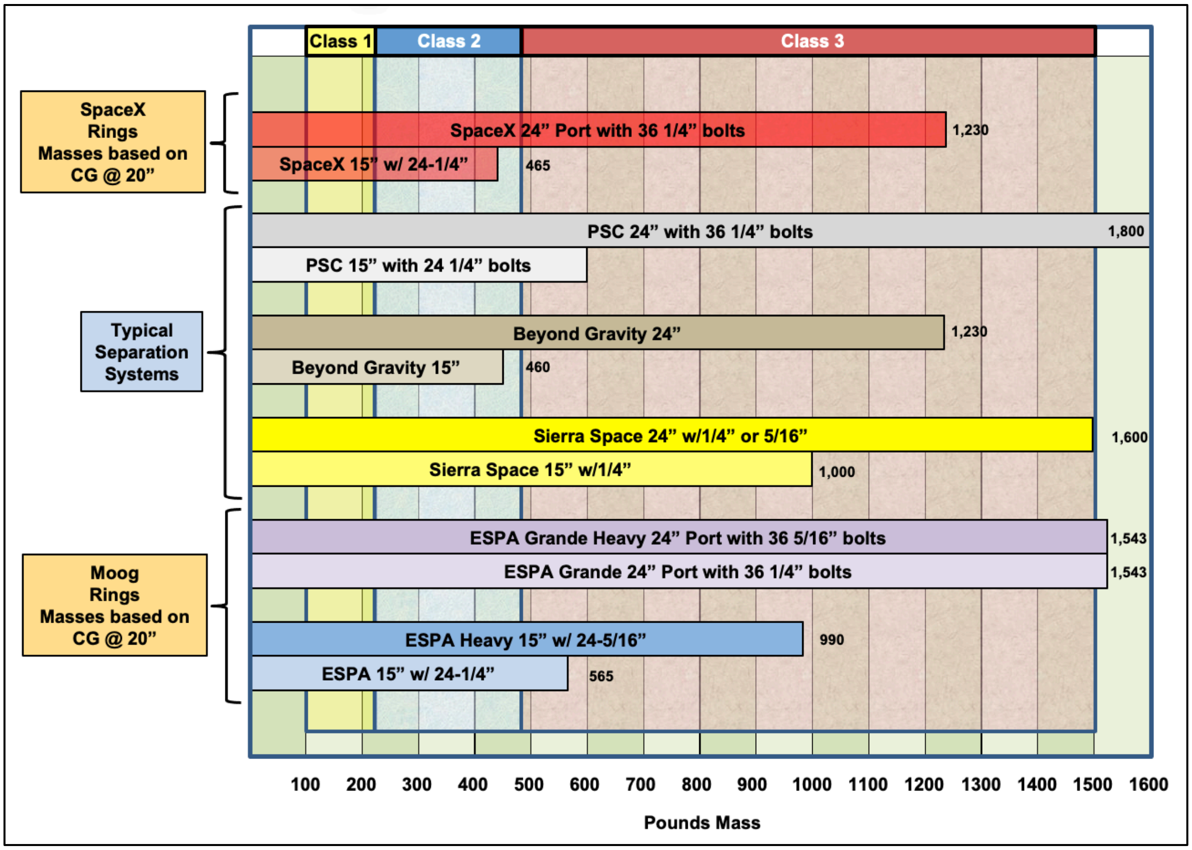


Figure 2.6. Comparison of Hardware Capability Constraints.

As can be seen, simply designing to the limits of the SPAs may not be adequate, as the separation systems may limit the actual mass available using the current hardware.

> ***Note:*** *The ESPA mass capabilities are based on the quasi-static loads used in the MMDS. SpaceX calculates their maximum mass differently making comparison more difficult. The values shown should be used only for initial system trades with details deferred to the applicable User's Guide.*

3.0. Spacecraft Design Requirements

The spacecraft design requirements addressed in the MMDS are those affecting the acceptability for inclusion on a multi-manifested flight opportunity. These are only a subset of all the requirements for a complete spacecraft design. Every effort was made to constrain the MMDS requirements to the minimum set to facilitate multi-manifesting considerations.

The design requirements have been grouped into two categories. The first category addresses the flight environmental conditions that the spacecraft will experience and must survive. To support the maximum flight opportunities these environments were enveloped to encompass as many launch vehicles as was considered practical. If these enveloped values have specific conditions that drive a design, the individual source environments that were used in the enveloping are provided in Appendix B. This information can be used to determine which launch systems drove the specific areas under the enveloped curves.

The second category of design requirements are those that are independent of the specific flight environments such as mechanical and electrical requirements. These were again constrained to only address the multi-manifesting considerations of the spacecraft design and the MMDS assumptions. Exceptions to these requirements or assumptions would likely involve additional design requirements not considered in the MMDS.

> ***Note:*** *The baseline design requirement for MMDS class spacecraft is that they will remain powered off from the time of encapsulation through their deployment on orbit. There will be no access to the spacecraft after encapsulation and no services (power, battery charging, telemetry, etc) will be provided.*
>
> *While there are options for many of these services, they represent an exception to the MMDS baseline and would require specific negotiations that could additionally limit launch options.*

3.1. Launch Environments

Spacecraft should be designed to and demonstrate compliance with the MMDS enveloped environments described in this Section 3.1 to maximize their launch options.

> ***Note:*** *The MMDS environments were developed for MMDS class spacecraft. Spacecraft less than 100 pounds mass should not use the MMDS environments.*

3.1.1. Quasi-Static Loads

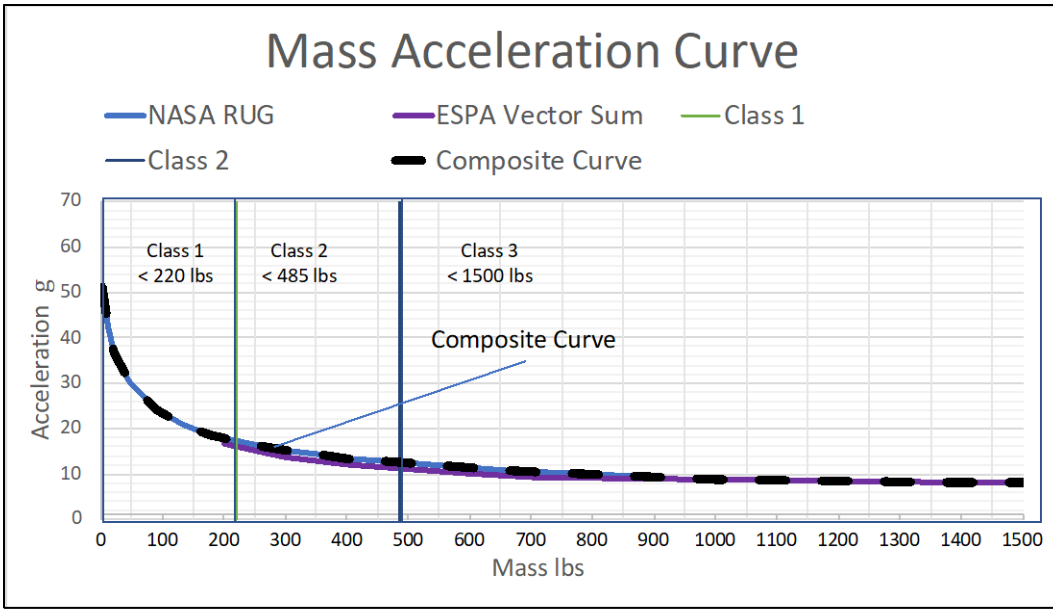
Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	Included – enveloped Class 1 & 2
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	Included – enveloped Class 3

For preliminary design, spacecraft and component designers have successfully used "Quasi-Static" load factors to account for the combined quasi-steady state and oscillatory dynamic loading occurring during the launch and flight events. The load factors are applied to the center of mass (CM) of a spacecraft to estimate the interface loading. The mass of the spacecraft/payload and its fundamental frequency have been shown to be significant factors in the loading. A composite curve enveloping two sources (NASA RUG and ESPA) is graphed and tabulated in Figure 3.1. The load should be applied as a vector in all orientations. The previously defined spacecraft classes 1, 2, & 3 are shown in shading. The load factors apply to spacecraft/payloads with any fundamental frequency.

The NASA RUG curve was supplied by NASA. The ESPA Mass Acceleration Curve (MAC) was provided by Moog and is based on the MAC developed by NASA's Jet Propulsion Laboratory (JPL) in the 1980's. Alternate forms of the load factor table can be found in many of the payload user's guides as 2D graphs. See for example, the Blue Origin New Glenn Payload User's Guide Figure 4-3: Design limit loads. The composite curve in Figure 3.1 is intended to envelope the 2D graphic form.

It should be noted that SpaceX indicates "payloads with fundamental frequencies below 40 Hz will be subject to increased load factors". After preliminary design, the adequacy of the design is assessed by simulations through the coupled loads analysis procedure and assessment for other environments.



Mass lbs	Composite Curve
2	51.3
11	42.4
22	36.6
44	30.3
88	24.2
132	20.9
176	18.7
220	17.2
265	15.9
309	15.0
353	14.2
399	13.5
441	12.9
661	10.8
882	9.5
1000	8.6
1200	8.3
1400	8.1
1600	8.0

Figure 3.1. Mass acceleration curve for spacecraft quasi-static loading.

3.1.2. Random Vibration

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	Included
2	GEVS, GSFC-STD-7000A, April 2005	Included
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	Included
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	Included

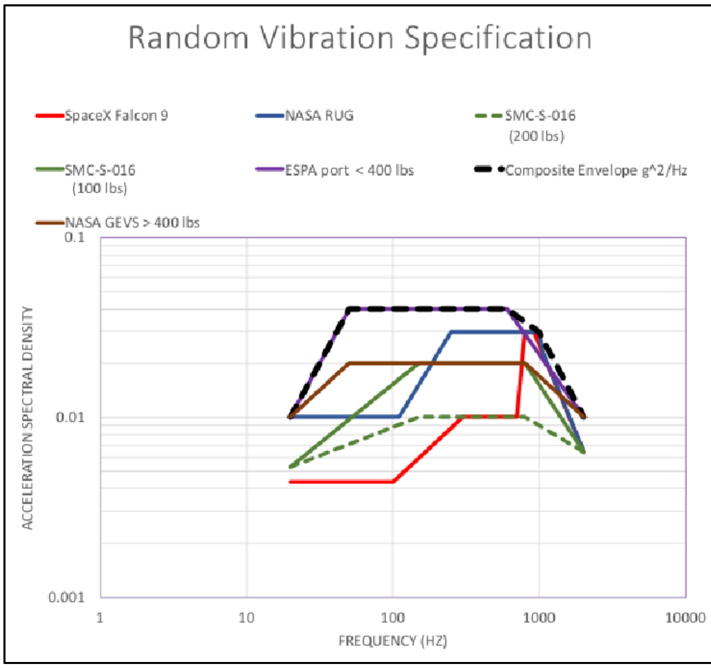
[Testing required to verify compliance]

The spacecraft interface random vibration environment is a result of both mechanical driven and acoustic effects. Levels suggested for design development are dependent on the spacecraft mass and design. A single enveloping curve is not possible due to the dependence of some of the specifications on the spacecraft mass. A generalized random vibration test level for components is provided in NASA GEVS. For components weighing over 400 lbs (182 kg) the test specification will be maintained at the level for 400 lbs (182 kg). The weight dependent levels (note the equations use weight, W, in pounds) are determined by the equations

$$dB\ reduction = 10 \log\left(\frac{W}{50}\right)$$

$$ASD(50 - 800\ Hz) = 0.16 * \left(\frac{50}{W}\right)$$

A curve enveloping the listed launch vehicles and design/test documents is shown in Figure 3.2.



Frequency Hz	Composite Envelope g^2/Hz
20	0.01
50	0.04
600	0.04
1000	0.03
2000	0.01

Figure 3.2. MMDS enveloped Random Vibration Requirements.

The payload (spacecraft, separation system, and any required adapter plates) first fundamental frequencies should be above 50 Hz to minimally impact the coupled loads analysis and improve flight opportunities.

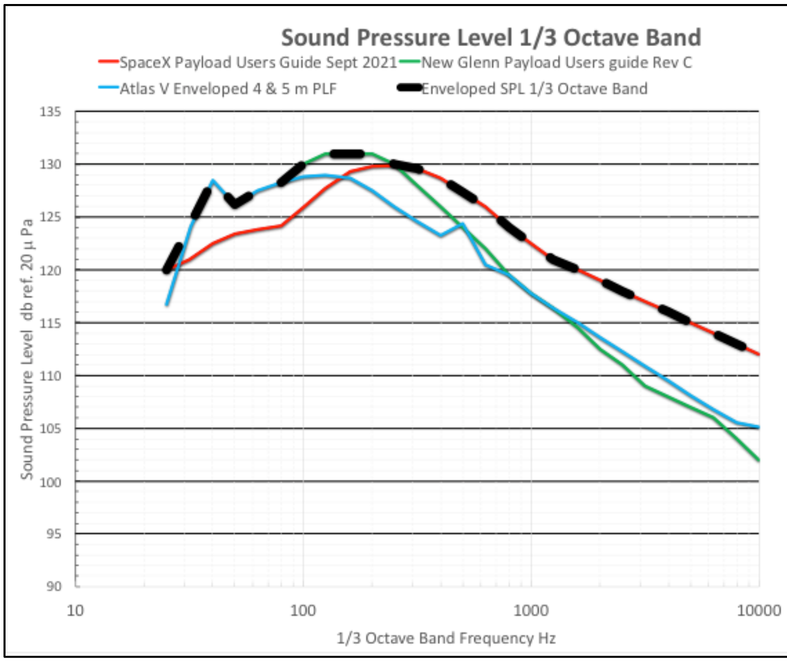
3.1.3. Acoustics

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	Included
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	Included
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

During liftoff and flight, the spacecraft will be exposed to direct acoustic excitation. Sound pressure levels (SPL) are often highest at liftoff and during transonic flight. The levels are affected by the configuration of the payloads (the fill factor within the fairing), the fairing characteristics, and the fairing acoustic blankets. The acoustic environment is typically defined as a spatial average sound pressure level (SPL) within the fairing and derived at a P95/50 level in decibels relative to 2.90 x 10^{-9} pounds per $inch^2$ (20 µPa). A curve enveloping multiple launch vehicle sound pressure levels using $1/3^{rd}$ octave bands is shown in Figure 3.3. (Specific inputs used for the envelope are given in Appendix B).



Freq Hz	Enveloped SPL 1/3 Octave Band
20	0
25	120
31.5	124.1
40	128.5
50	126.2
63	127.5
80	128.3
100	130
125	131
160	131
200	131
250	130
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

Figure 3.3. Enveloped Sound Pressure Levels within the fairing in dB.

Note: *Spacecraft may assess whether the random vibration environment envelopes the acoustic environment, and if so, use the random vibration test as their structural verification*

Note: *Any external spacecraft component with an area-to-mass ratio greater than 150 in²/lbm should undergo acoustic testing either as part of system testing (preferred) or as a subsystem.*

3.1.4. Sine Vibration

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	Included
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	Included
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Spacecraft developers need to be aware of the presence of sine content in the vibration environments and their designs must show compatibility with a low to mid-frequency sine vibration (< ~100 Hz) environment for a number of launch vehicles. Depending on the launch vehicle, spacecraft mass >485 lbs (225 kg) determines the expected vibration levels. For other launch vehicles, no statement of spacecraft mass is indicated. A coupled loads analysis (CLA) is used to validate the levels. Data specific to sine is provided in Appendix B. Shown in Figure 3.3 are representative sine vibration levels below 100 Hz for axial and lateral directions in the launch vehicle coordinate system.

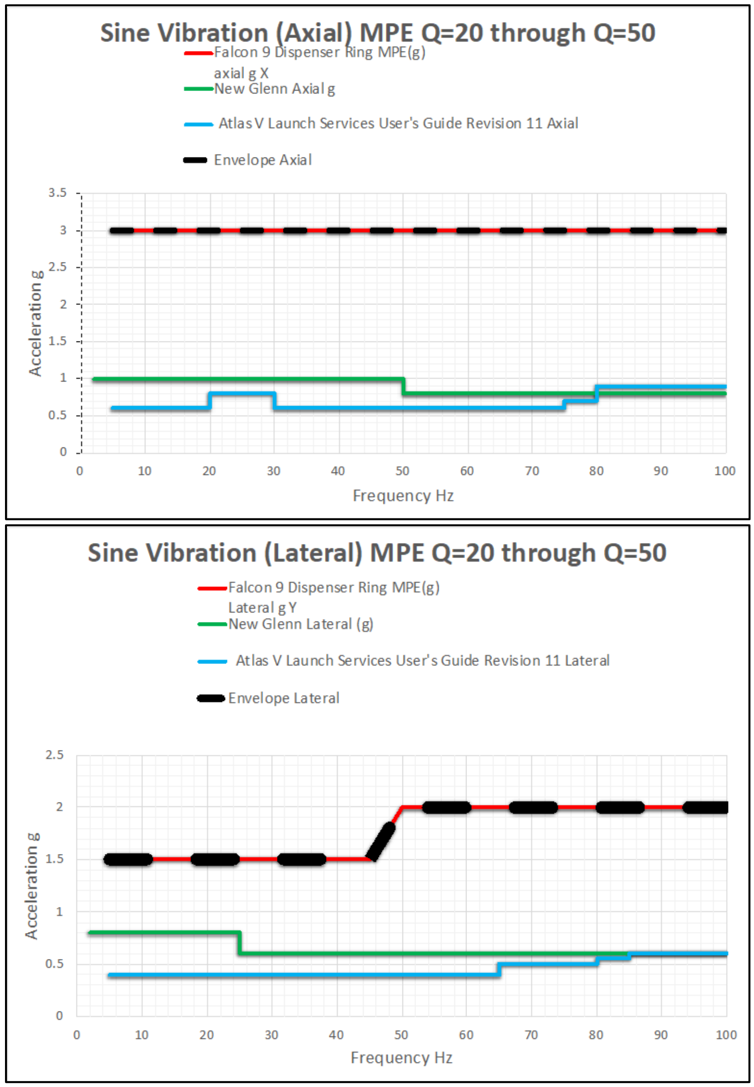


Figure 3.4. Potential sine vibration environment for several launch vehicles and spacecraft general specification.

3.1.5. Shock

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	Included

[Evaluation required to verify compliance]

Flight events such as liftoff, 1st and 2nd stage booster separation, payload fairing separation, and payload separations, create impulse waves in the launch vehicle structure. The transient, short duration waves result in rapid motion of the interface to the spacecraft. These are characterized with a shock response spectrum (SRS). An envelope of the listed documents displays the maximum predicted environment (MPE) of the shock induced by the launch vehicle (LV) and co-payloads as shown in Figure 3.4. The Atlas V curve, as an example, presents the worst-case environments with actual flight levels likely to be below the levels shown.

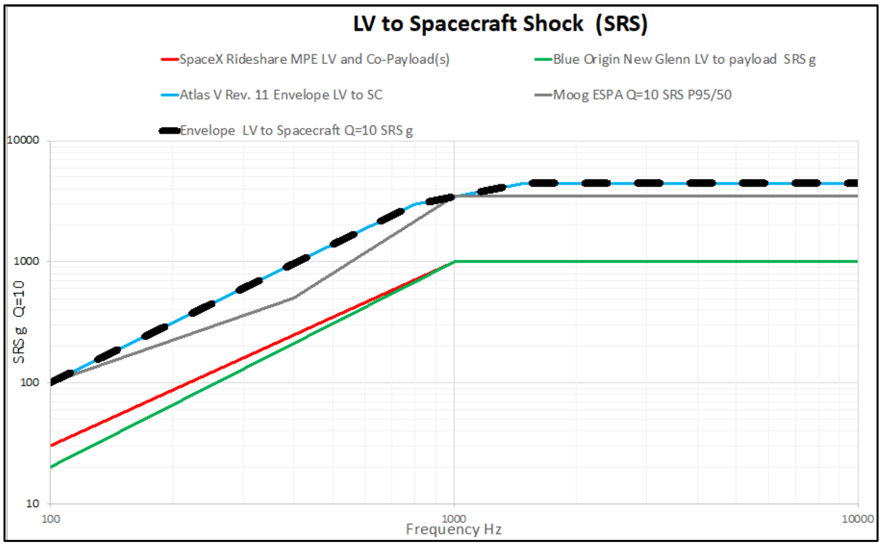


Figure 3.5. Maximum predicted launch vehicle and co-payload SRS and maximum allowable SRS produced by the spacecraft.

3.1.6. Pressure Decay

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

The Spacecraft should be capable of withstanding a launch ascent de-pressurization rate of 1.0 psi/second. (To be confirmed: Minimum levels should be ≤0.44 psi/sec (3.0 kPa/sec), apart from a transient phase of ≤0.73 psi/sec (5.0 kPa/sec) for ≤5 seconds.)

An example pressure profile (Atlas V) is shown in Figure 3.5.

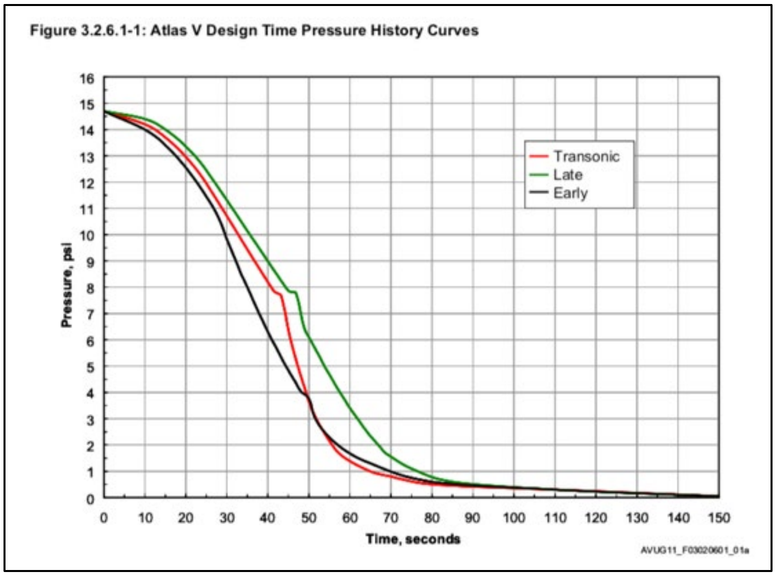


Figure 3.6. Typical Pressure decay curve[7]. (Courtesy of ULA)

3.1.7. Thermal

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

MMDS class spacecraft on a multi-manifested mission will experience three temperature environments. The first is the ground environments in the processing facility, within the fairing during transport to the pad, and while on the pad. These are well controlled and should not represent a stressing condition.

The second thermal environment is liftoff through insertion on orbit. These conditions are well understood and have been enveloped for MMDS design considerations.

The third, and potentially the most stressful, thermal environment is from insert on orbit through deployment. Both the thermal conditions and the length of time are mission dependent.

> ***Note:*** *Since MMDS spacecraft are powered off during this period, separately controlled heaters may be needed.*

Thermal environments are highly dependent on individual missions; however, ranges can be projected. These levels are representative of the levels found in the listed documents.

Processing: 70° ± 5° F (21° ± 3° C).

Encapsulation: 50° F to 90° F (10° C to 32° C)

On Pad: TBD°F to TBD°F (TBD°C to TBD°C)

Ascent: 135° F (57° C) to 200° F (93° C) during launch.

On-Orbit: For a typical 30-minute, geosynchronous transfer orbit mission, radiation environments ranging from -50° F to 125° F (-45° C to 52° C), and interface temperatures ranging from 32° F to 120°F (0° C to 49° C) at the forward end of the payload adapter.

Spacecraft should be designed to survive the ascent thermal environment and the space environment prior to their power on and deployment without the use of heaters.

3.1.8. Electro Magnetic Interference (EMI)

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

During launch MMDS spacecraft are in a powered down state[5].

OPEN: *This is an area where the community did not reach a consensus on the RF environments that should be enveloped and needs additional work.*

MMDS spacecraft will experience RF energy while in the processing facility where they will be both powered for testing and powered off for integration and encapsulation. Although powered off from encapsulation through deployment on orbit, they will still experience RF radiation from a variety of sources during transit to the pad, from range emitters, and the launch vehicle.

The spacecraft developer must evaluate the design for compatibility and sensitivity to these RF/EMI environments. Worst-case radiated environments are shown in Figure 3.7. The levels envelope the expected emissions from the launch vehicle, co-payloads, and launch site operations.

Once deployed, the spacecraft will experience RF radiation from the launch vehicle transmitters. These radiations must be considered from the time of separation (powered off) through a 45 minute window after the spacecraft is powered on. This level of radiation must also be considered as the distance between the launch vehicle and the deployed spacecraft increases.

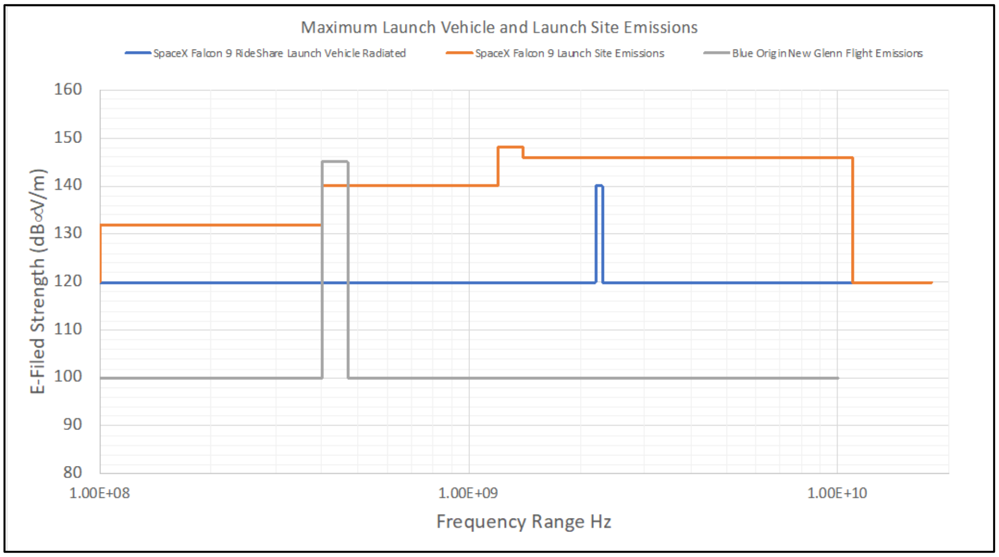


Figure 3.7. Launch Vehicle and Launch site emissions.

3.2. Mechanical Requirements

3.2.1. Mechanical Characteristics

MMDS spacecraft shall fit within the volumes identified for the three proposed spacecraft classes defined in Section 2.9. For Class 2 and Class 3 spacecraft, the CG should be within 20" of the mounting interface plane. The resonant frequency should be above 50 Hz[5].

> *Note: NASA requires the resonant frequency to be above 75 Hz.*

3.2.2. Mechanical Interface

The Moog ESPA rings, the SpaceX adapter ring, and SpaceX Starlink adapters all share standard bolt patterns for either a 15" or 24" circular mount. Most multi-manifested spacecraft are designed to separate and the standard separation hardware (described in Appendix D) mount to these standard bolt patterns shown in Figure 3.7. The separation systems included in the MMDS should provide a minimum separation velocity of 1 foot per second and a maximum of 3 feet per second[6]

The standard ESPA ring is also available with a 15" four-point mount. Figure 3.8 shows this mount in blue relative to the standard 15" circular mount for comparison. The circular and four-point mounts are only available in one configuration or the other. Since this mount is not available as a standard option on other small payload adapters, designing for this mount automatically reduces maximum flexibility with other launch options.

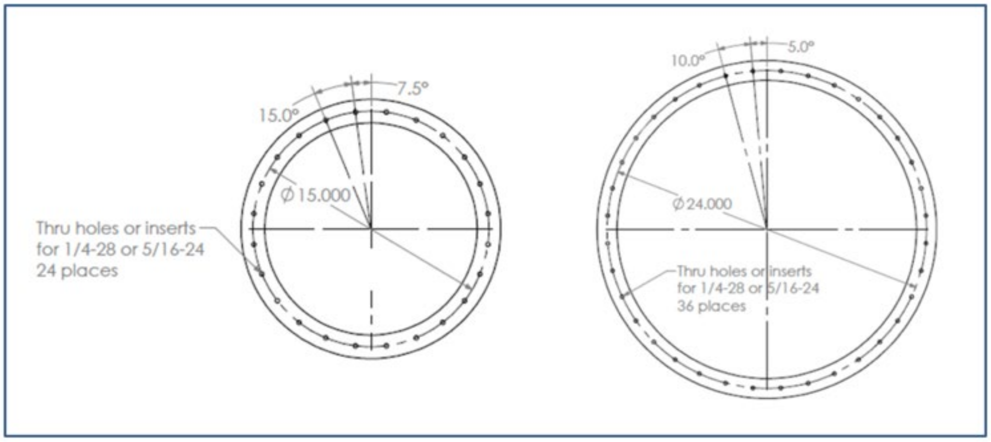


Figure 3.8. Standard 15" & 24" port interface bolt patterns[9].

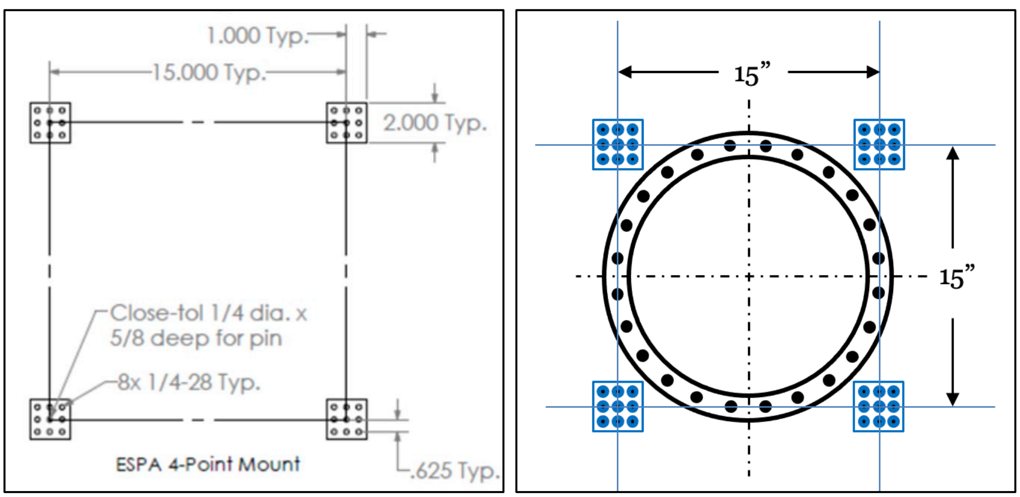


Figure 3.9. ESPA 15" four-point mount compared to circular 15" mount.[9]

Note: For maximum flexibility, the MMDS assumes the use of ¼" bolts only.

3.2.3. Coupled Loads

Enveloped Sources

1	SMC-S-016 – Standard Test Requirements	
2	GEVS - NASA General Environmental Verification Standard	
3	EELV Rideshare User's Guide	
4	NASA SMD Rideshare User's Guide & Do-No-Harm	
5	SpaceX Rideshare User's Guide	Included
6	ULA Atlas V Launch Services User's Guide	

7	Blue Origin New Glenn Payload User's Guide	
8	Moog ESPA User's Guide	Included

[Testing required to verify compliance]

Payload center of gravity shall be measured from the interface at the small payload adapter/launch vehicle mounting plane. The spacecraft center of gravity must take the separation system and any adapters into account to ensure the payload assembly is within the required constraints. The maximum distance of the payload Center of Gravity from the mounting interface is shown in Figure 3.9.

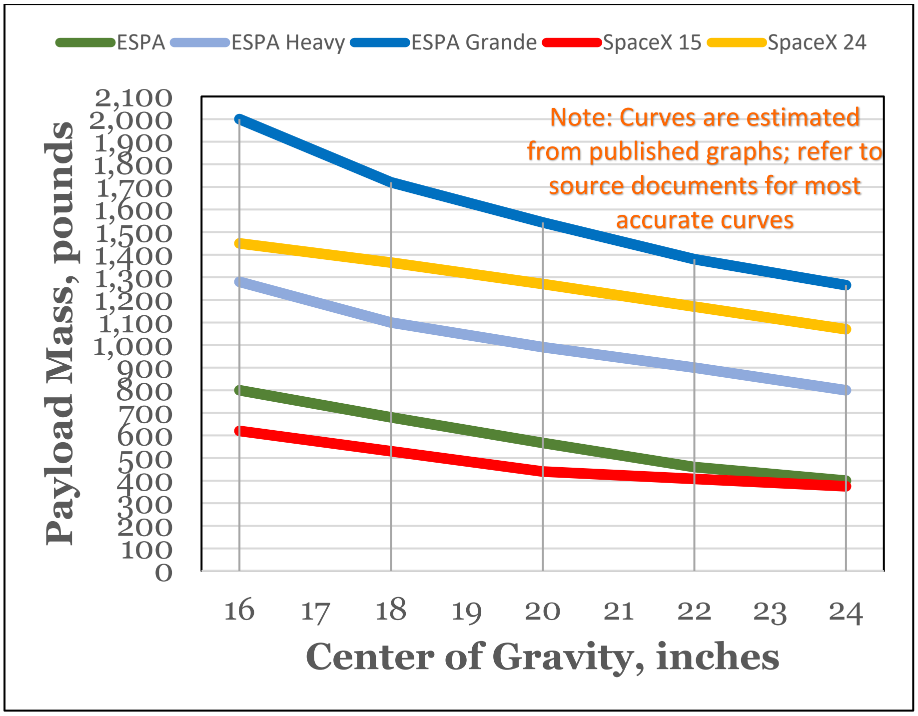


Figure 3.10. Mass – Center of Gravity Curve [6 & 9].

Note: The Moog ESPA ring allows a greater maximum distance from the mounting surface to the payload Center of Gravity for a given payload mass than the SpaceX ring.

Multi-manifested payloads (spacecraft, separation systems, and any required launch adapters) first fundamental frequency should be above 50 Hertz. The first fundamental frequency shall be demonstrated by test. Force limiting may be used to limit the vibration levels at resonant frequencies; all other notching methodologies should be avoided.

3.3. Electrical Requirements

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	

2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Spacecraft shall be completely powered off from the time they are integrated to the payload adapter and encapsulation through their separation on-orbit. Therefore, there is no powered electrical interface. The only electrical interface is the set of loop back circuits through the separation system to indicate separation.

3.3.1. Spacecraft Electrical Interface

The multi-manifested spacecraft electrical interface shall be with the separation system connectors. The example shown in Figure 3.10 is based on Planetary Systems Corporation's Advanced Light Band, but the Sierra Nevada and Beyond Gravity (RUAG) separation systems are similar and are provided for reference in Appendix D.

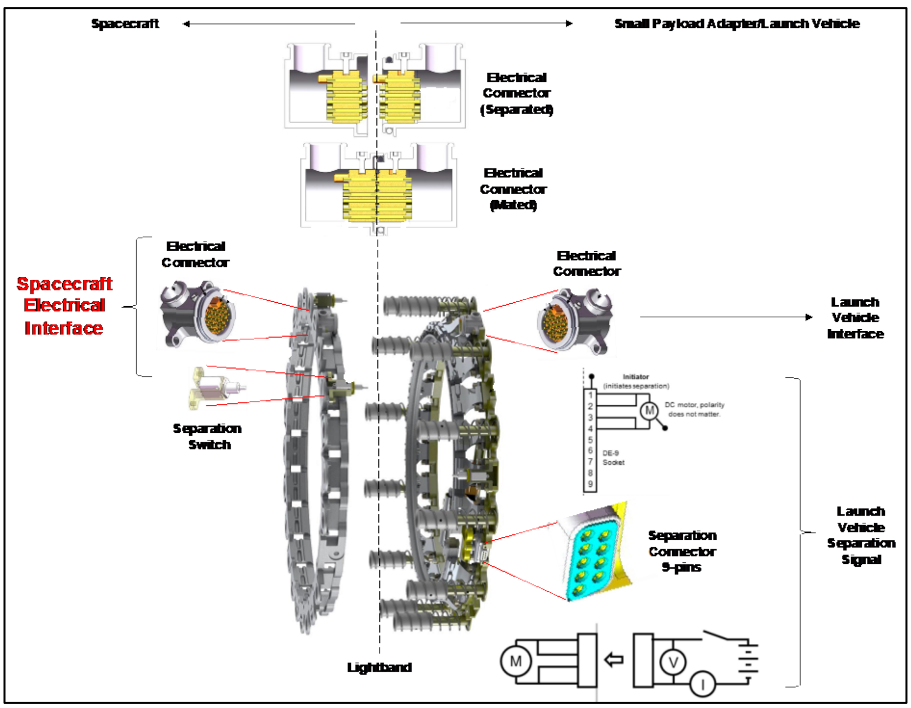


Figure 3.11. Spacecraft electrical interface to separation system.

The electrical interface for the spacecraft shall include as a minimum primary and redundant separation signals and separation confirmation of a minimum 2 circuits in the electrical interface to the launch vehicle to accommodate one separation signal and one separation indication as shown in Figure 3.11.

Separation loop back circuits can be provided through the 30 pin separation connector shown in Figure 3.11.

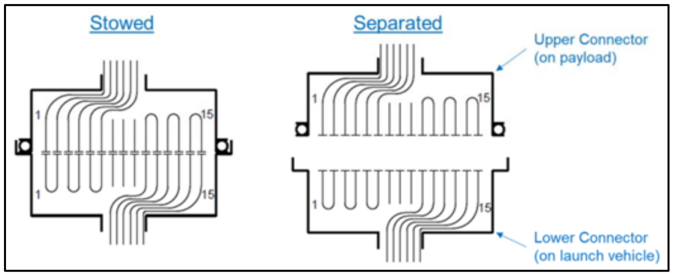


Figure 3.12. Separation loop back signals.

> ***Observation:*** *There are no standard interfaces among the current separation systems. The creation of standard electrical interfaces should be considered in the future.*

Spacecraft should be designed to require no access (no battery charging or software updates) for at least 2 months after integration to the LV adapter to ensure maximum launch opportunities.

3.3.2. Inhibits

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

At a minimum, there **must** be three inhibits to the activation of all critical functions. These include, but are not limited to, propulsion systems, deployable structures (such as solar arrays or antennas), and all transmitters. Verification of this requirement by analysis is acceptable (refer to AFSPCMAN 91-710).

> ***Note: Remove-Before-Flight/Install-Before-Flight items do not qualify as inhibits in this context.***

3.4. Fault Tolerance

Spacecraft shall ensure a fault tolerance architecture appropriate for each unique hazard. Some representative examples are described in the Table 3.1 below.

Hazard Level/Category	Minimum Architecture	Hazard Examples
Marginal (or better)	Single fault-tolerant (safe following any one failure)	• EMI due to inadvertent avionics power-up • EMI due to inadvertent activation of torque rods, reaction wheels, CMGs, etc. • *Release of deployables that do not pose a damage or injury threat to others*
Critical (or worse)	Dual fault-tolerant (safe following any two unrelated failures)	• *Fire and/or explosion and/or thermal runaway* • *Leak or release of hazardous substances (propellant, biologicals, ionizing radiation, etc. Even nitrogen or helium gas can be considered a hazardous substance due to asphyxiation in confined spaces.)* • *Release of ≥15 Joules stored energy* • *Leak or release of contamination (dust, lubricant, etc. Even distilled water can be considered a contaminant if it's in the wrong location)* • *Release of deployables that do pose a damage or injury threat to others*

Table 3.1. Fault Tolerance Examples. **(Courtesy of Spaceflight)**

> ***Note:*** *Required architecture (i.e. quantity of inhibits or barriers) may be unique for each spacecraft subsystem. For example, a propulsion system may require three inhibits/barriers while the electrical system on the same spacecraft might only require two inhibits because of the hazards those subsystems present.*

> ***Note:*** *The use of three independent inhibits is highly recommended and can reduce required documentation and analysis*

Note: *Hazards are defined with regard to scale of personnel and property damage by AFSPCMAN 91-710. The categories are Catastrophic, Critical, Marginal and Negligible. Customers are responsible for performing a full hazard analysis of their spacecraft.*

Note: *An inhibit or barrier is a physical device between an initiation source and a hazard activation or release*

Note: *Inhibits are used to prevent inadvertent activation of a system (e.g. a spacecraft turn-on switch).*

- *Barriers are used to prevent unintentional hazard release in subsystems with stored energy (e.g. pressurized propellant system fill-drain and check valves).*
- *A timer is not considered an independent inhibit.*
- *Electrical Inhibits are often implemented as separation switches on the separation system.*
- *The spacecraft fault tolerance architecture will be approved by the appropriate range safety authority.*

3.5. Electro-Explosive Ordnance

Enveloped Sources

SMC-S-016 – Standard Test Requirements	
GEVS - NASA General Environmental Verification Standard	
EELV Rideshare User's Guide	
NASA SMD Rideshare User's Guide & Do-No-Harm	
SpaceX Rideshare User's Guide	Included
ULA Atlas V Launch Services User's Guide	
Blue Origin New Glenn Payload User's Guide	
Moog ESPA User's Guide	

[Testing required to verify compliance]

The spacecraft deployment system shall not include the use of unconstrained pyrotechnics (e.g. frangible nuts).

Pyrotechnic subsystem and devices shall meet the design and test requirements of MIL-STD-1576, Electro-explosive Subsystem Safety Requirements and Test Methods for Space Systems. All electro-explosive ordnance shall demonstrate a 20 dB Electro-Magnetic Interference Safety Margin (EMISM) to the RF environment (vs. dc no-fire threshold) for all electro-explosive devices (EED) firing circuits. All safety critical circuits shall demonstrate a 6 dB EMISM to the RF environment for all safety critical circuits and circuits that could propagate a failure to the launch vehicle.

3.6. Propulsion Requirements

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Propulsion system designs shall comply with AFSPCMAN 91-710 Vol 3 (or equivalent) design and certification guidelines and the standards for loading and offloading of propellants and hazardous commodities.

3.7. Pressure Vessel Requirements

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Pressure vessel designs shall adhere to AFSPCMAN 91-710 Vol 3 Chapter 12, Section 2 (or equivalent) and may need to be DoT certified for transportation**.**

3.8. Contamination Requirements

Payloads shall be cleaned to VC-HS standards per NASA-SN-C-005D prior to integration. Payloads shall not create particulates during the vibro-acoustic launch environment or during the activation of any payload mechanisms.

3.8.1. Cleanliness

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Spacecraft shall as a minimum adhere to Class 100K cleanliness requirements and remain visibly clean of particulate matter.

3.8.2. Outgassing

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

Spacecraft shall undergo thermal bakeout per ASTM E2900 to limit outgassing and prevent contamination. Spacecraft materials shall have a Total Mass Loss (TML) $\leq$ 1.0 % and a Collected Volatile Condensable Material (CVCM) $\leq$ 0.1 %.

Note: NASA database of outgassing properties of certain materials can be found at: http://outgassing.nasa.gov.

Note: ESA database of outgassing properties of certain materials can be found at: http://esmat.esa.int/services/outgassing_data/outgassing_data.html

3.9. Spacecraft Induced Environments

3.9.1. Spacecraft Induced Shock

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	Included
7	Blue Origin New Glenn Payload User's Guide, June 2021	Included
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Any spacecraft generated shock, including separation system, shall be less than 50 in/sec on the launch vehicle side of the spacecraft to launch vehicle interface. The 50 in/sec velocity corresponds to the SRS levels shown in Figure 3.12.

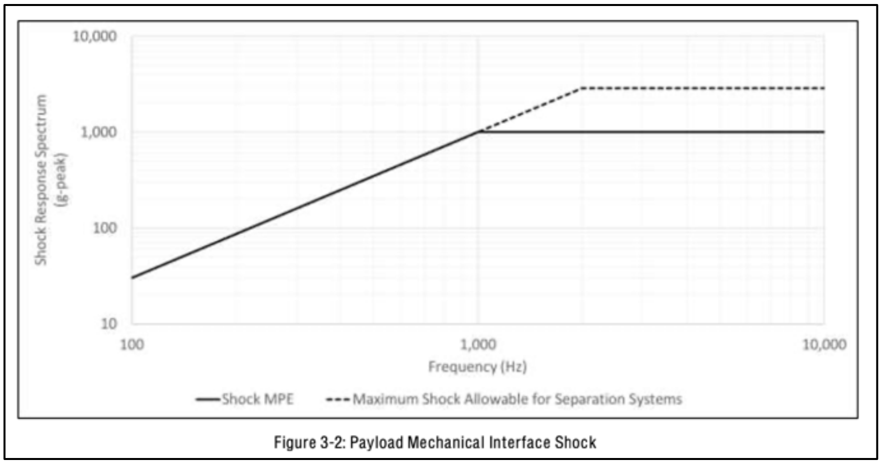


Figure 3.13. Payload mechanical interface shock.

(SpaceX Rideshare Payload User's Guide)

3.9.2. Spacecraft Induced RF

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

Multi-manifested spacecraft should remain powered off from encapsulation through deployment and should therefore provide no RF induced environments.

3.10. Spacecraft Activation after Separation

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Evaluation required to verify compliance]

3.10.1 Separation Rate

Spacecraft separation velocity should be a minimum of 1 foot per second and a maximum of 3 feet per second[6].

3.10.2. Power On

The Spacecraft shall be designed to sense the separation event has occurred via separation system break wires.

The spacecraft design shall not employ a timer to sense separation has occurred based on ground or T-0 launch events.

3.10.3. RF Compatibility

Spacecraft receivers shall be compatible with the levels of launch vehicle transmissions experienced after separation. Spacecraft RF levels shall always be below the launch vehicle maximum acceptable levels. Spacecraft should not radiate until a minimum of 3,300 feet between the deployed spacecraft and the launch vehicle has been achieved[6] or until 45 minutes after separation[5].

3.10.4. Spacecraft Maneuvers

Attitude control maneuvers shall not be performed until a minimum of 120 seconds after separation[6].

Propulsion activity shall not be initiated for a minimum of 45 minutes after separation[5].

3.10.5. Spacecraft Deployments

The spacecraft shall not deploy appendages for a minimum of 45 minutes (2,700 seconds) after separation[5]. [SpaceX requires a minimum of 120 seconds.]

4.0. Testing and Verification Requirements

4.1. General

One-of-a-kind spacecraft shall conduct proto-qualification testing to verify compliance while multiple spacecraft of the same design may conduct the more traditional qualification and acceptance testing approach. Acceptance testing shall be performed on all spacecraft.

4.2. Required Tests

4.2.1. Static Loads Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

All multi-manifest spacecraft should undergo static loads testing. Qualification and Proto-Qual levels shall be 1.25 times the load limits. Acceptance testing for recurring spacecraft previously qualified shall be 1.1 times the load limits.

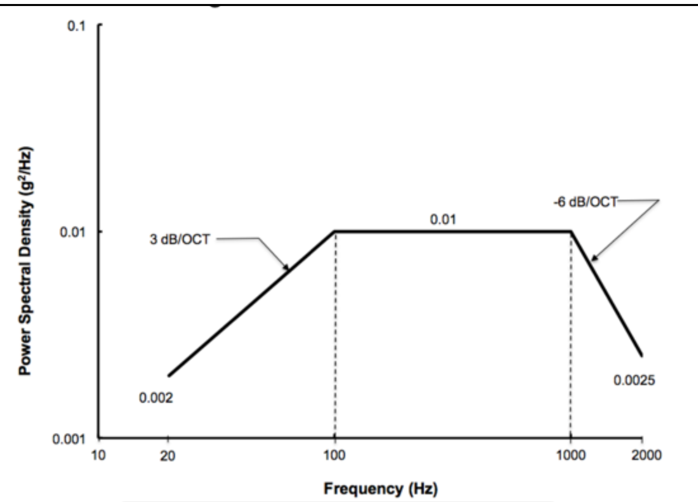
4.2.2. Random Vibration Test

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	Included
2	GEVS, GSFC-STD-7000A, April 2005	Included
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

For spacecraft families of equivalent design, the qualification levels for random vibrations tests shall be 6 dB above the required acceptance levels for 3 minutes in each of the three axes. For subsequent acceptance testing for these previously qualified spacecraft the random vibration levels shall envelope the MPE and minimum spectrum shown in Figure 4.1 for 1 minute in each of the three axes.



Spectrum Values	
Frequency (Hz)	Minimum PSD (g^2/Hz)
20	0.002
20 to 100	+3 dB per octave slope
100 to 1000	0.01
1000 to 2000	-6 dB per octave slope
2000	0.0025
The overall acceleration level is 3.8 grms.	

Figure 4.1. - Minimum vibration spectrum.

For one-of-a-kind spacecraft the proto-qual random vibration levels shall be 3 db above the acceptance levels for 2 minutes in each of the three axes.

4.2.3. Resonant Frequency Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

Multi-manifested spacecraft must be tested to verify resonant frequencies are above the 50 Hertz requirement to ensure acceptable interaction in the overall coupled loads analyses.

4.2.4. Shock Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

For spacecraft families of equivalent design, the qualification levels for shock tests shall be 1 activation of all shock events with 2 additional activations of significant events. Acceptance testing for these previously qualified spacecraft shall be 1 activation of significant shock-producing events.

For one-of-a-kind spacecraft the proto-qual shock tests shall be 1 activation of all shock producing events with 1 additional activation of significant events.

4.2.5. Pressure Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	Included
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

No qualification or proto-qualifications tests are required for pressure vessels.

Proof pressure testing is to be followed by leak testing at MEOP per the following requirements:

- For launch and upper-stage vehicles that contain pressurized structures, the pressurized subsystem shall be pressurized to a proof pressure that is 1.1 times the maximum expected operating pressure (MEOP) and held constant for a short dwell time, sufficient to assure that the proper pressure was achieved within the allowed test tolerance. The test pressure shall then be reduced to the MEOP for leakage inspection.
- For space vehicles, each isolated zone of a pressurized subsystem may have an individual proof pressure level. For zones including pressure vessels, the subsystem zone shall be pressurized to a proof pressure, which is 1.25 times the MEOP. For zones without pressure vessels, the proof pressure shall be 1.5 times the MEOP. In each case, the proof pressure shall be maintained for a time just sufficient to assure that the proper pressure was achieved, and then the pressure shall be reduced to the MEOP. This sequence shall be followed by inspection for leakage at the MEOP.
- The duration of evacuated propulsion subsystem leakage tests, matching the pressure levels of propellant servicing

conditions, shall not exceed the time that this condition is normally experienced during propellant loading.

4.2.6. EMC Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

MMDS spacecraft shall be powered off from encapsulation through deployment on orbit, mitigating the susceptibility to radio frequency interference. However, the RF environment will still include range emitters and launch vehicle emitters. SMC-S-016 defines the requirements for electromagnetic compatibility testing. Compliance by test is required.

> ***OPEN:*** *This is an area where the community did not reach a consensus on the RF environments and needs additional work.*

4.3. Recommended Tests

4.3.1. Sinusoidal Vibration Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	
2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	Included
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

Only SpaceX requires sine vibration testing if spacecraft is greater than 496 pounds or the fundamental frequency is below 40 Hz.

> ***OPEN:*** *This is an area where the community did not reach a consensus and needs additional work.*

4.3.2. Acoustic Tests

Enveloped Sources

1	SMC-S-016, SMSC Standard Test Requirements	

2	GEVS, GSFC-STD-7000A, April 2005	
3	EELV Rideshare User's Guide, May 2016	
4	NASA SMD Rideshare User's Guide & Do-No-Harm, December 2021	
5	SpaceX Rideshare Payload User's Guide, September 2021	
6	ULA Atlas V Launch Services User's Guide, March 2010	
7	Blue Origin New Glenn Payload User's Guide, June 2021	
8	Moog ESPA User's Guide, November 2018	

[Testing required to verify compliance]

For spacecraft families of equivalent design, the recommended qualification levels for acoustic tests should be 6 dB above acceptance levels for 3 minutes. Acoustic acceptance testing for these previously qualified spacecraft shall envelope the MPE and the minimum spectrum shown in Figure 4.2 for 1 minute.

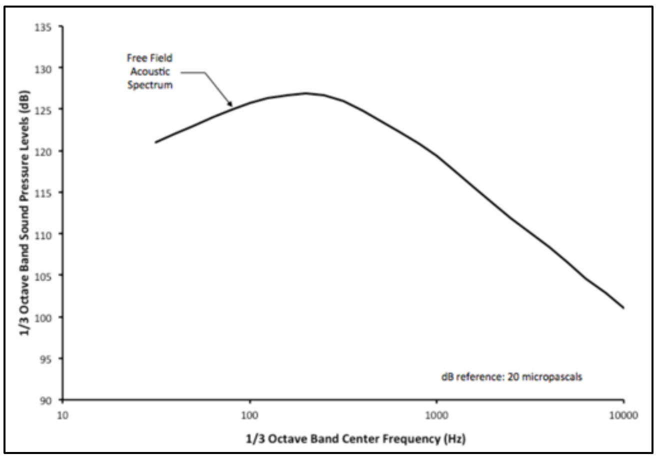


Figure 4.2. Minimum acoustic spectrum.

4.4. Tests Summary

The required and recommended testing levels are summarized in Table 4.1.

Test	Criteria	Qualification	ProtoQual	Acceptance
Static Load	Required	1.25 x limit load	1.25 x limit load	1.1 x limit load
Random Vibration	Required	6 dB above acceptance levels for 3 minutes in each of 3 axes.	3 dB above MPE spectrum for 2 minutes in each of 3 axes.	MPE spectrum for 1 minute in each of 3 axes.
Sinusoidal Vibration	SpaceX Only	1.25 times limit levels, 2 octaves/minute sweep rate in each of 3 axes.	1.25 times limit levels, 2 octaves/minute sweep rate in each of 3 axes.	1.0 times limit levels, 4 octaves/minute sweep rate in each of 3 axes.
Acoustic	Advised	6 dB above acceptance levels for 3 minutes.	3 dB above acceptance levels for 2 minutes.	MPE spectrum for 1 minute.
Shock	Required	6 dB above MPE 3 times in each of 3 orthogonal axes. 1 activation of all shock producing events: 2	3 dB above MPE 2 times in each of 3 orthogonal axes. 1 activation of all shock producing events: 1	1 activation of all shock producing events.

		additional activations of significant events.	additional activation of significant events.	
Pressure Systems	Required	Not Required	Not Applicable	Proof pressure as specified in SMC-S-016, 7.3.3.3 for pressurized subsystems: leak test at MEOP per 7.3.3.3
EMC	Required	12 dB minimum duration same as acceptance	6 dB minimum duration same as acceptance	6 dB for 20 minutes at each spacecraft transmitter frequency for radiated susceptibility

Table 4.1. Enveloped SMC-S-016 and SpaceX User's Guide test summary.

5.0. Documentation Requirements

5.1. General

Every mission requires a set of documentation that is essential to multi-manifest mission planners to accomplish two major objectives:

1. Communicate spacecraft characteristics that affect the other stakeholders of the mission, to include the mission integrator, launch vehicle provider, and other spacecraft providers on the manifest and,

2. Serve as verification and validation (V&V) artifacts to demonstrate that the spacecraft complies with all multi-manifest requirements. A complete set of documentation is essential for efficient acceptance onto multi-manifested missions.

The required documentation is generally provided chronologically as the information becomes available. Specific launch minus (L-) dates have been excluded from the discussion because there are varying requirements across the launch industry. Thus, this section will outline the required spacecraft documentation, broken up into three major chronological phases: Initial required data, required updates and interim data submissions, and final required data. This is summarized in Figure 5.1 below.

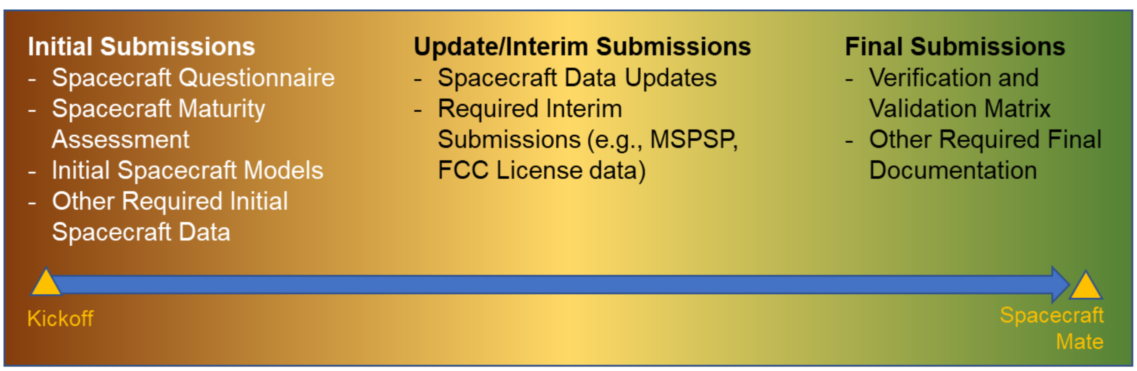


Figure 5.1. Documentation Delivery Chronology

5.2. Initial Required Spacecraft Data

5.2.1. Spacecraft Questionnaire

For a multi-manifest mission, a spacecraft questionnaire provides information about the general program and mission, the specific spacecraft, and any security or other mission unique requirements. This general information is essential for the multi-manifest integrator to understand the options and constraints that would affect the possible multi-manifest launch opportunities.

> ***Observation:*** *A standard spacecraft questionnaire would be beneficial in an environment where flexibility among launch options is desirable.*

5.2.2. Spacecraft Maturity Assessment

Mission integrators require data on the maturity of each candidate spacecraft to assess the readiness of a spacecraft for potential integration on specific scheduled launch opportunities.

The following list presents the types of information and questions typically found in this type of assessment:

- Program funding
- Level of overall spacecraft design (e.g., "PowerPoint" level, pre-preliminary design review (PDR), critical design review (CDR), etc.)
- Level of maturity of each critical payload on the spacecraft
- Expected development milestones

5.2.3. Initial Spacecraft Models

Initial models are required as inputs into larger, multi-manifest-level analyses and assessments, such as coupled loads analyses (CLAs) and general mission design. The multi-manifest spacecraft provider shall provide the necessary inputs to the models as determined by the multi-manifest integrator.

5.2.4. Other Required Initial Spacecraft Data

Mission integrators may also require other data to input into larger, multi-manifest-level analyses and assessments. The list below provides typical additional data that may be asked of each spacecraft provider:

- Spacecraft Mass Properties
- CAD/CAM drawings of the spacecraft
- Detailed description of other mission unique requirements

5.3. Updates and Interim Data Submissions

As the spacecraft design matures, changes to the initial submissions of the spacecraft models and/or data must be communicated to the mission integrator to assess progress as the mission integration process continues. Additionally, during spacecraft development and mission integration, several statutory data submissions must be prepared and sent to obtain approvals for spaceflight in time for the mission integration and launch date. These two categories are outlined in this section.

5.3.1. Spacecraft Data Update Requirements

The list below outlines some of the updates of the previously submitted models and data that typically need to be resubmitted as the spacecraft design matures and completes final build.

- Updated Assessment of Spacecraft Maturity
- Updated Spacecraft CAD Model
- Updated Spacecraft FEM (Craig-Bampton)
- Updated Spacecraft Thermal Model
- Updated Spacecraft Mass Properties

5.3.2. Required Interim Data Submissions

For multi-manifest missions, many of these statutory data packages are submitted by the mission integrator or the launch vehicle integrator as an aggregated submittal. Therefore, it is imperative that each multi-manifest payload provider furnishes their data submissions on time and accurately to avoid delays and rework on a multi-manifest mission.

The list below outlines the typical required interim data submissions and spacecraft providers must provide their inputs to the submitting entity complete and on time.

- Missile System Prelaunch Safety Package (MSPSP)
- Flight Safety Data Package
- Orbital Debris Assessment Report (ODAR)
- Federal Communications Commission (FCC) License
- Federal Aviation Administration (FAA) License (commercial missions only)
- National Oceanic and Atmospheric Administration (NOAA) Imaging License (earth imaging payloads only)

Failure to prepare and deliver these data will result in an inability to receive required certifications and jeopardize inclusion on a multi-manifested mission. Earlier submissions are highly recommended.

5.5. Final Required Spacecraft Data

Prior to final approval for launch, spacecraft providers must submit a set of data to demonstrate compliance with verification and validation requirements to ensure spaceflight worthiness and do-no-harm to other payloads on the multi-manifested mission. This section outlines the typical deliverables that enable mission integrators to convey spaceflight readiness to the launch approval authority.

5.5.1. Requirements Verification Matrix (RVM)

A Requirements Verification Matrix (RVM), typically in spreadsheet format, that contains all the required spacecraft integration requirements **must** be completed prior to approval for launch. The multi-manifest spacecraft provider shall submit to the multi-manifest integrator the mission specific required RVM matrix.

Observation: *A standard spacecraft Requirements Verification Matrix (RVM) would be beneficial in an environment where flexibility among launch options is desirable.*

For multi-manifest missions, the completion of the RVM is paramount to ensure that the complex interactions between each ridesharing payload and the launch vehicle are built and tested as planned to ensure interoperability and compatibility with all manifested spacecraft and the launch vehicle.

Table 5.1 provides typical data required in a RVM. Each matrix includes the requirement, the verification method, and the required data artifacts necessary to demonstrate compliance.

Function	Category	Verification	Compliance
Quasi-Static Loads	Required	Test	Test Report
Random Vibration	Required	Test	Test Report
Sinusoidal Vibration	SpaceX Only	Test	Test Report
Acoustic	Recommended	Test	Test Report
Shock	Required	Test	Test Report
Pressure Systems	Required	Analysis	Analysis Report
EMC	Required	Test	Test Report
Resonant Frequency	Required	Test	Test Report
Mass & CG	Required	Measurement	Analysis Report
Outgassing	Required	Test	Test Report
Cleanliness	Required	Inspection	Not Applicable

Table 5.1. Typical Requirements Verification Matrix contents.

5.5.2. Other Required Final Documentation

In addition to the deliverables in the RVM, mission integrators typically require additional final documentation to ensure all mission, statutory certification, and other information is documented to ascertain the readiness of a payload for launch.

For multi-manifest missions, as with the Requirements Verification Matrix, these final documents serve as artifacts to demonstrate that a particular satellite will do no harm to other payloads and the booster. These artifacts aid in establishing evidence of each payload provider's due diligence to contribute to the mission success of the launch itself.

The following list provides some of the typical final documentation beyond the RVM, required of each spacecraft provider before spacecraft mate to the launch interface:

- Program Requirements Document
- Flight Safety Data Package
- FCC License
- NOAA License
- FAA License
- Mission Readiness Review (MRR) Package
- Do No Harm (DNH) Matrix

6.0. Launch Campaign

6.1. Transportation to the Launch Site

This section describes commercial transportation requirements that should be considered when shipment of the hardware to the launch site is the responsibility of the spacecraft builder. If shipment is provided by a mission integrator or launch service provider, their specific shipping requirements shall apply.

6.1.1. Spacecraft Pressure Systems

All spacecraft pressurized systems should plan to be shipped to the launch site at ambient pressure. If a spacecraft provider intends to ship the spacecraft to the launch site with a pressurized system, then the applicable DOT, range safety and processing facility safety requirements and verifications shall apply.

6.1.2. Spacecraft Shipping Containers

Spacecraft shipping containers arriving at the launch site shall be designed to meet all applicable range safety and processing facility requirements. Lift and tie down points shall be designed and tested in compliance with NASA STD-8719.

Shipping containers arriving at the launch site via aircraft shall be designed to and tested in compliance with MIL-STD-1791, titled, "*Designing for Internal Aerial Delivery in Fixed Wing Aircraft*". Shipping containers that are purged with Gaseous Nitrogen (GN2) shall have the proper labels attached warning of potential asphyxiation hazards present when opening said containers.

6.1.3. DOT Requirements

All hardware arriving at the launch site shipped over the road via commercial carriers shall be compliant with applicable Department of Transportation (DOT) requirements. Liquid Nitrogen (LN2) Dewars, K-bottles and other pressurized systems shall be DOT compliant for design, marking and labeling and appropriate warning labels or placards applied. Regulations for transporting materials can be found at: https://www.fmcsa.dot.gov/regulations/hazardous-materials/how-comply-federal-hazardous-materials-regulations

6.1.4. Ground Support Equipment

All Ground Support Equipment, (GSE applied to Electrical, Mechanical, etc.) that shall be used at the launch site shall be compliant with the safety, test, and labeling requirements in effect at that time for the range, payload processing facility, and launch service provider.

> ***Note:*** *Launch range safety requirements vary according to the launch site. For example, some ranges or spaceports levy seismic restraint requirements on GSE, while others levy severe weather survival requirements. It is the responsibility of the spacecraft builder that is arriving at the launch site to be aware of these requirements ahead of arrival and plan accordingly.*

6.1.5. Facility Receiving

Spacecraft builder offload requirements for material handling equipment provided by the launch service provider or alternatively the payload processing facility or mission integrator shall be specified by the Spacecraft builder in advance of Spacecraft and GSE delivery to the launch site.

6.2. Processing Facility Requirements/Services

6.2.1. Power, Temperature, & Humidity

Processing facility requirements are typically stated to apply from arrival until the "hand off" point of the spacecraft builder to the launch service provider and/or the mission Integrator. Typical facility capabilities are provided in Table 6.1 for reference.

Service	SpaceX	Astrotech
Power	**TBD**	**TBD**
Temperature	**70 ± 5 °F**	**TBD**
Humidity	**45% ± 15%**	**TBD**
Cleanliness	**Class 100,000**	**TBD**

Table 6.1. Standard Facility services.

6.2.2. Cleanliness

The spacecraft provider should assume cleanliness requirements and cleanliness protocols will be levied during ground processing. The expected requirements should be assumed to be ISO-14644 Class 8 which is roughly equivalent to FED-STD 209, Class 100K for air cleanliness. Prior to integration into the launch system hardware, the spacecraft builder may be requested to provide evidence and/or certification information that the Spacecraft has met the cleanliness requirements of the mission.

6.2.3. Handling

Spacecraft handling operations typically imply the movement or transfer of the spacecraft via the use of overhead cranes, tugs, rotation equipment, or other material handling devices and fixtures. These handling operations usually fall into the hazardous and non-hazardous categories in effect by the respective organizations and facilities where these operations occur. Spacecraft handling operations are typically performed via a written procedure that has been reviewed and approved by all parties and/or organizations Involved.

The spacecraft builder is responsible for stating and negotiating the handling equipment requirements and process and safety controls to be applied for spacecraft handling operations with the payload processing facility, launch service provider or mission integrator.

For maximum flexibility, provisions for both horizontal and vertical lifting and mounting should be provided.

Lifting ground support equipment such as lift handles or lift points shall be designed and tested as defined in NASA-STD-8719.9B or equivalent.

6.2.4. Commodities – Liquids & Gasses

Unless negotiated under separate arrangements with the launch service provider, mission integrator or the payload processing facility, the spacecraft provider should expect to assume responsibility for the acquisition and management of all liquids and gasses used by the builder at the launch site.

6.2.5. Physical Security

The spacecraft provider is responsible for specifying the security requirements expected prior to launch site arrival. Typically, physical access at the launch sites and spaceports is controlled and access into the designated spacecraft builder spaces and processing areas is controlled via key coded badges at entry points.

6.3. Spacecraft Processing

6.3.1. Spacecraft Testing

Spacecraft testing conducted at the launch site should be minimized as much as possible. The spacecraft builder shall provide all GSE required to support spacecraft testing conducted at the launch site. Hazardous test plans and procedures shall be reviewed and approved before arrival by range safety and the Payload Processing Facility.

6.3.2. RF Radiation

The spacecraft builder should minimize the need to radiate RF energy at the launch site. Spacecraft shall not conduct free radiation at the payload processing facility or launch site.

Note: Antenna hats may be used for testing purposes.

If a spacecraft provider requires a test that will radiate, they shall seek approval by the cognizant agencies and organizations.

6.3.3. Battery Activation/Charging

The spacecraft builder shall provide all GSE required to perform battery servicing and/or charging operations conducted at the launch site.

The spacecraft shall be powered off from encapsulation through deployment on orbit[5].

6.3.4. Propellant Loading/Pressurization

It is the sole responsibility of the spacecraft builder to obtain or perform fuel loading and pressurization services. The Spacecraft provider shall complete all fueling and pressurization operations prior to the handoff of the Spacecraft to the mission Integrator or launch service provider.

6.4. Integration & Encapsulation Requirements

6.4.1. Safety

It is the responsibility of the spacecraft builder to comply with the safety requirements of the launch range or spaceport, the payload processing facility, and the launch service provider. The spacecraft builder is strongly encouraged to assign the responsibility for coordination of the spacecraft builder safety requirements with the various involved parties or organizations. Some typical safety requirements are listed as follows:

- Acceptable identification tags and/or labeling and proof tags attached for lifting/handling hardware
- Tip over analysis performed for dollies, handling devices, work stands, etc.
- Spacecraft lift point load test and analysis
- Correctly labeling procedures and processes with appropriate warnings and cautionary statements

6.4.2. Lifting

Stand-alone spacecraft lift operations should be performed via a written procedure or an alternative documented process. Spacecraft and GSE lifting and handling operations occurring near or over the launch service provider hardware or other payloads will need to be coordinated and approved.

Lifting slings, shackles and other rigging hardware provided by the spacecraft builder, should be labeled in compliance with range safety, the payload processing facility, and the launch service provider requirements.

6.4.3. Mate Operations

The roles and responsibilities for conducting spacecraft to launch service provider or mission integrator hardware are negotiated on a case-by-case basis, well in advance of performing these mate operations.

The mating operation processes are influenced by the attach and separation systems employed for the mission and by the agreed to roles for the launch vehicle, mission integrator and the spacecraft builder. Hand off points are clearly defined in the mate procedures.

6.4.4. Closeout – Remove Before Flight

The spacecraft builder should plan to complete all closeout operations prior to or during integration into the launch service provider hardware. Remove-Before-Flight covers, arming plugs, and any other close out items which need to be installed or removed after integration with the launch vehicle shall be negotiated on a case-by-case basis. Items that require physical access to install or remove after mating, shall employ captive hardware, incorporate a means for tethering the items, or employ other drop mitigation features.

6.4.5. Transit to Launch Pad Requirements

The spacecraft builder should ensure via system design practices, that they will not levy requirements for electrical connectivity, telemetry, or any other services to be provided during launch service provider transportation, hoisting and mate operations nor during roll-out to the pad.

The spacecraft builder should ensure the system design does not require "drag on" hardware required for servicing the spacecraft after mating to the launch service provider hardware.

7.0. Launch & Deployment Requirements

7.1. On-Pad Requirements

The spacecraft shall be powered off from encapsulation through deployment on orbit[5]. There shall be no access to the spacecraft while on the pad. Taking exception to these requirements would require negotiating optional services which could limit flexibility among launch options.

7.2. Ascent Requirements

The spacecraft shall be powered off from encapsulation through deployment on orbit[5]. The spacecraft design shall be designed to be compliant with the launch ascent pressure profile as defined in Section 3.1.6.

The spacecraft electrical system design shall be in a quiescent state during ascent until the separation event has occurred.

7.3. Post Separation Requirements

7.3.1. Spacecraft Separation Sensing

The Spacecraft shall be designed to sense the separation event has occurred via separation system break wires.

7.3.2. Spacecraft Power On

The spacecraft shall be designed to power on at or after separation. Subsequent spacecraft activity should be delayed until a safe separation distance between the deployed spacecraft and the launch vehicle has been achieved as described below.

7.3.3. RF Transmissions

The spacecraft shall not radiate RF energy until a sufficient distance from the launch vehicle has been achieved (nominally 45 minutes after separation)[5].

7.3.4. Deployments

The spacecraft shall not initiate any deployments until a sufficient distance from the launch vehicle has been achieved (nominally 45 minutes after separation)[5].

7.3.5. Maneuvering

The spacecraft shall not initiate any propulsive maneuvering until a sufficient distance from the launch vehicle has been achieved (nominally 45 minutes after separation)[5].

APPENDIX A – Reference Document Sources/Links

The following public domain documents are a source for parts of this document to the extent specified herein.

Primary Government Requirements Documents

- Air Force Space Command Manual 91-710, Range Safety User Requirements Manual (AFSPCMAN 91-710)
- Space and Missile Systems Center Standard Test Requirements for Launch, Upper-Stage and Space Vehicles (SMC-S-016)
- General Environmental Verification Standard for GSFC Flight Programs and Projects (GSFC-STD-7000 A), April 2005

Rideshare User's Guides

- Evolved Expendable Launch Vehicle Rideshare User's Guide, May 2016
- NASA SMD Rideshare User's Guide, December 2021
- SpaceX Rideshare Payload User's Guide, March 2022
- Moog ESPA User's Guide, November 2018

Industry Product Documentation

- ULA Atlas V Launch Services User's Guide, March 2010
- Blue Origin New Glenn Payload User's Guide, June 2021

Related Government Documents

- RSLP-62-2019-02, Small Launch Interface Spec (SLIS), Aug 2019
- NASA Procedural Requirements for Limiting Orbital Debris (NPR 8715.6A)
- Force Limited Vibration Testing (NASA-HDBK-7004C)
- Space and Missile Systems Center Standard Independent Structural Loads Analysis (SMC-S-004)
- Standard Practice for Spacecraft Hardware Thermal Vacuum Bakeout (ASTM E2900)
- NASA Standard for the Design and Fabrication of Ground Support Equipment (NASA-STD-5005D)
- NASA Lifting Standard (NASA-STD-8719.9B)

The following appendices remain a work in progress and represent a placeholder for the information intended in each section.

APPENDIX B – Vehicle Environments & Enveloping Logic

B.1. Launch Vehicle Flight Environments.

Launch vehicle flight environments were collected and divided into two categories.

The first category included those baseline multi-manifest launch vehicles listed in MMDS Section 2.4, i.e. Falcon 9, Atlas V (also representing Vulcan), and New Glenn. These were considered the near-term baseline multi-manifest vehicles and their data was used to establish the baseline MMDS flight environments.

The second category included those smaller launch vehicles which would be likely candidates for increased flexibility in launch opportunities when multi-manifesting on the larger systems was not available. The flight environments for these systems were compared to the baseline MMDS envelopes of the larger systems. This allowed understanding of where each of these systems fell within or exceeded the baseline envelopes.

This Appendix remains a work in progress and represents a placeholder for the information intended in this section.

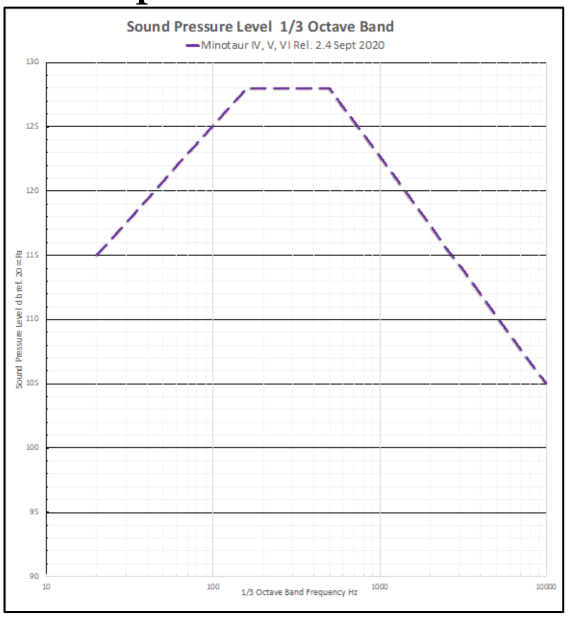
The following Table B.1. summarizes the data used in the comparison of flight environments.

Vehicle	Loads	Random Vib	Acoustics	Shock	Pressure	Thermal	EMI
Large LVs							
Falcon 9	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Atlas V/Vulcan		Yes	Yes	Yes	Yes	Yes	Yes
New Glenn		SMC-S-016	Yes	Yes	Yes		Yes
Small LVs							
Minotaur IV							
Electron	Yes	Yes	Yes	Yes	Yes		Yes
LauncherOne	Yes*	Yes	Yes*	Yes	Yes		Yes
Firefly Alpha		Yes	Yes	Yes	Yes		Yes
Relativity Terran-1							
Astra Rocket 4							
ABL Space RS-1							
USG Docs							
SMC-S-016	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GEVS	Yes	Yes	Yes	Yes			Yes
Enveloped	??	Yes	Yes	Yes	Yes	??	??

Table B.1. Flight Environments Data Summary. ***Out Of Family**

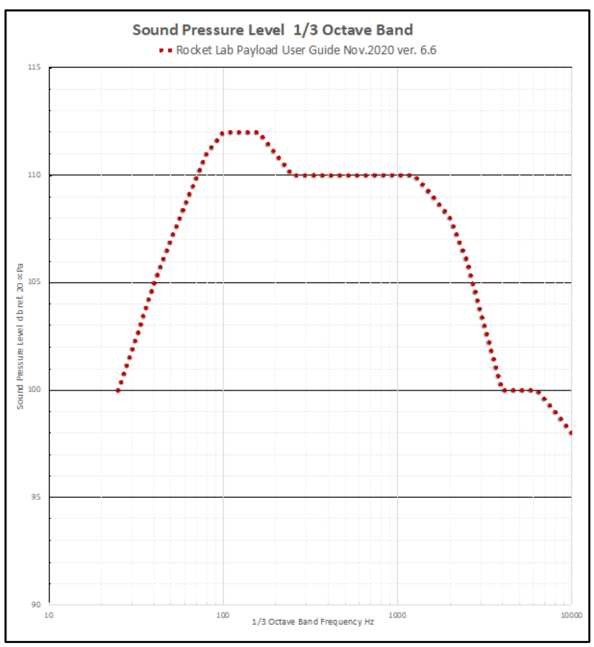
B.2. Individual Smaller Launch Vehicle Flight Environments Data

B.2.1. Northrop Grumman Minotaur IV:
To be expanded



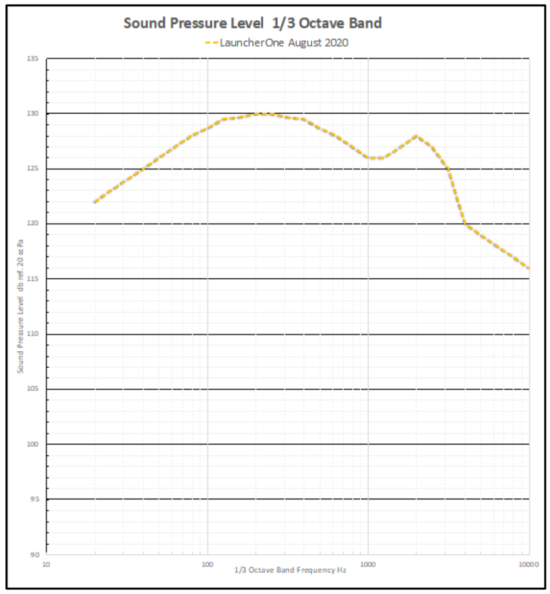
Minotaur IV Acoustics.

B.2.2. Rocket Lab Electron:
To be expanded



Electron Acoustics.

B.2.3. Virgin Orbit LauncherOne:
To be expanded



LauncherOne Acoustics.

B.2.4. Firefly Alpha:
To be included

B.2.5. Relativity Space Terran-1:
To be included

B.2.6. ABL Space RS-1:
To be included

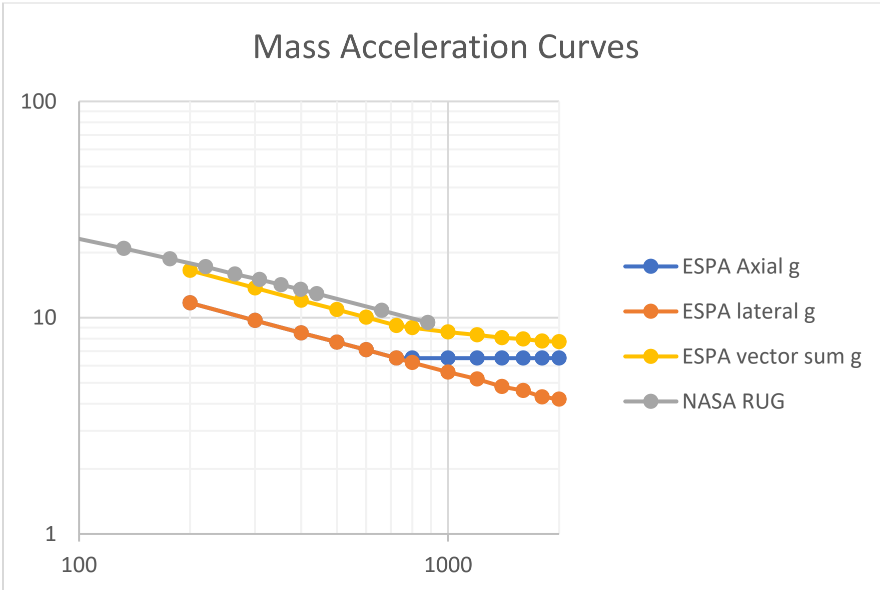
B.2.7. Astra Rocket 4:
To be included

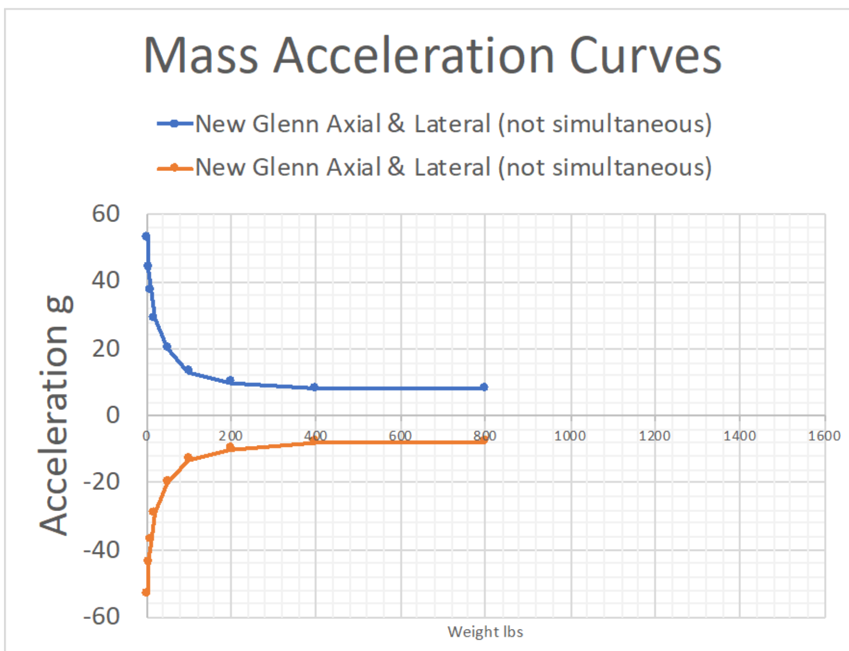
B.3. Baseline Enveloping Logic
Quasi-Static Loads

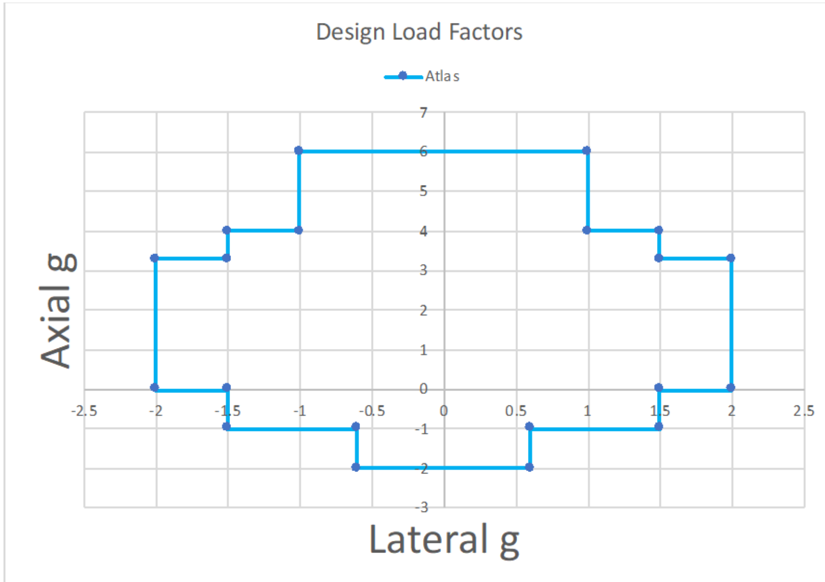
Load Case(s)

Source: Composite Enveloping Mass Acceleration Curve

For preliminary design, the steady state and dynamic responses are combined into “Quasi-Static” load factors. The expected satellite quasi-static loads can be displayed in a graphical form. Payload maximum predicted load factors are listed as a function of payload mass for spacecraft/payloads with fundamental frequencies greater than **50 Hz**. Frequencies below **50 Hz** need approval from the launch vehicle provider.


Mass Acceleration Curves
100
10
1
100
1000
ESPA Axial g
ESPA lateral g
ESPA vector sum g
NASA RUG


Mass Acceleration Curves
New Glenn Axial & Lateral (not simultaneous)
New Glenn Axial & Lateral (not simultaneous)
Acceleration g
60
40
20
0
-20
-40
-60
0
200
400
600
800
1000
1200
1400
1600
Weight lbs



Spacecraft Interface Random Vibration

Load Case(s)

Source: SpaceX Falcon 9 Rideshare User's Guide

Launch Vehicles (LV) with significant structure borne random vibration excitation at the payload attach fittings (PAF) specify the environment with an acceleration spectral density representation. The random vibration environment is driven by three fundamental forcing functions – vehicle motion and modes (coupled loads) dominating the low frequencies (<100 Hz), aeroacoustics driving the mid-frequencies (100-600 Hz), and structural vibrations driving the higher frequencies (600-2000 Hz). As indicated in the SpaceX Ride Share Payload User's Guide, the maximum predicted environment (MPE) "is derived from ground testing, flight data, and vibroacoustic models…". The smooth line is calculated using flight data from the top of the PAF and the expected vibration attenuation through the Launch Vehicle hardware to the Payload. The MPE is an envelope of all flight events (liftoff, first stage ascent, and second stage burns) and is derived at a P95/50 statistical level".

Spacecraft should be designed to and demonstrate compliance with the launch random vibration levels shown in Figure B.3. which envelopes the Falcon 9 and NASA random vibration requirements.

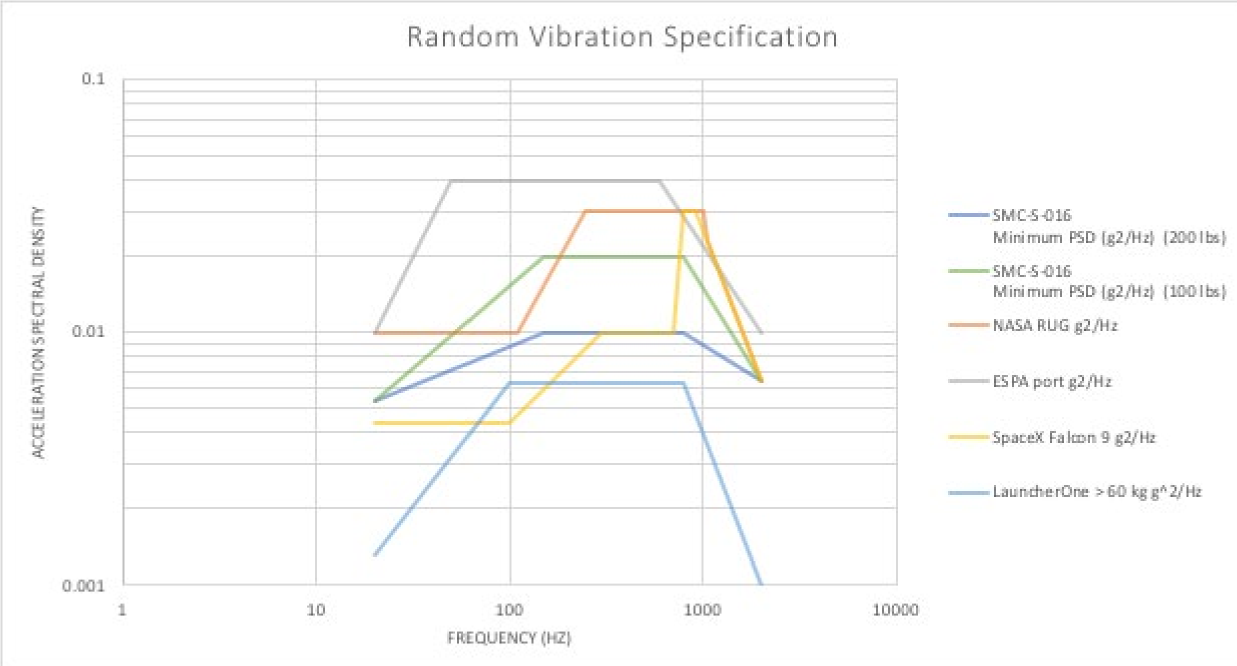
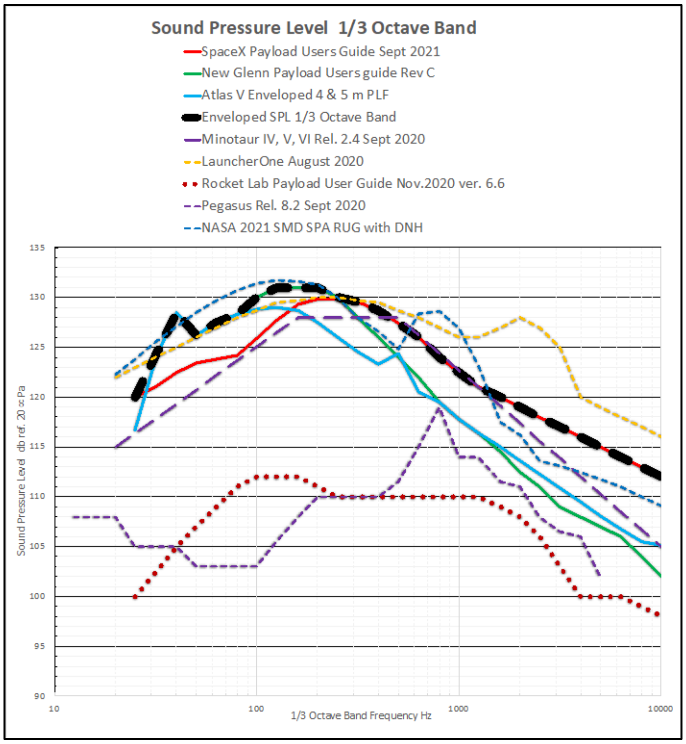


Figure B.3.4. Enveloped random vibration environment at interface to spacecraft.

Sinusoidal Vibration

Acoustic



Shock

Pressure Decay

Thermal

Radio Frequency/Electro Magnetic Interference (EMI)

Contamination

Comparisons

	SpaceX Falcon 9 RideShare User's Guide	Blue Origin New Glenn	Vulcan	NASA RUG
Launch Vehicle System as a source of Contamination: all sources and Collision and Contamination Avoidance Maneuver (CCAM)		Between encapsulation at the PPF and payload separation for most missions, the New Glenn system limits particulate contamination of the payload such that it obscures less than 1% of payload surfaces and minimizes molecular contamination of the payload to deposition of less than 150 angstroms.	Design Limits: onto SC surfaces to a molecular thickness of 150 Angstroms and a particle obscuration of 1.0% for most missions.	
Spacecraft Contamination Assessment			each SC mission has unique requirements, in the majority of cases one Mission Peculiar Design Review (MPDR) is sufficient to successfully review compliance of the mission design to the SC mission requirements.	
General/Visual Cleanliness	Payloads must be cleaned to VC-HS standards per NASA-SN-C-005D prior to integration onto Launch Vehicle hardware.			RPLs shall be cleaned to a level that will not cause a cleanliness violation for any other mission partner. shall adhere to a minimum of ISO Level 8 (Class 100,000) cleanliness requirements. shall be cleaned, certified, and maintained minimally to level 500R1 per IEST-STD-CC1246E.
Non-Metallic Materials	Non-metallic materials 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. A complete vacuum-exposed non-metallic materials list including quantities (surface area or mass) will be delivered to SpaceX for review. Any exceedances will be evaluated and approved on a case-by-case basis.	To minimize outgassing of non-metallic spacecraft materials, all payloads must meet these requirements when exposed to thermal vacuum: o Less than 1% total mass loss (TML) o Less than 0.1% collected volatile condensable material (CVCM) Similarly, the payload volume environment contamination is limited to the same targets for TML and CVCM (see Section 4.2.4: Contamination Control, Flight). Contamination levels are verified by analysis according to ASTM E595-15 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment.		RPLs material selections shall be in accordance with NASA-STD-6016 Standard Materials and Processes Requirements for Spacecraft. High outgassing materials may need to comply with ASTM E1559 testing for contamination sensitive surfaces.
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.			RPLs material selections shall be in accordance with NASA-STD-6016 Standard Materials and Processes Requirements for Spacecraft. High outgassing materials may need to comply with ASTM E1559 testing for contamination sensitive
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.			RPLs will be assessed against the risk of contaminating sensitive components of other rideshare partners. The DNH process must ensure that nothing from the RPL being assessed can be re-deposited on critical components of rideshare partners. This includes both particulate matter and volatile compounds. This requirement is assessed by a combination of test (thermal cycle or thermal vacuum) and analysis (materials lists, contamination control plans, line of sight to sensitive components). While thermal vacuum testing is generally considered an electrical stress test, the level and duration of the upper temperature soak can be used to demonstrate that any volatile compounds will have baked out of the system and no longer pose a threat to the mission. Particulate matter mitigation must be addressed prior to the first-time payloads are in the same area or in a co-used clean-room for launch processing.
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 RTV silicones with probability of transfer to Co-Payload(s) or Launch Vehicle hardware will require SpaceX approval, coordination, and notification prior to use.			RPLs should limit the use of uncured silicone to minimize impact to other mission payloads. *Max flight opportunity: No use of silicone on spacecraft.*

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APPENDIX C – Small Payload Adapter References

Small Payload Adapters. The following small payload adapter's information will be used to develop the generalized MMDS requirements. In those instances where a requirement is unique to a specific adapter or cannot be generalized, it will be highlighted as device specific.

C.1. Moog ESPA Rings (Courtesy of Moog).

ESPA rings are available in two sizes. The standard ESPA ring is 24 inches tall and has six 15-inch mounting ports evenly spaced around the ring. The ESPA Grande is 42 inches tall and has four 24-inch mounting ports evenly spaced around the ring. Both use standard ¼ inch bolts, but 5/16-inch bolts are an option providing additional load carrying capability. Moog identifies the ESPA ring configuration by a three-digit designator based on the number of ports, the port diameter, and the ring height. The standard ESPA ring would be listed as 6-15-24.

The 15-inch and 24-inch circular mounting ports are shown in Figure C.1.1. The 15 -inch port has 24 evenly spaced bolt holes, and the 24-inch port has 36 evenly spaced bolt holes.

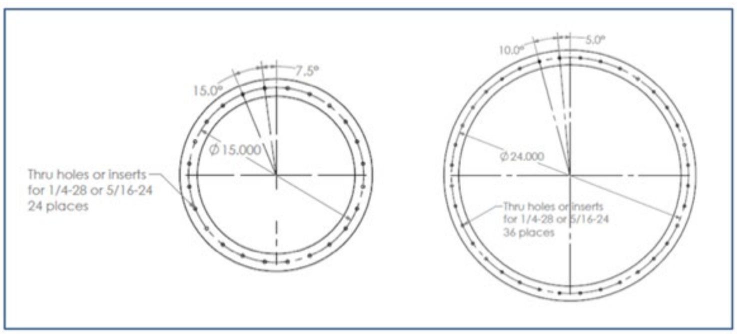


Figure C.1.1. ESPA Ring mounting ports. **(Moog ESPA User's Guide)**

A 15-inch square mount is also available on the standard ESPA ring and is shown in Figure C.1.2.

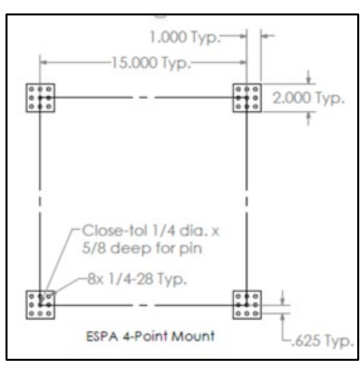
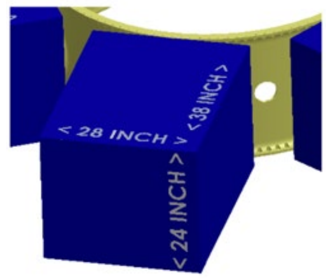


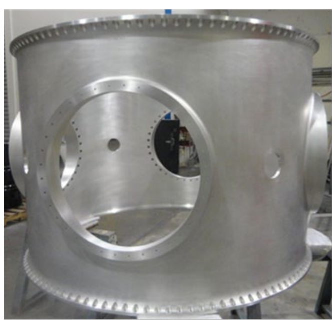
Figure C.1.2. ESPA 15" square mount.

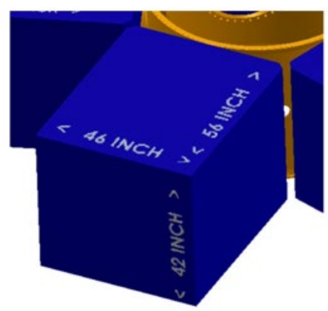
The standard ESPA ring is typically configured to accommodate six 485 pound (220 kg) spacecraft within a volume limited to a 24 inch height and a 28 inch width mounted at the port and constrained to less than 38 inches long. This 38" limiting length was based on a 4-meter fairing which will likely not be used in the future. This length can increase to about 55" when a 5-meter fairing is used.



(Moog ESPA Use's Guide)

The standard ESPA Grande ring is typically configured to accommodate four 1,545 pound (700 kg) spacecraft within a volume limited to a 42 inch height and a 46 inch width mounted at the port and constrained to less than 56 inches long.





(Moog ESPA Use's Guide)

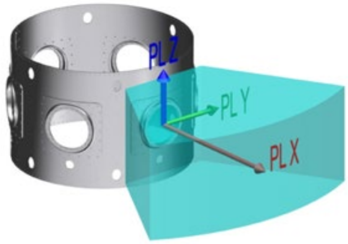
While ESPA rings can be provided in a variety of configurations, these standard configurations are the basis of the MMDS specifications.

Adapter	# of P/L s	Mass (lbs)	Height	Width	Length	Shape
15" Ring	6	565	24"	28"	38"	Rectangular
24" Ring	4	1,543	42"	46"	55.75"	Rectangular

C.2. SpaceX Secondary Payload Adapters (Courtesy of SpaceX)

SpaceX offers two secondary payload adapter rings similar to the Moog ESPA rings. Their smaller ring adapter has six 15-inch circular mounting ports spaced evenly around the ring. The available volume allocated to each secondary payload mounted on their ring is

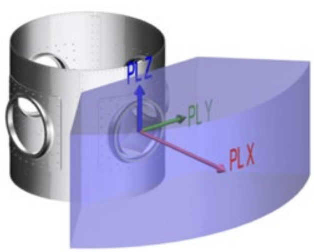
34 inches high by 33 inches wide at the port. The volume extending out from the port is 56 inches in length along a 60-degree cone constrained by the 34-inch height.



(SpaceX Rideshare Payload User's Guide)

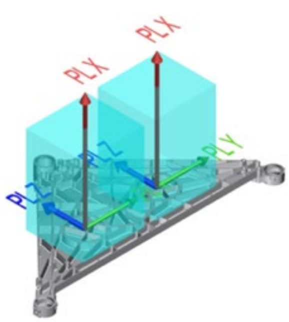
While this volume may be available to each secondary payload, it could complicate assembly if each payload filled the available volume. This is also the volume which each deploying payload must not exceed when ejected.

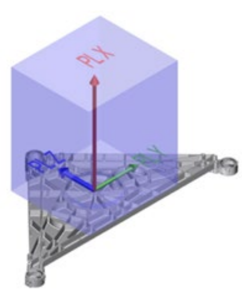
The larger SpaceX secondary adapter ring provides four evenly spaced 24- inch circular mounting ports. The payload area at the mounting port is 48 inches in height and 59 inches wide. The volume extending out from the port is 56 inches in length along a 90-degree cone constrained by the 48-inch height. While this volume may be available to each secondary payload, it could complicate assembly if each payloads filled the available volume. This is also the volume within which each deploying payload must not exceed when ejected.



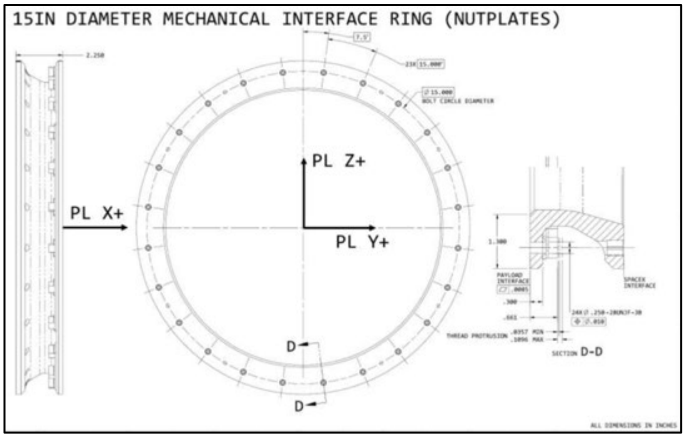
(SpaceX Rideshare Payload User's Guide)

SpaceX also offers A Starlink secondary payload adapter which can be configured with either two 15-inch circular mounts or a single 24-inch circular mount.

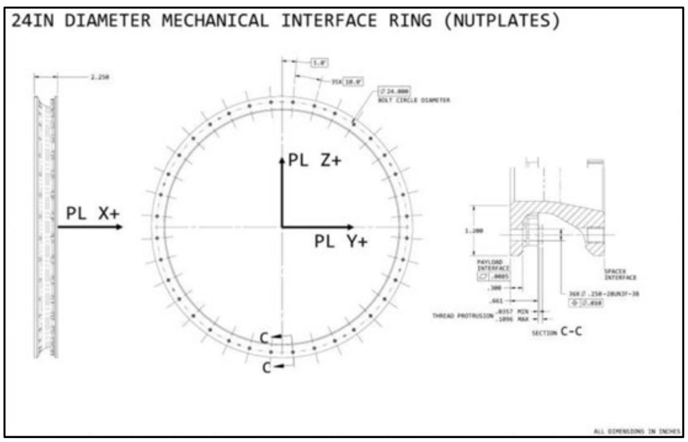




(SpaceX Rideshare Payload User's Guide)



(SpaceX Rideshare Payload User's Guide)



(SpaceX Rideshare Payload User's Guide)

The 15-inch mounts can each accommodate a secondary payload with a 28-inch by 28-inch base at the mount extending 40 inches above the mount. The single 24-inch mount can carry a 42-inch high by a 48-inch wide secondary payload at the mount extending 60 inches above the mount.

The following Table shows the parameters for each of this secondary payload options.

Adapter	**# of P/Ls**	**Mass (lbs)**	**Height**	**Width**	**Length**	**Shape**
15-inch Ring	6	465	34"	32.6"	55.75"	Pie shaped
24-inch Ring	4	1,230	48"	58.8"	55.75"	Pie shaped
Dual Starlink	2	465	28"	28"	40"	Rectangular
Single Starlink	1	1,230	42"	48"	60"	Rectangular

APPENDIX D - Current Separation Systems

This Appendix remains a work in progress and represents a placeholder for the information intended in this section.

D.1. Planetary Sciences Corporation – Motorized Light Bands.

To be provided.

D.2. Beyond Gravity (RUAG) Separation Systems

To be provided.

D.3. Sierra Nevada Separation Systems

To be provided.

APPENDIX E – Small Payload Class Definitions

This Appendix remains a work in progress and represents a placeholder for the information intended in this section.

Small Payload Classes for Multi-manifesting and Dedicated Small Launch Vehicles. Although not the focus of the MMDS, a review of the performance and fairing volumes of the small, dedicated launch vehicles is instructive in defining potential classes of small secondary spacecraft. Table E.1 provides a summary of these values based on data to specific reference orbits provided by each of these launch services providers and includes to two multi-manifesting sizes as well.

System	High Z (in)	Wide Y (in)	Long X (in)	Mass (lbs)*	Class 1 24 x 24 x 24 220 lbs	Class 2 24 x 28 x 50 465 lbs	Class 3 42 x 46 x 48 1,500 lbs
ESPA 15" Port	24	28	55.75	565	Two	One	No
Electron	29.7	29.7	> 74	330	One	No	No
Space X SL-2	28	28	40	465	One	No	No
SpaceX 15 Port"	34	32.6	55.75	465	Two	One	No
LauncherOne	49	49	83	660	Three	One	No
ESPA 24" Port	42	46	55.75	1,543	Two	One	One
SpaceX SL-1	42	48	60	1.230	Two	One	One
Firefly Alpha	79	79	> 98	1,639	Multiple	Two	One
SpaceX 24" Port	48	58.8	55.75	1,230	Two	One	One
Minotaur IV	81	81	>214	2,340	Multiple	Three	One
Astra Rocket 4	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ABL Space RS-1	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Relativity Terran-1	TBD	TBD	TBD	1,984	TBD	TBD	TBD

Table E.1. Small satellite launch capabilities. Rideshare adapters shown in blue and dedicated small launchers shown in green. *** Mass to 270 nm (500 km) circular.**

Small spacecraft designed to be less than the dimensions and mass of a Class 2 spacecraft could fly on essentially all the launch options shown in Table E.1 except Electron. Spacecraft designed to be less than the dimensions and mass of a Class 3 spacecraft could fly on all the options shown in Table E.1 except for standard ESPA, Electron, SpaceX SL-

Carefully selected payload classes could also be important for multi-manifested flight selections as well. Replacing a satellite that failed to meet flight schedules with another spacecraft ready to fly, might be more feasible if the replacement satellite was in the same spacecraft class. This could ease or obviate the need for additional coupled loads analyses. The swapping of similarly sized multi-manifested spacecraft was discussed in a regularly scheduled MMDS session. This topic needs additional discussion.

2, and LauncherOne. These conditions would tend to maximize the number of potential launch options. However, spacecraft may choose to optimize for a larger set of conditions to take advantage of additional volume and/or mass at the expense of reducing the number of possible launch options.

APPENDIX F – Regulatory References

This Appendix remains a work in progress and represents a placeholder for the information intended in this section.

Regulatory Requirements

All spacecraft shall comply with all U.S. radio license agreements and restrictions.

> ***Note:*** *Spacecraft operator should refer to the International Telecommunication Union (ITU) to determine what licenses and approvals are needed.*

Spacecraft operators shall obtain and provide to the launch provider the documentation of proper licenses for use of radio frequencies prior to spacecraft integration.

Spacecraft should generate no orbital debris.

Spacecraft should satisfy one of the following end-of-life criteria:
TBD [Review]

Developers shall be able to provide orbital debris mitigation data/assessment.

> ***Note****: This applies to both time in orbit as well as re-entry requirements.*

> ***Note:*** *Analysis can be conducted to satisfy U.S. debris requirements with NASA DAS software, available at http://orbitaldebris.jsc.nasa.gov/mitigate/das.html.*

Remote Sensing Requirements

Any spacecraft capable of private remote sensing shall obtain a valid remote sensing license from NOAA.

Non-government spacecraft shall prove compliance with government rules and regulations regarding remote sensing.

> ***Note****: More information is available at* www.nesdis.noaa.gov/crsra/licensehome.html

Miscellaneous

Spacecraft shall coordinate with the 18th Space Control Squadron prior to any orbital maneuvers to minimize risk of collision with other space objects.

> ***Note:*** *More information can be found at* www.space-track.org

Spacecraft shall submit a safety package to the launch coordinator, adhering to guidelines laid out in AFSPCMAN 91-710 Volume 3, Chapter 4 and Attachment 1, or equivalent.

Spacecraft developers shall ensure all applicable DOT (or equivalent) approvals have been granted for any shipment/transportation of any hazardous materials.

Hazardous materials are defined as liquids, gases, or solids that may be toxic, reactive, or flammable or that may cause oxygen deficiency either by themselves or in combination with other materials.

> ***Note:*** *More information can be found at* ***https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/approvals-andpermits/hazmat/general-approvals/17656/approvalsbrochureweb2.pdf***

Spacecraft launching on commercial launches in the US are required by the FAA to sign cross-waivers of liability with the other spacecraft on their launch vehicle.

Spacecraft shall comply with export control regulations, ITAR and EAR requirements, where applicable. More resources found here:

ITAR: https://www.pmddtc.state.gov/ddtc_public
EAR: https://www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear

Insurance will be the prerogative of the spacecraft owner.

