

Best Practices in the Qualification and Analysis of Launch Vehicle Payload Fairings

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Abstract

The United States Space Force (USSF) and National Aeronautics and Space Administration (NASA) organizations have launched a mix of small to super-heavy launch vehicle capabilities serving a wide variety of missions from warfighter and intelligence community needs to space exploration. The USSF and NASA have executed launches over many decades with tremendous success. The backbone for the unprecedented success has hinged on the strong partnerships established with launch service providers, and most importantly, the periodic improvements to National Security Space Launch (NSSL) and NASA standards. One area that has received attention over the years is the payload fairing (PLF), which protects the payload as the rocket ascends. PLFs are intended to enclose and protect a payload on the launch pad and during early flight, and are then jettisoned when the launch vehicle has achieved an altitude where aeroheating and aerodynamic loads on the payload are no longer a factor. While PLF design practices exist, there have been many examples of PLF failures, with different failure modes, over the history of rocketry. These failure modes include collapse, composite facesheet separation from honeycomb core, damage during the separation event, recontact after separation, and failure to separate. A reexamination of industry qualification practices has revealed some shortcomings, particularly with structural testing. Many PLF failures have occurred, primarily due to the design complexity and manufacturing shortcomings. PLF design requirements are currently disjointed and spread across several industry standards, and these designs require an integrated multidisciplinary approach consisting of mechanisms, ordnance, structures, dynamics, contamination, materials, nondestructive evaluation, and radiofrequency experts. The focus of this paper is to summarize key proposed best practices in the qualification and acceptance approaches for PLFs, while also highlighting areas for improvements in current best practices.

I. Background and Reported Fairing Incidents

The United States Space Force (USSF) and National Aeronautics and Space Administration (NASA) organizations have launched a mix of small to super-heavy launch vehicle capabilities serving a wide variety of missions from warfighter and intelligence community needs to space exploration. The USSF and NASA have executed launches over many decades with a tremendous success. The backbone for this unprecedented success has hinged on the strong partnerships established with launch service providers, and most importantly, the periodic improvements to National Security Space Launch (NSSL) and NASA standards. One component that requires special consideration is payload fairing (PLF), which protects the payload as the rocket ascends. While PLF design practices exist, there have been many examples of PLF failures, with different failure modes, over the history of rocketry. These failure modes include collapse, composite facesheet separation from honeycomb core, damage during the separation event, recontact after separation, and failure to separate.

A list of reported failures can be found in References 1-4. Trapped core pressure has led to several failures, some of which include:

Mariner 3 PLF failed at T+103 seconds due to pressure buildup in the honeycomb sandwich panel and debonding of the inner skin. Pre-flight tests were performed at temperature and at pressure, but not combined. Post-flight tests of honeycomb with vent holes that were subjected to pressure and temperature survived, while the addition of high humidity led to failure even in the vented design (1964).

Titan III fiberglass phenolic honeycomb sandwich PLF dramatically separated due to expansion of entrapped gases in an unvented honeycomb. The team improved the non-destructive evaluation (NDE) process, increased the bond strength between the skin and the core, and minimized water (1966).

Atlas Centaur AC-59 carried the FLTSATCOM 5 spacecraft into orbit. At high altitude, the inner layer of the fairing expanded inwards, damaging the spacecraft (1981). The Atlas III unvented honeycomb PLF failed in a weak bond during a pressure proof test simulating conditions at 90,000 ft. Tap testing did not initially identify the area of weak bond. A proof test was implemented due to an earlier anomaly during launch of the FLTSATCOM F-5 spacecraft where it was postulated that the PLF may have failed during ascent (1987).

During the third flight of the Long March 2E booster, carrying the Aussat B2 and Optus B-2 spacecraft, the PLF collapsed during ascent at T+48 seconds, resulting in severe damage to the spacecraft. Speculation was that high-altitude winds were higher than expected and the wind shear destroyed the fairing (1992). The fifth launch of the Long March 2E booster failed to deliver its payload, the Apstar 2 spacecraft, to orbit due to PLF failure; it appeared to be nearly identical to the failure on the third flight and occurred at T+51s (1995).

In 1995, Soyuz 11A511U booster carrying the Kometa 18 Yantar-1KFT payload suffered a PLF collapse at T+49 seconds. PLF failure was due to a defective manufacturing process that resulted in weak glue bonds in the fiberglass material. The same failure mode repeated in 1996. The Soyuz 11A511U, carrying the Yantar-4K1 payload, failed at T+51 seconds due to composite defects and weak bonds.

Delta II 7920 booster lifted off from Vandenberg Air Force Base with a payload of an Iridium spacecraft. The conclusion was that some of the insulation material in the fairing had come loose and damaged the payload (1997). In 2002, the PLF of the Volna launch vehicle carrying the second Inflatable Re-entry and Descent Technology (IRDT) payload came off early and damaged the payload prior to separation.

In 2020, Ariane PLFs were also being investigated due to excess vibration during fairing separation on two European missions, Reference 4. The PLF separated from the Ariane launcher in a “less than fully nominal” manner, causing vibrations on the rocket’s satellite above safety limits. The satellites were not damaged by the PLF separation anomalies, and the Ariane 5 successfully placed the payloads into their intended orbits. The article in Reference 4 also states “that the fairing separation, both in terms of dynamics of the launcher and in the kinematical separation effects was with no issues.” The PLFs on the most recent Ariane 5 launches worked perfectly, including the successful launch of the James Webb Space Telescope according to Reference 5.

In addition, five instances of the PLF failing to separate include: (1) Tsiklon 3 booster (1981), (2) Athena 2 booster carrying the Ikonos-1 (1999), (3) the first KSLV-1 Naro launch vehicle launched by South Korea (2009), (4) Taurus XL 3110 booster carrying the Orbiting Carbon Observatory (2009), and (5) Taurus XL 3110 for the Glory E1P Hermes KySat-1 mission (2011).

Many fairing failures have occurred, primarily due to their complexity and manufacturing shortcomings. These structures are intended to enclose and protect a payload on the launch pad and during early flight and are then jettisoned when the launch vehicle has achieved an altitude where aeroheating and aerodynamic loads on the payload are no longer a factor. PLF design

requirements are currently disjointed and spread across several industry standards, and these PLF designs require an integrated multidisciplinary approach consisting of mechanisms, ordnance, structures, dynamics, contamination, materials, nondestructive evaluation, and radiofrequency experts. The focus of this paper is to summarize key proposed best practices in the qualification and acceptance approaches for PLFs, while also highlighting areas for improvements in current best practices.

II. Industry Best Practices and Standards

PLFs are critical, primary structures that protect the payload during ascent and must be designed to separate properly so that no damage is induced to the spacecraft. PLFs must be designed for ascent loads (aerodynamics), acoustics, separation shock loads, and separation clearances/dynamics. While PLF design practices exist, there also have been many examples of PLF failures, with different failure modes, over the history of rocketry. PLF qualification tests generally include structural verification of the design, separation testing, clearance analyses, shock and ordnance testing, acoustic analyses and tests and contamination protection. In the final paper, the key requirements addressing fairing failure modes will be discussed, including those in AIAA-S-110, Ordnance AIAA-S-113 (A or B), Dynamics SMC-S-004, and System Level tests in SMC-S-016. A reexamination of industry qualification practices has revealed some shortcomings, particularly with structural and ordnance testing.

The following documents are used within the aerospace industry to define and guide design, testing, safety, and performance requirements for PLFs:

AIAA S-110-2005 / NSSL-S110-2023 “Standard: Space Systems — Structures, Structural Components, and Structural Assemblies”: Establishes design, analysis, and qualification requirements for structures and structural assemblies used in space systems. Addresses the selection of materials, load analysis, structural integrity, and qualification of components to ensure the overall system reliability during launch and in space.

AIAA S-113-2005 “Criteria for Explosive Systems and Devices on Space and Launch Vehicles”: Provides criteria and guidance for the safe design, integration, and operation of explosive systems (such as separation devices or pyrotechnic actuators) on space and launch vehicles. Emphasizes reliability, safety, and performance to ensure that these systems operate as intended under extreme conditions and do not adversely affect overall vehicle performance.

AIAA S-114-2005 “Moving Mechanical Assemblies for Space and Launch Vehicles”: Addresses design, testing, and qualification processes for mechanical assemblies that involve motion (such as hinges, latches, or deployment mechanisms) used in launch and space vehicles. Focuses on ensuring that moving parts function correctly in the harsh environments of launch and space operations, accounting for factors like vibration, temperature extremes, and vacuum conditions.

SMC-S-016 “Test Requirements For Launch, Upper-stage And Space Vehicles” (2014): Defines the testing requirements needed to validate the performance and safety of various systems on launch vehicles, upper stages, and in-space vehicles. Provides a framework for test planning, execution, and analysis so that all vehicles and components meet the necessary standards before flight.

III. System-Level Fairing Tests

System-level fairing tests include separation testing, mode survey testing, and structural qualification testing. The required evaluations per the SMC-S-016 standard are listed in Figure 1.

Separation: Separation tests under vacuum conditions serve to provide data on the separation performance, validation of the separation clearances, and provide data to support structural modeling. The recommended strategy involves full-scale testing of the PLF under both vacuum and thermal environments while utilizing comprehensive instrumentation. Although vacuum conditions may not perfectly replicate flight—particularly for partially vented structures where chamber vacuum are achieved

too slowly for direct comparison—the approach is focused on validating performance requirements rather than serving as a traditional structural qualification test. Key performance parameters to be validated include separation velocity, acceleration, angular motion, clearance distances, flexible-body distortions and loads, as well as shock levels. The test setup also verifies that no debris is liberated from either the shell or internal attachments during structural failure. To better simulate flight conditions, gravity offload systems are used during vacuum chamber tests that replicate altitude conditions, and the separation subsystem or boundary conditions are mimicked to accurately capture the separation shock load environment without added safety margins. Instrumentation plays a critical role; strain gauges are positioned adjacent to the vertical separation system to provide dynamic data for developing input models that capture both strain and bending strain rates on nearby structures. Additional gauges are placed throughout the PLF to measure overall structural response. Advanced full-field measurement techniques like Digital Image Correlation (DIC) with high-speed video further enhance the understanding of deformations near critical areas, such as the separation rail. The resulting data is then compared to ascent environment profiles to assess severity, but also to validate forcing functions from the separation event.

Mode Survey: Mode survey tests are also typically required. One test is performed to characterize Boost Phase load conditions, where a test is generally conducted to collect data necessary for determining the natural frequency, damping, and mode shapes of the system up to 100 Hz. Frequency Identification (Freq ID) tests can be used to establish the input conductance, damping, and modal density across this frequency range. In addition, non-linear bending stiffness data can be gathered through Freq ID/Stiffness tests and bisector tests, which help support the validation of analytical models used during separation analysis. Finally, mode survey tests are typically performed under both mated and bisector configurations to fully characterize the modal behavior of the system.

Structural Qualification: Structural qualification testing is also required for primary structures such as fairings. The purpose of structural qualification testing is to establish confidence in the load paths, identify failure modes, and design build. The philosophy associated with structural qualification testing is discussed in Section IV.

Table 7.3-1. Subsystem Qualification and Protoqualification Test Summary

Test	Reference	Suggested Sequence	Payload Fairing	Structure	Bus	Payload/Instrument	Multi-Unit Module
Inspection ⁽¹⁾	4.6	1, 11	R	R	R	R	R
Performance ⁽¹⁾	7.3.1	2–10	R	R	R	R	R
Static Load	7.3.2	3	R	R	R	R	R
Pressure and Leak	7.3.3	4	ER	ER	ER ⁽⁴⁾	ER	ER
Shock	7.3.6	7	— ⁽⁵⁾	ER	ER	ER	ER
Random Vibration or Acoustic	7.3.4	5	R	ER	ER	ER	ER
Thermal Vacuum	7.3.7	6	—	ER	ER	R	R
Separation and Deployment ⁽³⁾	7.3.8	8	R	—	R	R	ER
EMC	7.3.9	9	ER ⁽⁶⁾	—	R ⁽²⁾	R	ER
Mode Survey	7.3.10	Any	R	—	R ⁽²⁾	R ⁽²⁾	ER

R Required

ER Evaluation required (see 6.3)

(5) Performed as part of the separation and deployment test

(6) Evaluation required when active electronics installed on fairing

Table 7.3-2. Subsystem Acceptance Test Summary

Test	Reference	Suggested Sequence	Payload Fairing	Structure	Bus	Payload	Multi-Unit Module
Inspection ⁽¹⁾	4.6	1, 11	R	R	R	R	R
Performance ⁽¹⁾	7.3.1	2, 10	R	R	R	R	R
Static Load	7.3.2	3	ER ⁽²⁾	ER ⁽²⁾	ER ⁽²⁾	R	—
Pressure and Leak	7.3.3	4	—	—	R	R	R
Shock	7.3.6	5	— ⁽⁵⁾	ER	ER	ER	ER
Random Vibration or Acoustic	7.3.4	6	ER	—	—	ER	R
Thermal Vacuum	7.3.7	7	—	—	ER	R	R
Separation and Deployment ⁽³⁾	7.3.8	8	ER	—	R	R	ER
EMC ⁽⁴⁾	7.3.9	9	—	—	ER	ER	—

R Required

ER Evaluation required (see 6.3)

(2) Required for composite and/or bonded structures. Evaluation required for all other structures.

(5) Performed as part of the separation and deployment test

Figure 1. Subsystem qualification and acceptance tests per SMC-S-016.

IV. Structural Integrity Verification

A. Environments Definition

The load envelopes for qualification testing are required, and these are found through conducting a comprehensive analyses assessment of the combined effects such as acoustic pressure, vent pressure, and other critical loadings derived from coupled loads analysis (CLA). Thermal and moisture conditions which can depend on storage and flight trajectories also need to be considered, as these inform the material allowable.

B. Structural Qualification

Full-scale static structural qualification tests are designed to induced ascent loads. Transient dynamic loads are challenging to include into a static structural test. This test serves to validate the manufacturing and the design for the ascent phase. A full-scale PLF article should be subjected to ultimate static load tests at loading levels corresponding to a 1.25 factor of safety (FoS), which are further adjusted with thermal blanket and/or heat lamp simulations where necessary. These tests can incorporate worst-case manufacturing key design features (KDFs), accounting for temperature variations and moisture effects, ensuring critical features are evaluated under combined loading conditions that mimic both ascent and separation environments. It may not be realistic to achieve all the conditions required for a structural qualification of a PLF in full-scale test conditions, therefore, test programs may be complemented by using untested failure mode evaluations with a 2.0 FoS when models are validated with test data and paired with subscale tests.

Factor of Safety Philosophy: The normal practice for design and analysis of non-human rated Launch Vehicle (LV) primary structures is to use a FoS on an ultimate strength of 1.25 and to verify compliance by performing a full-scale static test to ultimate load or the equivalent. For most secondary structures, and in exceptional cases for primary structures, qualification for flight by analysis only (i.e., with no full-scale structural test) may be established by increasing the ultimate FoS for design and analysis to 2.0. The rationale behind these design/test options is to achieve comparable structural reliability, regardless of whether a test has been performed. The approximate equivalence of the 1.25 FS for tested structures and 2.0 FS for untested structures can also be justified in practical terms, as follows:

- a. The FoS of 1.25 for tested structures is intended primarily to account for the variations in strength that could reasonably be expected in structural assemblies built to the same design drawings and subject to the same specifications. These variations include part-to-part variations in physical dimensions and material properties, including differences in ultimate strength that may arise from tolerances permitted in the built-up assembly. The expectation is that a successful test to 1.25 times limit load effectively precludes the possibility that an identical flight article will fail at less than limit load.
- b. When no structural test is performed, two additional uncertainty factors are present: (1) uncertainty in predicting internal load distributions and structural interactions and (2) uncertainty in anticipating complex failure modes and quantifying their strength. If each of these factors is assigned a value of 1.25, the total FoS required is the product of these factors times the normal 1.25 FS required for tested structures.

A no-test FoS of 2.0 may not be achievable in cases where the design loads increased after the structural qualification test was completed. These can be referred to as the so-called “partially-tested” structure, where the fully tested structure is designed with “undertested” FoS ranging from 1.25 to 1.60 as the test factor diminishes from 1.25 to 1.0. Another way to look at the 1.60 FoS for structures that are tested nominally to limit load is to consider that the uncertainty on internal load distributions is mitigated, so the total factor required is the ratio of 2.0 and 1.25; or equivalently 1.60.

PLF-Specific Guidelines: PLF jettison and LV stage separation events pose a few unique issues relative to structural design. One problem relates to qualification testing. Due to the highly dynamic nature of these loading events, it is difficult to perform a structural test, either statically or dynamically, which demonstrates an appropriate FoS on strength. Another issue is the question of structural risk associated with failure of expended hardware, where the concern is the potential for debris to impact the LV, so only those failure modes that might create debris need be considered. The third issue is the highly transient loading.

Typically, PLF separation tests are performed to demonstrate compliance with system level requirements, such as ordnance function, separation force margin and clearance. Consequently, PLF separation tests do not normally qualify the structure for strength but do provide a nominal demonstration of strength to something approaching a limit load condition. If the tests include instrumentation, they may serve to reduce uncertainties in internal load predictions. It is therefore reasonable to reduce the ultimate FS from 2.0 to 1.60 based on a successful full-scale separation test so as long the load path and failure modes are well understood and validated by subscale tests.

Considering these unique issues, and recognizing that minimizing the impact of PLF separation on the design is a very practical goal, the following guidelines are proposed:

1. The majority of PLF primary structures should be designed for ascent flight loading conditions, using a 1.25 FoS verified by a full-scale static test to ultimate load.
2. Strength design for PLF Separation Loads:
 - a. For primary and secondary structures that are tested to 1.25 times the limit PLF separation loads, a FoS of 1.25 is appropriate. Note that a dynamic separation test will rarely provide this level of qualification. More typically, selected PLF structures may be qualified for separation loads via subcomponent or “bench” tests.
 - b. For failure modes involving components on the PLF outside surface and away from the separation joint, a FoS of 1.25 is acceptable. An example is outer facesheet buckling near the “spine” of the bisector. The risks associated with such failure modes are usually minimal, since any debris that may be created will not likely have a line of sight to contact the LV.
 - c. For failure modes of internally-mounted components, structures, fasteners and the shell inner facesheets, a FoS of 1.60 is acceptable, provided that these structures were present during the separation test.
 - d. For failure modes of internally-mounted components, structures, fasteners and the shell inner facesheets that were absent during the separation test, a FoS of 2.0 is required.
 - e. Finally, structural tests and ordnance tests were never designed to impart qualification loads from the separation event. In this failure scenario, a transient load is imparted to the adjacent structure to the separation plane during the separation event, and a force travels from the separation plane to the adjacent composite structure. The test program should include a dedicated series of tests designed to simulate separation events under dynamic conditions. A factor of safety of 1.25 for separation loads is demonstrated through subscale tests that target the composite structure adjacent to the separation plane. These tests replicate flight-like core pressures, temperatures, build quality, and strain rates—ensuring that the composite directly adjacent to the separation interface is exposed to the maximum allowable strains and core shear stresses at elevated temperatures and internal pressures. Special emphasis is placed on dynamically replicating loading conditions imparted on the adjacent structure and any potential defect located between the facesheet and the core. Repeated testing under these controlled yet variable environments, combined with pre- and post-test NDE inspections, ensures not only that the induced dynamic conditions encompass the full spectrum of potential variabilities but also that the dynamic behavior observed in subscale tests correlates with those documented in full-scale separation tests.

Buckling margins should be verified by performing rigorous analytical evaluations that include geometric imperfections, using either a conservative analysis FoS of 2.0 or, when the load path and stiffness are well understood, a factor of safety of 1.25.

B. Structural Acceptance Testing

In addition to the full-scale proof tests, the qualification plan should include an acceptance test program for each production article prior to achieving the ultimate load condition, using a 1.1 test factor on the maximum flight loads and corrected for test-like-you-fly (TLYF) differences. This approach should be accompanied by a non-destructive evaluation (NDE) inspection conducted both before and after the proof tests to verify that the production articles are free from hidden defects. The proof test approach can be augmented with witness panel testing, tag-end testing, and other quality metrics to increase confidence in the production article.

C. Trapped Pressure

Trapped pressure in the PLF presents a serious concern, as past failures have shown that high internal pressure—combined with manufacturing challenges—can lead to the facesheet detaching from the core. This issue also extends to spacecraft and even aviation applications (Reference 2-3). The general approach requires fully characterizing the internal pressure, external loading, and environmental conditions to define the critical flaw size between the facesheet and the core, and ensuring that the critical flaw size can be screened by NDE, Figure 2.

In flight, the facesheet may experience this trapped pressure during ascent and can be exacerbated by varying venting rates, heating conditions during flight, and potential defects between the facesheet and the core. To address these risks, testing is necessary to determine core pressure during ascent and the venting rates under different environmental loads. A key part of

the evaluation process is to define what size defect is acceptable using a step-by-step approach. This involves testing that characterizes the strength at which the facesheet fails, measuring the fracture toughness at the interface between the core and facesheet, and assessing environmental factors. Subscale tests that apply pressure loads along with external loads are used to validate the analysis used to predict failure. This process helps set a threshold for detectable flaws in the structure.

Proof tests are capable of simulating both internal pressure and external loads, but this could prove to be impractical in certain applications; the focus then, must shift toward improving the quality of the hardware itself and enhancing the sensitivity of inspection techniques. The allowable flaw size is defined using coupon testing and analyses, with a factor of safety applied to account for uncertainties in non-destructive evaluation methods. This approach addresses the potential for undetected flaw growth during proof testing and ensures that the full range of environmental conditions, including the effects of material porosity, are taken into account.

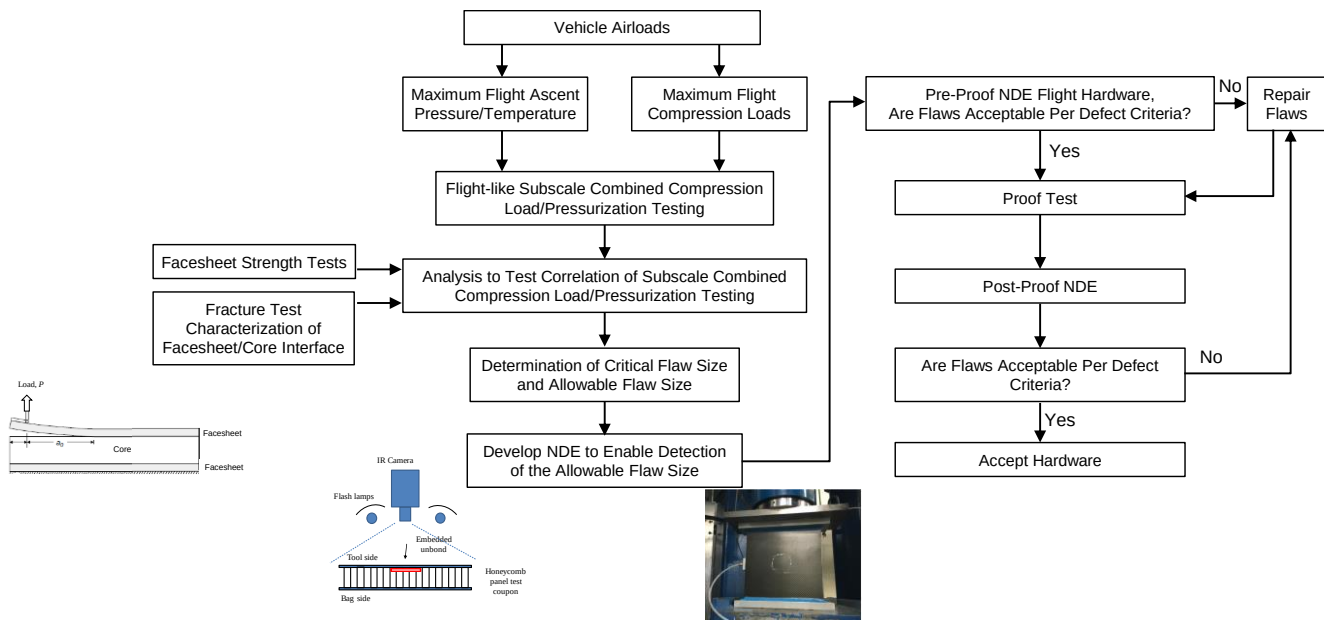


Figure 2. Flow logic for establishing the acceptable flaw sizes for trapped pressure conditions.

V. Acoustic Testing, Contamination, Clearance Analyses, and RF

Acoustics: A best practice for acoustic testing begins with a system-level approach that captures the overall behavior of the component during simulated flight conditions. The primary concern is ensuring that debris generated from any internal surface to the fairing does not adversely affect the spacecraft, as has been the case in past failures. This necessitates acoustic testing that replicates full flight environments to capture any potential failure modes that could lead to the release of contaminants.

Subscale vibration tests can also be conducted under vibration levels ranging from the minimum probable environment to levels slightly exceeding this threshold. These tests can be acceptable if the test configuration reliably simulates flight conditions and captures possible failure modes.

It is also important to evaluate the need for a full-scale re-test based on any design changes that might impact acoustic noise reduction. Historical testing has demonstrated that system-level acoustic evaluations can be used not only to verify internal acoustics and noise reduction but also to provide critical vibration data for component margin verification and model correlation. A comprehensive test program should include validation of vibroacoustic models and direct comparisons to flight measurements.

Contamination: The goal is to reduce particulates that could break loose from the fairing internal mold line that could degrade the performance of the spacecraft. Typically, it is advised that a dedicated clean room be established for acoustic panel installation, other final assembly operations, and shipment preparation. Cleanliness controls should be maintained rigorously throughout the entire lifecycle—from initial construction and storage to integration on the fairing and final preparation before launch. Any mechanisms that could generate debris and/or foreign object debris such as metal-to-metal abrasion during the boost phase can be of concern. To reduce this risk, improvements in the design should be made to mitigate the generation of debris and/or particulates. The effectiveness of the improved design should be validated through flight-like vibration testing that accurately simulates the boost phase conditions.

Clearance analysis: Post-flight data can be used to compare expected and actual clearance dimensions at critical interfaces, as typically these types of analyses are challenging to conduct. Any expected discrepancies can be addressed by improving models and enhancing model correlation efforts for modes up to 70 Hz or lower depending on the primary modes of the system. Strict correlation criteria outlined in applicable industry standards such as AIAA S-110-2005, SMC-S-004 and NASA-STD-5002A should be followed. The analysis should be refined and updated to match the clearance measurements documented during test flights.

Radiofrequency (RF) testing: Required for PLF to ensure spacecraft's communication and sensor systems during flight will meet operational needs. PLF constructions can potentially interfere with radio frequency signals by unduly attenuating, reflecting, or otherwise distorting the electromagnetic waves that need to pass through or around them. The fairing materials and design may create unintended resonant cavities or signal leakage points which could compromise the performance of onboard systems. Tests need to be conducted to validate performance of RF shielding, absorption, or transmission characteristics. In practice, RF testing might involve measuring signal loss, interference, and emission levels under simulated flight conditions, ensuring that the fairing preserves the intended performance of the communication, telemetry, or sensor systems installed within or near the structure.

VI. Ordnance

Linear separation systems, as defined in AIAA S-113B-2023 [6], are used to connect flight vehicle structures (such as in stage or payload fairing separation) and actively separate upon initiation, Figure 3.

Thrusting joints are not comprehensively addressed in AIAA S 113A 2016, and most requirements must be inferred by comparison with similar devices. In contrast, AIAA S 113B 2023 introduces a dedicated section for Linear Separation Systems and explicitly defines thrusting joints. A thrusting joint is a mechanically fastened structural joint—secured by rivets and incorporating a flat bellows or tube—that is inflated by an explosive cord or an attached gas generator (which may include a pressure attenuator). This actuation force both breaks the mechanical joint and performs work on the separated bodies.

There are two minor but significant omissions in the Standard that must be addressed: the 120% explosive load margin test and a 10°C temperature margin on the MPE for qualification and acceptance testing.

The design requirements (Section 5.3.9.5) mandate that the system carry flight loads prior to function, with no foreign object debris or contamination present at initiation, and that the joint separates at a specified velocity. Margin requirements (Sections 5.4.11.5 and 6.2.12.5) call for three tests each at MPE hot and cold. For performance margins, the system should either use the nominal explosive load with fasteners sized to 120% of the break area or an 80% explosive charge weight with nominal fasteners. Although the structural margin requirement is omitted in the Standard, it is recommended that the system maintain structural integrity with a 120% explosive charge weight.

For the linear separation system (Section 6.3.22), lot samples of the explosive cord must be inspected via X-ray, and measurements of weight, density, and detonation velocity must be performed. Additionally, pull testing is required for the explosive cord and its end cups, shear testing for fasteners, and leak testing of bellows both before and after assembly into the separation rail.

Finally, subscale test specimens—typically 1–2 meters in length with appropriate boundary conditions and composite panels—may be used when full-scale tests are impractical. Ideally, the subscale test is as flight-like as possible to introduce forcing functions and loading rates in a manner that is similar to flight conditions with the appropriate margins and environments.

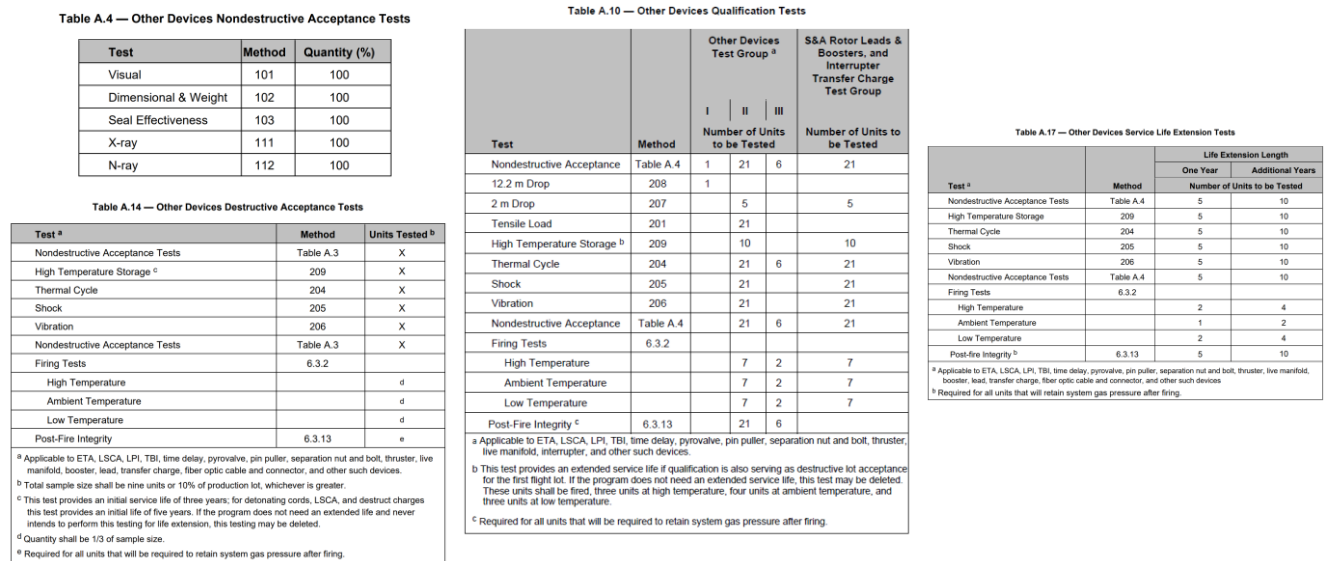


Figure 3. AIAA S-113B key ordnance requirements.

VII. Summary

Key test and analysis methodologies for improving the reliability of payload fairings (PLFs) in space launches are presented. Despite a historical success rate in missions by the USSF and NASA, PLF failures—such as collapse, separation issues, and damage during separation—have necessitated a reevaluation of industry qualification practices.

Best practices for PLF qualification are proposed, emphasizing an integrated multidisciplinary approach. Key standards include AIAA S-110, S-113, S-114, and SMC-S-016, addressing requirements for structural integrity, system-level tests, and specific guidelines for PLF design and testing.

The importance of structural qualification, acceptance testing, and managing trapped pressure within PLFs are discussed. Essential practices for acoustic testing, contamination control, clearance analyses, radiofrequency testing, and ordnance systems—including thrusting joints and linear separation systems—are outlined.

VIII. References

[1] Eleazer W., “Launch failures: fairings,” 28 March 2022, Last Accessed 24 April 2025: <https://www.thespacereview.com/article/4354/1>

[2] Goyal V., Tuck-Lee J.P., Rome J., and Lundgren E.. “Failure Analysis of Unvented Honeycomb Structures,” Conference Proceedings for the 29th American Society of Composites, 2014.

[3] Goyal V., Maghsoudy-Louyeh S., “Proof Test Methodology For Reducing The Risk Of Unvented Honeycomb Core Failures In Aerospace Structures,” Journal of Sandwich Structures & Materials. 2022;25(1):61-76]

- [4] Selding, P. “Fairing-separation issue has grounded Ariane 5 since August 2020, also affected ULA’s Atlas 5,” 19 March 2021, Last Accessed 24 April 2025: <https://www.spaceintelreport.com/fairing-separation-issue-has-grounded-ariane-5-since-august-2020-also-affected-ulas-atlas-5/>.
- [5] Clark, S. “Ariane 5 fairing cleared for Webb launch after “perfect” performance on last flight,” 7 November 2021, Last Accessed 24 April 2025: <https://spaceflightnow.com/2021/11/07/ariane-5-rocket-fairing-cleared-for-webb-launch-after-perfect-performance-on-last-flight/>
- [6] Standard: Criteria for Explosive Systems and Devices on Space and Launch Vehicles (AIAA S-113B-2023)