NASA
SPACE VEHICLE
DESIGN CRITERIA
(STRUCTURES)

NASA SP-8045

ACCEPTANCE TESTING

APRIL 1970

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform criteria for the design of space vehicles. Accordingly, criteria are being developed in the following areas of technology:

Environment
Structures
Guidance and Control
Chemical Propulsion

Individual components of this work will be issued as separate monographs as soon as they are completed. A list of all published monographs in this series can be found at the end of this document.

These monographs are to be regarded as *guides* to the formulation of design requirements and specifications by NASA Centers and project offices.

This monograph was prepared under the cognizance of the Langley Research Center. The Task Manager was W. C. Thornton. The authors were O. L. Gillette and R. J. Varga of Hughes Aircraft Company. Other individuals assisted in developing the material and reviewing the drafts. In particular, the significant contributions made by H. P. Adam, T. P. Brooks, and I. Tuchman of McDonnell Douglas Corporation; E. F. Baird of Grumman Aircraft Engineering Corporation; T. N. Bartron of NASA Langley Research Center; M. D. Brinson of Ling-Temco-Vought Corporation; E. G. Davies of Lockheed Missiles & Space Company; M. Dublin of General Dynamics Corporation; J. S. Gilbert of Chrysler Corporation; F. P. Klein of Electronic Specialty Company; H. W. Klopfenstein and H. J. Runstad of The Boeing Company; C. E. Lifer of NASA George C. Marshall Space Flight Center; D. R. Reese of Wyle Laboratories; and L. St. Leger of NASA Manned Spacecraft Center are hereby acknowledged.

NASA plans to update this monograph when need is established. Comments and recommended changes in the technical content are invited and should be forwarded to the attention of the Design Criteria Office, Langley Research Center, Hampton, Virginia 23365.

April 1970

GUIDE TO THE USE OF THIS MONOGRAPH

The purpose of this monograph is to provide a uniform basis for design of flightworthy structure. It summarizes for use in space vehicle development the significant experience and knowledge accumulated in research, development, and operational programs to date. It can be used to improve consistency in design, efficiency of the design effort, and confidence in the structure. All monographs in this series employ the same basic format – three major sections preceded by a brief INTRODUCTION, Section 1, and complemented by a list of REFERENCES.

The STATE OF THE ART, Section 2, reviews and assesses current design practices and identifies important aspects of the present state of technology. Selected references are cited to supply supporting information. This section serves as a survey of the subject that provides background material and prepares a proper technological base for the CRITERIA and RECOMMENDED PRACTICES.

The CRITERIA, Section 3, state *what* rules, guides, or limitations must be imposed to ensure flightworthiness. The criteria can serve as a checklist for guiding a design or assessing its adequacy.

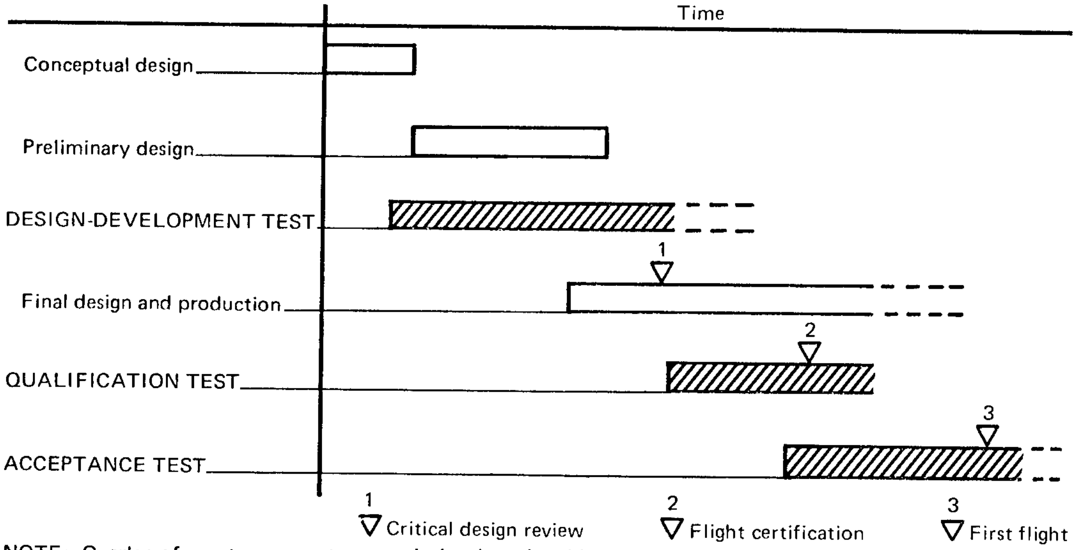
The RECOMMENDED PRACTICES, Section 4, state *how* to satisfy the criteria. Whenever possible, the best procedure is described; when this cannot be done, appropriate references are suggested. These practices, in conjunction with the criteria, provide guidance to the formulation of requirements for vehicle design and evaluation.

CONTENTS

ACCEPTANCE TESTING

1. INTRODUCTION

Structural acceptance tests are conducted on flight hardware to verify that materials, manufacturing processes, and workmanship meet specifications, and that the hardware is suitable for flight. Acceptance tests follow design-development and qualification tests as indicated in figure 1.



NOTE: Overlap of events represents a practical rather than ideal situation on typical programs

Figure 1. – Typical test-program phasing.

Design-development tests are conducted early during the conceptual and preliminary design phase to establish the feasibility of the design approach or manufacturing process, and as an aid in refinement of analytical techniques. Qualification tests follow and are conducted on flight-quality hardware at load levels and for durations that usually exceed flight conditions to demonstrate that all structural design requirements have been achieved. Acceptance tests are the final series of tests conducted in a typical hardware program. The specific characteristics of each of the three types of tests are shown in table I. With the satisfactory completion of these tests, the flight hardware is considered to be structurally and functionally adequate for flight.

TABLE I. – STRUCTURAL TESTS

Tests	Load levels	Purpose	Type of hardware used
Design-development	Variable, often to destruction.	To determine ultimate strength and design feasibility.	Decided by engineering.
Qualification	To design ultimate load (not necessarily to failure).	To verify structural adequacy.	Flight quality.
Acceptance	Usually not exceeding flight-limit loads (except for pressure-proof tests).	To ensure hardware meets specification.	Flight.

Acceptance tests have proven invaluable in disclosing imperfections in flight hardware resulting from the use of unsuitable materials, improper manufacturing processes, or faulty workmanship. In one case, approximately 10 percent of the structural inserts installed in the honeycomb sandwich shell of a spacecraft for attaching a large solar panel array to the shell failed during acceptance test. Since the major load path was through the inserts, the failure would likely have resulted in a loss of the entire spacecraft. The prototype solar panel had been designed and constructed to a positive margin of safety and the design verified by development tests. A faulty production process was identified by the acceptance test and the inserts repaired and requalified to meet design requirements.

Major problems in structural acceptance testing include the following:

- Determining which hardware must be subjected to a structural acceptance test and at what stage of manufacture the test should be conducted.
- Determining the test sequence, environments, load levels, and the distribution and duration of the loads and environments, particularly if the same hardware is to be used for both structural and system acceptance tests.
- Determining maximum acceptable degradation of the hardware which can occur during the test and ensuring that this maximum is not exceeded.
- Providing realistic test conditions to achieve the desired stress distribution in the specimen.
- Developing test procedures in sufficient detail to minimize the need for engineering judgment by the test conductor.
- Developing a test program that defines all acceptance tests from the start of manufacturing until final delivery of the vehicle.

This monograph establishes criteria and recommends practices for formulating a sound acceptance test program. It is concerned only with the *structural* aspects of acceptance tests performed on flight hardware; this includes general structure, bracketry, pressure vessels, and functional components that act as load-carrying members. It does not identify values of load or proof-test levels which must be established to meet specific mission requirements. The following types of acceptance tests are considered:

- *In-process.* Tests on materials during manufacturing to verify their mechanical properties and the quality of the manufacturing processes. These tests include both nondestructive and destructive tests on material samples.

- *Component and subassembly.* Tests on flight hardware at the component or subassembly level to verify that the manufactured hardware meets design requirements before it is installed in a system. These tests include functional tests and static or dynamic load tests.

- *Full system.* Functional tests on assemblies to verify that components and subsystems perform as required and integrity of interfaces is assured.

A successful acceptance test program requires a thorough understanding of the strength and rigidity requirements for the design of space vehicle structure, the predicted loads and environments the structure will experience during its mission, and the materials and manufacturing processes used. This knowledge is obtained from appropriate structural and functional analyses, evaluation of manufacturing processes, and the results of design-development tests. The engineering organization and the program office should reach early agreement on general test objectives and accept-reject criteria. The test plan and documentation should be comprehensive, and effective communication and understanding should be maintained among all the technical disciplines from the initial hardware concept through acceptance testing.

The related subjects of design-development and qualification testing are treated in other monographs in this series. Design, analysis, and test considerations that bear on acceptance testing are presented in the monograph – Fracture Control of Metallic Pressure Vessels (SP-8040); assessment of aeroacoustic vibration prediction, design, and testing in the monograph – Acoustic Loads Generated by the Propulsion System (SP-8072); and experimental and development testing in the monograph – Structural Vibration Prediction (SP-8050).

2. STATE OF THE ART

Present practices in structural acceptance testing were adopted to meet the rigid quality requirements of space vehicles. The test load levels and durations are designed to certify the hardware for the mission environments and usually do not exceed the flight levels. Before the development of space vehicles, acceptance tests were performed on aircraft and missile structure on a limited scale, frequently in conjunction with design-development and qualification tests. Consequently, acceptance testing has drawn heavily on the methods and facilities used for development and qualification testing and the material-testing procedures developed by the American Society for Testing and Materials.

In many instances, the methods of loading and the fixtures used in acceptance tests are the same as those used in qualification tests. The differences between acceptance and qualification testing, then, occur in the load levels and test durations, type of inspection and control, type of data required, and the test objectives. The load levels are usually lower in acceptance testing than in qualification testing, and the test duration is shorter.

Facilities are available for most of the complex testing required by present technology. For example, there are facilities for full-system testing of complete spacecraft and complete vehicle stages with accepted methods for application and sequencing of heat and aerodynamic and inertia loads.

Problems arise in structural acceptance testing when new processes and materials are developed and when extreme test conditions must be met. There is often a time lag between the development of materials and fabrication techniques and the development of test and inspection procedures to qualify them. In the nondestructive testing and evaluation of honeycomb sandwich panels, for example, which are fabricated by a fairly new process, no satisfactory method has yet been developed for determining the quality of the bond between the honeycomb and a face sheet. (Some methods can detect debonding, but not bond quality.) However, infrared, sonic, and other techniques are being investigated. In extreme test conditions, such as those of heat-shield tests, where excessive degradation occurs, one or more samples from a lot are tested to accept the entire lot.

There is also a shortage of test facilities in which certain extreme flight conditions can be duplicated (e.g., vibration of Saturn-type vehicles or proof testing at the temperature of liquid hydrogen).

2.1 Test Planning

Some major space-vehicle test programs are presently operating from a general test plan (refs. 1 and 2) that includes in a single document the plans for all tests to be performed in the program. The test plan lists all tests to be conducted, the general objectives of each test, the test conditions, and number of specimens. The general test plan can be used to determine the need to purchase and fabricate test equipment which requires a long lead time, to establish manpower estimates, and to evaluate the test schedules. The original plan, however, must sometimes be modified because new tests must be added as the program progresses. Further, since unforeseen technical problems often appear after the test plan has been completed, the original statement of test objectives may require modification.

2.2 Test Documentation

Test documentation includes all test procedures, data, records, and reports of tests conducted during manufacturing operations and of all other acceptance tests, including full-system tests. The test procedure, which describes the test in detail, is prepared from the design drawing or the control document. The data, especially in complicated tests, show changes in structural behavior which occur during the test (e.g., strain rate, load-buildup rate, temperature-rise rate). These data are used to prepare the data sheets, which are the final evidence of the acceptability of the hardware for certification.

Often acceptance tests are performed in the same manner and with the same test fixtures and loading equipment used in design-development or qualification tests. Therefore, in the event of a failure, the acceptance test records are carefully compared with those of the design-development or qualification test to determine whether the failure was caused by a defect in the hardware or by the test facility, test techniques, or human error.

2.3 Types of Tests

2.3.1 In-Process Tests

In-process tests verify compliance with material and process specifications. If a single material or part in a complex assembly has not been properly processed (e.g., a part not heat treated to the required strength), the whole assembly may fail to perform. These tests are conducted on the basic material or on test samples cut from the same piece of material as the flight hardware. The tests are normally conducted in accordance with specific ASTM standard procedures (ref. 3), except when new materials or compositions are not yet covered by a standard.

Some materials, such as new metallic and plastic composites, are sensitive to loading rates; therefore, high-speed testing is becoming a common requirement. The testing speeds and loading rates depend on the service environment to which the material will be subjected. Sometimes, large loads [over 1000 lb (454 kg)] are applied in 0.01 sec. Section 3.3 of reference 4 contains some information on testing standards.

One problem in the evaluation of material is that test data obtained in one laboratory cannot always be duplicated in another. This problem results from lack of detail in the test procedures and from variances in techniques, test equipment, fixtures, sizes of test specimens, and the like. A deviation in test results is often caused by the method in which the load is applied to the specimen. Considerably different results (as much as ±30 percent) can be obtained from a specimen tested in compression using spherical bearing blocks than from the same specimen tested using parallel bearing plates. For every type of test and laboratory, there are many different methods which can be used to apply loads to a specimen. If the method is described sufficiently in the test procedure, the test can be run correctly and can be repeated if necessary.

The various nondestructive tests performed on material to verify manufacturing processes are an important part of in-process testing. These tests include, but are not limited to, X-ray, visual inspection, pressure tests, dye penetrant, and ultrasonics. Considerable information on these methods can be found in references 5 to 8.

2.3.2 Component and Subassembly Tests

Most of the time and effort in structural acceptance testing is spent at the component and subassembly level. A very important consideration in testing components and subassemblies is the simulation of representative boundary conditions to ensure realistic stress distributions. It is extremely difficult, if not impossible in some cases, to ensure realistic stress distribution at the boundaries of some subassemblies, particularly if the structure is complex. A test which subjects the specimen to an unrealistic stress distribution will not prove that the hardware is flightworthy, even if the test is successful. Further discussion of this problem maybe found in Section 2.5.

2.3.3 Full-System Tests

A full-system test subjects a completed or assembled stage, payload, or vehicle to a simulation of the loads and environments anticipated during flight. Interfaces and components which cannot be tested under the proper environments and interactions in lower-level testing are tested in full-system tests.

The types of tests usually conducted on full systems include dynamic, static, solar-thermal-vacuum, proof, shock, pressure, and leak tests. Some or all of these tests may be performed on a completely assembled vehicle (e.g., captive firing of a completed stage). A partial listing of facilities available for these tests can be found in references 9 and 10. However, facilities are not always adequate for full-system tests because of problems in simulating the space environment (e.g., zero gravity, hard vacuum, or particle radiation) in a ground test. Approaches to simulation of less-than-1-g earth gravity are by controlled drop tests or by side displacement when the test article is suspended by cables. These cables must be of sufficient length to minimize any counter-forces produced at the attach points by displacement. These forces may create unrealistic loads or may interfere with the normal operation of the system.

2.4 Test Conditions

A test condition is a combination of loads and environments which simulates a specific flight condition. For adequate tests, the simulated environments and loads must be controlled to prevent undertesting or overtesting. The ability to control these environments to the desired tolerances is often limited by the available measuring instruments and recording equipment, as well as by the methods used to apply the loads and environments. The more sophisticated control systems are digital systems which are capable of accuracies of ±0.05 percent full scale. Analog systems are normally accurate to ±2.0 percent full scale. Generally, accuracies of ±2 to 5 percent are adequate for acceptance tests; however, for pressure vessel proof tests, accuracy is maintained at ±2 percent or less.

The methods of applying various types of loads and environments, and their limitations, are presented in table II. The miscellaneous tests listed in the table are not conducted as frequently as the static and dynamic load tests. Additional information may be found in reference 11.

Dynamic-acceptance testing up to flight levels is gaining importance in acceptance testing. However, the degradation of hardware due to these dynamic tests must be carefully controlled to maintain the flightworthiness of the hardware.

2.5 Test Fixtures and Support Structure

A test fixture is used to transmit or react to loads applied to the test specimen. The design of a fixture which will impose realistic flight loads to a component or a subsystem under test requires considerable skill and a thorough understanding of structural characteristics and load paths. The test fixture should have sufficient rigidity to prevent excessive deformation when transmitting the applied loads to the specimen and should not interact with the test specimen in such a way as to affect significantly the input range of interest. Fixtures designed to have no significant resonances in the frequency range of a dynamic test are usually massive and stiff and do not ensure that realistic boundary conditions will be applied to the specimen.

TABLE II. – TEST LOADS AND ENVIRONMENTS

Types	Methods of application	Limitations
Static loads		
Inertia and applied forces	Large components – usually applied with hydraulic cylinders and distributed load points (whiffletrees).	Loads concentrated at discrete points. Units or areas may be overloaded or completely unloaded.
	Smaller test articles – usually applied in a centrifuge. Eliminates need for other loading devices.	Size of the centrifuge – largest available today is with a 25-ft (7.6 m) radius, rated at 1.6×10^6 g lb (7.26×10^5 g kg), or 35 ft (10.7 m) at 4.5×10^5 g lb (20.4×10^4 g kg). Arms can be extended to about a 67-ft (20.4-m) radius, at a lower g force to produce a more uniform force across the test specimen.
Pressure	Applied hydraulically with water or oil as the pressure medium. If a gas is used as the pressure medium, special care is taken for personnel safety.	Possible contamination of the pressure vessel with testing fluid.
	Often used in conjunction with other applied loads.	Some state and city safety codes require special precautions with pressure tests, such as testing away from populated areas.
		Remote special facilities are required when cryogenic temperatures must be employed (e.g., LH_2, LO_2).

TABLE II. – TEST LOADS AND ENVIRONMENTS – Continued

Types	Methods of application	Limitations
Dynamic loads		
Vibration	Electrodynamic and electrohydraulic shakers used to apply forces. Large tests may require multiple shakers.	Shaker size – electrodynamic 50 000 lbf (222 000 N) and electrohydraulic 200 000 lbf (890 000 N), maximum force rating. Interaction of fixture resonances with input. Size and scope of test limited by the resonant frequency of the test fixture.
Acoustic	Reverberant and progressive wave chambers are available for application of acoustic pressure levels.	Size – 200 000 ft^3 (5670 m^3) maximum reverberant chamber size. Sound pressure level – 160 to 180 dB (2000 to 20 000 N/m^2).
Shock/ impact	Impact – usually simulated in drop towers with simulated gravity conditions of the flight environment. Shock – pyrotechnic shock loads are usually simulated on electrodynamic shakers and by firing.	Size of machine and ability to apply the shock over large areas. Selection of instrumentation having accuracies required for high-g forces. Simulating proper boundary conditions.

TABLE II. – TEST LOADS AND ENVIRONMENTS – Concluded

Types	Methods of application	Limitations
Miscellaneous		
Thermal	Thermal heating under ambient pressure conditions is normally applied by infrared radiant-heat lamps.	Maximum heating density 100 Btu/ft^2-sec (1.135 MW/m^2), maximum temperature 3000°F (1922°K).
	Solar heating is usually done with carbon arc lamps or infrared and ultraviolet lamps of the proper spectrum.	Normally performed in a vacuum chamber which limits the size of the test specimens.
	Thermal-vacuum tests are conducted with hot and cold radiation walls using resistance heaters and LN_2 as the mediums.	Maximum temperature range –320°F (78° K) to 1500°F (1090°K).
Vacuum	Many large sophisticated test chambers are available for vacuum pressures down to 10^{-9} torr (1.33×10^{-7} N/m^2).	Size – approximately 100 ft (30.4 m) in diameter x 120 ft (37 m) high with a volume of 800 000 ft^3 (22 640 m^3).
		Access is difficult during testing.
		Pump-down time – 1 to 2 days, less for smaller chambers.
Functional	Operational test performed under simulated environments which usually include one or more of above tests. Zero gravity usually simulated by counter forces at discrete points.	As stated above for each load or environment.

Consequently, support structure consisting of flight hardware or simulated flight structure is often used between the fixture and the specimen. For example, a flight payload adapter may be used to support a full-system test vehicle in vibration testing, or extra length may be added to a test panel or bulkhead to provide the transition area for the application of loads. If the support structure is properly designed to satisfy interface constraints, it will provide the proper load distributions throughout the specimen. In full-system tests these interface problems are minimized or eliminated – and this serves as an incentive for going to a full-system test.

The performance requirements placed on the test fixture and support structure may produce a problem when these structures must perform other functions besides loading the test specimen. For example, during solar-vacuum testing, the test fixture and support structure must position and rotate the test specimen, provide proper restraint for thermal stress, and provide a reference platform for measurement or evaluation of the resulting thermal distortion. Design and construction of a test fixture and support structure that can perform all these functions are therefore generally given careful consideration during the planning of the test.

2.6 Instrumentation

Instrumentation used in acceptance testing is less complex than instrumentation used in design-development and qualification tests. Moreover, fewer measurements are required. Off-the-shelf instrumentation is used mainly for monitoring the environments and loads. The Instrument Society of America (ISA) maintains a standards-and-practices document for instrumentation (ref. 12) which is used as a guide. A list of available transducers, along with their specifications, is also published periodically by the ISA (ref. 13).

3. CRITERIA

Structural acceptance tests shall be conducted on selected flight hardware used in space vehicles to verify that the materials, manufacturing processes, and workmanship meet design specifications and that the hardware is suitable for flight. The test plan shall list all tests to be performed and corresponding accept-reject criteria. Test documentation shall include detail test procedures, data sheets, and all other test results. The tests shall include, as appropriate, in-process tests, component and subassembly tests, and full-system tests. Test conditions shall adequately simulate flight loadings without compromising flightworthiness of the structure. Test fixtures and support structures shall be designed to accommodate the required test conditions. Sufficient data shall be collected to allow unequivocal application of the accept-reject criteria.

3.1 Test Plan

A test plan shall be prepared which specifies the type of structural acceptance tests to be conducted, test objectives, test environments, specimen configurations, and accept-reject criteria. The accept-reject criteria shall define acceptable requirements to permit a determination of whether material and manufacturing specifications have been satisfied and whether the hardware is flightworthy.

As appropriate, the test plan shall define alternative plans to cover interruption of test, failure of test articles to pass test, revision of test procedures, and modifications or adjustment to the test article undergoing test.

3.2 Test Documentation

Complete test procedures shall be prepared for each test. A complete and continuing record of all test results shall be compiled for each specimen to permit determination of whether the material or hardware meets the established specifications.

3.3 Types of Tests

3.3.1 In-Process Tests

In-process tests shall be performed to verify that the materials, manufacturing processes, and workmanship involved in the production of flight hardware meet the design specifications.

3.3.2 Component and Subassembly Tests

Component and subassembly tests shall be conducted to verify that the components and subassemblies have been manufactured to meet design requirements when verification of structural adequacy cannot be obtained by incoming and in-process tests.

3.3.3 Full-System Tests

Full-system tests shall be conducted to verify the adequacy of the entire structure to perform the mission unless it can be clearly shown that verification of structural adequacy can be obtained by lower-level tests.

3.4 Test Conditions

3.4.1 Test Loads

Test loads shall adequately simulate the combined flight loadings but shall not exceed the limit loads except in proof tests on pressurized structure. The sweep rate of dynamic tests and the limit durations of complex wave testing shall be controlled to prevent the possibility of fatigue damage to the specimen beyond the allowable levels established by the engineering analysis. Captive firing, handling, and transportation loads shall be accounted for.

3.4.2 Test Fixtures and Support Structure

Test fixtures shall be designed to permit application of all the test loads without jeopardizing the flightworthiness of the test article. Fixtures used in performing vibration tests shall be designed to avoid fixture-induced attenuation, amplification, or resonance within the range of the test conditions. Support structure shall be designed to simulate flight structure in order to obtain proper distribution of loads.

3.5 Test Data

Sufficient data shall be collected in the acceptance test to permit comparison of test results with subsequent performance of the flight article.

4. RECOMMENDED PRACTICES

The type and extent of structural acceptance tests of flight hardware should be determined on the basis of the following factors:

- Flight criticality of the hardware.
- Complexity of design.
- Component and subsystem interaction.
- Complexity of manufacturing processes.
- Variability of materials and processes.
- Need for proof of quality of workmanship.

- Ability to simulate loads.
- Adequacy of inspection methods.

Standard acceptance tests on incoming purchased parts and materials are always conducted. These tests are covered by standard operating procedures (e.g. ref. 3) and will not be discussed in this monograph.

When an aluminum panel of riveted skin and stringers is used only to support predictable light loads, it may not be subjected to an acceptance test because the behavior of the panel under the expected loads can be accurately calculated, the complete panel can be reliably inspected for workmanship, and it may not be flight critical. However, certain critical load-carrying structures should be acceptance tested to at least limit-load levels due to inherent variability in some materials and manufacturing processes. Acceptance tests (proof test in case of pressure tests) to verify structural integrity should be conducted on (1) castings, (2) pressure vessels, (3) pressurized structures, and (4) honeycomb sandwich structures unless satisfactory nondestructive test methods are used. In particular, an acceptance test should be run on sandwich structure with thin face sheets of fiberglass since the panel-to-panel strengths have been known to vary as much as ±30 percent.

The effect of flight temperature (high or low) should be accounted for in the acceptance test.

4.1 Test Plan

An overall test plan (refs. 1 and 2) should be prepared as soon as the tests can be defined. It should list all the structural tests, including the acceptance tests, which are required for a particular program. The test plan should be continually updated to reflect changes in the test program. Tests may be added or changed because of design changes or to provide additional confidence in the adequacy of a component, or they may be deleted because of confidence gained through previous tests, if the test specimens are sufficiently similar.

The test plan should be prepared in enough detail to permit an evaluation of the scope of the test program and the level of confidence it will produce. The plan for a structural acceptance test should specify at least the following:

- Hardware configuration.
- Type of tests to be conducted, including, as appropriate:

  - (a) Procedure in event of test interruption
  - (b) Procedure in event of failure of part to pass test point
  - (c) Procedure for modifying test
  - (d) Provisions for modifying article undergoing test

- Test objectives.
- Supporting documents.
- Environments.
- Data requirements.
- Accept-reject criteria.

Clearly defined accept-reject criteria should be included in every acceptance-test procedure. The criteria should reflect the minimum requirements that the hardware must achieve to be flightworthy. Acceptance or rejection of the hardware is accomplished by quality-control personnel, who compare the test results with the requirements cited in the accept-reject criteria. When required by the test procedure, photographs should be included with the data sheets to demonstrate the test results (i.e., the specimen response).

Accept-reject criteria should include the following:

- Go/No-Go requirements for operation of structural units and deployable items.
- Design performance requirements.
- Fit-check requirements.
- Alignment requirements.
- Leakage requirements.
- Test duration and cycle requirements.

4.2 Test Documentation

The test documentation should consist of detailed test procedures, data sheets, and all other test records.

The test procedures should be in agreement with the test requirements, and with the general objectives listed in the test plan. The major items that should be stipulated in the test procedure are as follows:

- Test objectives.
- Configuration of specimen to be tested.
- Tooling, fixtures, and recording equipment to be used.
- Test media or loading mechanism to be used.
- Test setup (including drawings, description, and photographs).
- Sequence of operations for the specimen's installation into and removal from the test setup.
- Chilling and heating procedures.
- Specimen instrumentation, such as the type and ranges of strain gages, accelerometers, or thermocouples, and the location and method of installation.
- Type and amount of data.
- Measurement tolerances.
- Definition of test conditions and their tolerances.
- Safety considerations.
- Definition of all operations during the test presented in the order they are to be performed.
- Accumulated test time and/or cycle limitations where applicable.
- Measures of allowable behavior (derived from accept-reject criteria).

- Data sheets.
- In-test and post-test inspection.

Other items may be added as required. The details presented in the test procedure should permit the test to be performed in the prescribed manner and repeated in an identical manner without requiring the exercise of judgment during the performance of the test. When photographs can be used to describe the test setup, manner of hardware installation in the fixture, load device attachments, etc., they should be included in the test procedure.

The data sheet should be prepared in advance of the test and should indicate all the information needed to determine whether to accept or reject the hardware being tested. Photographs should also be in the documentation, whenever they can be used to exhibit visually the success or failure of the test.

4.3 Types of Tests

Table III is provided as a guide to the selection of types of tests to be performed on the various categories of hardware.

TABLE III. – INTEGRATED STRUCTURAL ACCEPTANCE TESTING PROGRAM

Hardware category	Type of testing		
	1. In-process tests	2. Component and subassembly tests	3. Full-system tests
Structures and bracketry	Most important; in many instances, the only acceptance test performed.	Important especially where Type 1 cannot be completely relied on. Applied loads and support-interface conditions must be carefully considered.	Used to verify performance of systems, components, or interfaces not verified in Types 1 and 2, and for proper simulation of environment.
Tanks, pressure vessels, and pressure systems	Important in preventing costly failures in Type 2 testing; important for complex welding methods and heat treat.	Mandatory; easily predicted loads; test will ensure reliability with respect to strength and leakage. Environments to which hardware is subjected in flight must be considered.	Extremely important where external static, dynamic, and thermal loads affect hardware in conjunction with pressure loads. System leak tests performed.
Functional components	Used mainly to ensure proper heat treatment and material specification.	Most important; will ensure required structural integrity and performance when subjected to loads.	Important for combined loading and its effect on the working mechanism.

4.3.1 In-Process Tests

Incoming and in-process tests should be performed periodically during production to verify material mechanical properties and confirm that manufacturing processes, such as welding, bonding, and riveting, meet specifications. These tests often make use of tensile coupons to check the quality of welded, riveted, and bonded joints. Hardness tests, chemical analysis, and leak tests should be specified to check weld porosity.

In-process tests should also be performed on materials and parts undergoing processing, such as heat treatment, surface treatment, or chemical etching, to ensure that the materials and parts are being properly processed, and thus to avoid later costly rejections of completed flight hardware.

When component, subassembly, and full-system tests are not conducted, greater emphasis should be placed on the in-process tests, with more frequent sampling and a larger number of test coupons at each sampling.

4.3.2 Component and Subassembly Tests

Component and subassembly tests should be performed on structure and bracketry when the incoming and in-process testing does not provide adequate proof of flightworthiness. Proof tests should be performed on pressure vessels, castings, composite structures such as honeycomb panels and fiberglass, and assemblies of components where interface integrity is questionable.

These interface problems usually occur in one of the following conditions:

- When multiple load paths result in indeterminate structure.
- When bulkheads, shelves, or tanks are penetrated by fuel lines or electrical cable, which can produce load and stress discontinuities.
- When transmissibility of bracketry, shelves, or other structure is difficult to define.
- When a structural member that has an operational function is also a primary load-carrying member (e.g., an engine-gimbal thrust structure or a hinge member for solar-panel deployment).

The number and types of tests should be determined by an evaluation of the following:

- Anticipated loads and environments.
- Function and flight criticality of the component or subassembly.
- Ability of test equipment to simulate potentially critical loads and environments.

4.3.3 Full-System Tests

Full-system tests should be performed on completed or assembled stages, payloads, or vehicles when the combined influences of interfaces and adjacent structure cannot be simulated in tests at the subassembly level or when load paths cannot be simulated to provide realistic stress distribution and dynamic responses in lower-level testing. The number of test conditions and environments to which the full system is subjected should be determined by an evaluation of the mission objectives, the function and flight criticality of the system, the extent of lower-level testing, and the adequacy of simulation of the potentially critical loads and environments. When full-system tests are planned, reduction of lower-level testing should be considered.

A full-system, captive-firing test is usually conducted on all vehicle stages used in a manned space program. However, the overall cost of the full-system test or the size of the facility required may be of such magnitude that a full-system test is impractical. In such cases, component tests and, particularly, subassembly tests should be more extensive, with added test conditions and more instrumentation used in critical areas. When full-system tests are not performed or when there is insufficient confidence that the full-system test has realistically simulated flight conditions, at least the first flight vehicle should be instrumented to confirm the test results and the validity of the test conditions.

4.4 Test Conditions

4.4.1 Test Loads

In any structural acceptance test, care must be taken not to jeopardize the flightworthiness of the test article. The loading levels, except for proof tests, should not exceed limit loads. When sufficient confidence in the hardware can be achieved with lower loads, they should be used to minimize degradation of the hardware during the test. Thermal and vacuum environments should be applied simultaneously when practical in order to produce a more accurate representation of flight conditions and to permit fewer tests to be conducted on the hardware. This practice saves the article from the structural degradation incurred through continued testing.

If a component or stage were run through several consecutive tests, the handling alone would increase the probability of excessive degradation.

Where the loads, durations, and environments encountered during captive firing or other functional tests are more severe than those experienced in flight, they should be considered to be acceptance tests of affected structural components and assemblies.

Nonflight conditions, such as handling, transportation, and ground test, should be accounted for in choosing acceptance test levels.

4.4.1.1 Static-Load Tests

Static loads should be applied to represent the flight load distribution as closely as necessary to meet specific acceptance requirements. Measurements should be taken to ensure that the resulting stresses in the specimen are within the desired range and distribution. Simplification of the load application should not cause unrealistic stresses in the specimen. For example, if a series of concentrated loads is substituted for a uniformly distributed load, care should be taken to ensure that the stress distribution in the specimen is approximately the same. Centrifuge tests simulating inertia forces should be considered when applicable.

Acceptance tests (proof-pressure tests) should be conducted on all tanks and pressure vessels. The tests should be conducted hydraulically to minimize burst hazards to personnel during the tests. The hydraulic test liquid should be compatible with the tank materials to prevent any undesirable residual contamination or chemical reaction that would lead to crack initiation.

4.4.1.2 Shock/Impact Tests

The shock-and-impact pulse loads imposed on the test specimen should match the frequency-amplitude spectrum of the predicted service load.

These loads can occur during vehicle firing and flight (e.g., squib firing, stage separation, or satellite landing). Whenever shock-and-impact acceptance testing would cause degradation of the hardware beyond allowable limits, only samples of hardware lots should be tested.

4.4.1.3 Acoustic Tests

Acoustic loading should be simulated on the test article by broadband random noise, and the simulated load should match the frequency-amplitude spectrum of the predicted service load. Care should be taken to prevent overload in one frequency range when achieving the required load at another frequency. Occasionally, turbine-whine and air-transport (propeller-beat) acoustical environments should also be considered.

Since acoustic tests are difficult to set up, chamber-survey tests should be performed at acceptance test levels on dummy hardware prior to testing of flight hardware.

When a vehicle is subjected to a captive ground firing, it may experience acoustic loads far larger than it will experience in service. In this case, the ground firing should satisfy all acoustic acceptance testing requirements. Information on this subject is presented in the monograph – Acoustic Loads Generated by Propulsion Systems (SP-8072).

4.4.1.4 Vibration Tests

Vibration tests of a large and heavy assembled space vehicle are difficult and costly to perform, but these tests should be conducted when it is necessary to simulate true boundary conditions (ref. 14). Although simple sinusoidal vibration is seldom encountered in flight, in many cases the sine-wave test is the only feasible method of duplicating the expected flight load distribution for certain transient conditions. Alternative types of excitation that should be considered include transient excitation, narrow-band complex wave, harmonic excitation of discrete modes at specific amplitudes, etc. To minimize hardware degradation, sinusoidal or random-vibration tests should be performed only when the specimen and its predicted response to the service environments requires verification.

For random vibration, care should be taken to simulate the distribution of the dynamic response over the test-frequency range so that overtest in some frequency areas and undertest in others will not result from the method of excitation or measurement. Vibration-survey tests should be performed on representative hardware (such as a specimen from a qualification test) at acceptance-test levels before the flight hardware is tested. Multipoint-monitoring instrumentation with override capability should be provided at critical locations on the test article. Initial surveys should be conducted at lower power levels prior to full-power-level testing of the flight hardware in order to ensure proper spectral density, to find critical locations, and to prevent overtest or undertest.

4.4.1.5 Thermal Tests

When all flight thermal conditions are not incorporated in the acceptance test, the effects of these conditions in the form of significant reductions or increases in strength, changes in pressure, and significant thermal stresses and gradients should be simulated or compensated for, as appropriate for each test.

4.4.1.6 Solar-Thermal-Vacuum Tests

Solar-thermal-vacuum tests should incorporate the effects of the combined solar-thermal-vacuum environmental extremes expected during normal mission operation. The effects of temperature gradients and pressure transients (such as those experienced during launch and ascent) should be evaluated before the test is begun to ensure that the test environment is adequate. Care should be taken in the design of the test fixture to ensure that unintentional shading of the test specimen does not occur during exposure to the thermal environment.

4.4.2 Test Fixtures and Support Structure

The test fixtures and support structure should allow a realistic specimen response. The support structure should consist of flight hardware, whenever possible. When the support structure is simulated, the strength and stiffness of the flight structure should be duplicated. The test fixture should not interfere with the deflection of the test specimen and support structure. Clearance must be provided for operation of structural units and deployable elements under appropriate environments and loadings.

For dynamic tests, sufficient support structure should be provided to ensure that the dynamic response of the test specimen is realistic. The fixture should be as rigid as possible to minimize the loss of power and to obtain the desired dynamic control and response of the specimen. For a test with thermal inputs, both linear and nonlinear heat-transfer characteristics should be simulated at the interface between the test specimen and the support structure.

4.5 Test Data

The types of data needed for application of the accept-reject criteria should be stipulated in the test procedure for each test phase.

Data should be gathered on strain, deflection, temperature, position, load, acceleration, pressure, and time. The definition of specific data requirements and the selection of instrumentation should be based on an evaluation of the following:

- Specific parameters to be measured (e.g., force, acceleration, or position).
- Characteristics of the parameters to be measured (e.g., range, frequency, magnitude, and rate of change).

- Exact location and accessibility of the area under consideration.
- Required accuracy and type of data desired (e.g., analog, digital, or quick-look).
- Effect of specimen behavior on the instrumentation and the effect of instrumentation on the specimen.
- Feasibility of measurement with existing equipment or the need for development of new equipment or techniques.

On completion of the test, the hardware should be inspected to ensure that any degradation occurring during the test was within the specified allowables. Changes in dimensions, changes in joint conductivity, cracks, and misalignment are often evidence of excessive degradation. For life or operational tests, the permanent life-cycle data sheets should be checked to verify that the allowable life allotted for testing was not exceeded.

The test results should be recorded on appropriate forms which identify the test, dates, configuration of the test items, and test procedure and test fixture used, as well as the actual results. Data sheets certified by the witnessing inspector should be used for the final acceptance of the hardware.

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