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FRACTURE CONTROL REQUIREMENTS FOR PAYLOADS USING THE SPACE SHUTTLE

NASA TECHNICAL STANDARD

FOREWORD

This standard is approved for use by NASA Headquarters and all Field Centers and is intended to provide a common framework for consistent practices across NASA programs.

This document establishes requirements for fracture control of payloads and associated hardware flown on the Space Shuttle. The document also provides guidance in an area critical for the safety and mission success of space programs. It was developed by a NASA-wide Fracture Control Working Group to harmonize and provide a common framework for fracture control practices on NASA programs. This document is an update of the previously published version of NHB 8071.1.

Although initially developed to meet the need for guidance on Space Shuttle payloads, the document may be tailored for other applications. Updates of this document will be designed to facilitate such tailoring.

Questions concerning the application of this document to a particular payload shall be referred to the procuring NASA Center or to the Space Shuttle Program Integration Office, NASA Johnson Space Center, Houston, TX, 77058. Requests for general information, corrections, or additions to this standard shall be referred to the Materials and Failure Analysis Branch, Mail Code EM211, Johnson Space Center, Houston, TX, 77058. Requests for additional copies of this standard should be sent to NASA Technical Standards, EL02, MSFC, AL, 35812 (telephone 205-544-2448).

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FRACTURE CONTROL REQUIREMENTS FOR PAYLOADS USING THE SPACE SHUTTLE

1. SCOPE

1.1 Purpose. The purpose of this document is to establish the fracture control requirements for all payload hardware to be launched or retrieved using the Space Shuttle. Meeting these requirements implements the minimum fracture control requirements of National Space Transportation System (NSTS) 1700.7, *Safety Policy and Requirements for Payloads Using the Space Transportation System*. All payload fracture control shall be in accordance with the requirements stated herein.

1.2 General requirements. For payloads using the Space Shuttle, NASA requires full assurance of system safety. This is accomplished through good design, manufacturing, test, and operational practices, including the judicious choice of materials, detailed analysis, appropriate factors of safety, rigorous testing, control of hardware, and adequate inspection. For payloads carried on the Space Shuttle, it is specifically required that design shall be based on fracture control procedures when failure of structure can result in a catastrophic event. Because fracture control is a safety-critical issue, all deviations from the requirements in this document must be approved by the responsible program authority (i.e., the program director/project manager) and concurred with by the designated safety and fracture control authorities at the NASA Center or sponsoring institution (see 3, Definitions).

1.3 Applicability.

a. The requirements set forth in this document are the minimum fracture control requirements for all Space Shuttle payloads. Any deviations from these requirements for Space Shuttle payloads shall be approved by the Space Shuttle Program.

b. For applications other than payloads using the Space Shuttle, this standard may be tailored to meet specific application requirements, and it may be cited in contracts and program documents as a technical requirement or as a reference for guidance. Determining the suitability of this standard and its provisions is the responsibility of program/project management and the performing organization. Individual provisions of this standard may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints.

c. This document contains the requirements for metallic and nonmetallic structural components. Components that are exempt from fracture control are those that are clearly nonstructural and not susceptible to failure as a result of crack propagation (e.g., insulation blankets, electrical wire bundles, and elastomeric seals). Some small mechanical parts such as bearings and valve seats have traditionally been developed and qualified through strong test programs and rigorous process control which demonstrate their reliability. In the presence of these strong development programs, these type parts may be exempt from fracture control with the approval of the responsible fracture control authority.

d. Individual NASA Centers or other payload-sponsoring organizations may establish more restrictive, project-specific requirements and/or guidelines as appropriate. These additional requirements/guidelines shall be approved by the responsible program authority.

1.4 Other requirements. Nothing in this document shall be construed as requiring the duplication of effort dictated by other contract provisions. Conversely, provisions stated herein shall not be interpreted to preclude compliance with requirements invoked by other provisions.

1.5 Prerogatives of the Government. All plans, data, and documentation generated under contract to NASA or its suppliers in fulfillment of these requirements are subject to examination, evaluation, and inspection by the procuring installation or its designated representatives.

2. APPLICABLE DOCUMENTS

2.1 General. The applicable documents cited in this standard are listed in this section only for reference. The specified technical requirements listed in the body of this document must be met whether or not the source document is listed in this section.

2.2 Government documents

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. The latest released versions of the following documents at the time this document is imposed form a part of this document to the extent specified herein. Unless otherwise specified, the issuances in effect on date of invitation for bids or request for proposals shall apply.

DEPARTMENT OF DEFENSE

MIL-STD-410	-	*Nondestructive Testing Personnel Qualification and Certification*
MIL-STD-1522A	-	*Safe Design and Operation of Pressurized Missile and Space Systems*

NASA

JSC-22267	-	*Fatigue Crack Growth Computer Program "NASA/FLAGRO"*
MSFC-HDBK-527/ JSC-09604	-	*Materials Selection List for Space Hardware Systems*
MSFC-SPEC-522	-	*Design Criteria for Controlling Stress Corrosion Cracking*

(Unless otherwise indicated, copies of the above documents are available from any NASA Installation library or documentation repository.)

2.2.2 Other Government documents, drawings, and publications. The following documents form a part of this document to the extent specified herein. The latest released versions of the following documents at the time this document is imposed form a part of this document to the extent specified herein. Unless otherwise specified, the issuances in effect on date of invitation for bids or request for proposals shall apply.

NSTS 1700.7 - *Safety Policy and Requirements for Payloads Using the Space Transportation System (STS)*

NSTS 13830 - *Implementation Procedure for NSTS Payload System Safety Requirements*

NSTS 14046 - *Payload Verification Requirements*

(Unless otherwise indicated, copies of the above documents are available from any NASA Installation library or documentation repository.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. The latest released issuances of the following documents at the time this document is imposed form a part of this document to the extent specified herein. Unless otherwise specified, the issuances in effect on date of invitation for bids or request for proposals shall apply.

ASNT-CP-189 - *American Society for Nondestructive Testing (ASNT) Standard for Qualification and Certification of Nondestructive Testing Personnel*

ATR-93(3827)-1 - *Guidelines for Design and Analysis of Large, Brittle Spacecraft Components,* by E. Y. Robinson, The Aerospace Corporation; report prepared for NASA/Johnson Space Center, September 1, 1993

(Unless otherwise indicated, copies of the above documents are available from any NASA Installation library or documentation repository.)

2.4 Order of precedence. Where this document is adopted or imposed by contract on a program or project, the technical guidelines of this document take precedence, in the case of conflict, over the technical guidelines cited in other referenced documents in this Standard.

3. DEFINITIONS

3.1 Acronyms used in this standard.

a. ASNT - American Society for Nondestructive Testing

b. JSC - Johnson Space Center, NASA

c. MIL-STD - Military Standard

d. MSFC - Marshall Space Flight Center, NASA

e. MSFC-HDBK - MSFC Handbook

f. MSFC-SPEC - MSFC Specification

g. MUA - Materials usage agreement

h. NASA - National Aeronautics and Space Administration

I. NHB - NASA Handbook

j. NSTS - National Space Transportation System

3.2 Analytical life. Predicted life of a component based on fracture mechanics analysis which assumes the presence of a crack at the beginning of service.

3.3 Catastrophic failure. Failure that results in loss of the Space Shuttle or the lives of personnel, or in major injury to personnel that results in the incapacitation of the flight crew.

3.4 Catastrophic hazard. Presence of a potential risk situation caused by an unsafe condition that results in the potential for loss of the Space Shuttle, lives of personnel, or major injury to personnel that results in the incapacitation of the flight crew.

3.5 Component. Hardware item that is considered a single entity for the purpose of fracture control classification. The terms “component” and “part” are interchangeable in this document.

3.6 Crack or crack-like defect. Defect which behaves like a crack and which may be initiated during material production, fabrication, and testing, or which is developed during the service life of a component.

3.7 Critical initial crack size. Largest crack that can exist at the beginning of the service life of a structure that has an analytical life equal to four service lifetimes.

3.8 Fail-safe. Redundant structural part shown to be a nonfracture-critical component by meeting the requirements of 4.2.2.3.

3.9 Fastener. Any metallic element which joins other structural elements and transfers loads from one element to the other element across a joint.

3.10 Fracture control. Rigorous application of those branches of engineering, assurance management, manufacturing, and operations technology dealing with the analysis and prevention of crack propagation leading to catastrophic failure.

3.11 Fracture control plan. Document which specifies the activities to be imposed on the design, analysis, testing, change control, and documentation of payload components. The intent of this document is to establish procedures required to prevent catastrophic damage associated with cracks or crack-like flaws from occurring during the service life of these components.

3.12 Fracture-critical component (or part). Classification which assumes that fracture or failure of the part resulting from the occurrence of a crack will result in a catastrophic hazard as defined in NSTS 1700.7. Such classification is required unless the contrary is demonstrated using the criteria of 4.2.2.

3.13 Fracture mechanics. Engineering discipline which describes the behavior of cracks or crack-like flaws in materials under stress.

3.14 F_{tu}. Allowable tensile ultimate strength.

3.15 F_{ty}. Allowable tensile yield strength.

3.16 Hazardous fluid. Any liquid or gas which, if released while associated with the Space Shuttle, could result in the potential for personnel injury, loss of Orbiter, or loss of launch or ground facilities.

3.17 Hazardous fluid container. Any single, independent (not part of a pressurized system) container, or housing that contains a fluid whose release would cause a catastrophic hazard, and has stored energy of less than 14,240 foot-pounds (19,310 Joules) with an internal pressure of less than 100 psia (689.5 kPa).

3.18 $1/2I\omega^2$. Rotational energy of a rotating component where “I” is the mass moment of inertia and ω is the rotational frequency in radians per second.

3.19 K_c. Critical stress-intensity factor for fracture.

3.20 K_{Ic}. Plane strain fracture toughness.

3.21 K_{Ie}. Effective fracture toughness for surface or elliptically shaped crack.

3.22 K_{Iscc}. Stress corrosion or environmental cracking threshold for no crack growth under sustained stress conditions.

3.23 K_{max}. Maximum stress intensity in the fatigue cycle.

3.24 Leak-before-burst (LBB). Fracture mechanics design concept in which it is shown that any initial flaw will grow through the wall of a pressure vessel and cause leakage prior to burst (catastrophic failure) at MDP.

3.25 Limit load. Maximum expected load on a structure during its service life.

3.26 Limited life part. Multi-mission part which has a predicted safe-life that is less than four times the service life required for all expected reflights.

3.27 Low fracture toughness. Material property characteristic for which the ratio K_{Ic}/F_{ty} < 0.33 in.$^{1/2}$ (1.66 mm$^{1/2}$). For steel bolts with unknown K_{Ic}, low fracture toughness is assumed when $F_{tu} > 180$ ksi (1240 mPa).

3.28 Maximum design pressure (MDP). The highest pressure defined by maximum relief pressure, maximum regulator pressure, or maximum temperature. Transient pressures shall be considered. Design factors of safety shall apply to MDP. Where pressure regulators, relief devices, and/or a thermal control system (e.g., heaters) are used to control pressure, collectively they must be two-fault tolerant from causing the pressure to exceed the MDP of the system.

3.29 Maximum expected operating pressure (MEOP). MDP shall be substituted for all references to MEOP in MIL-STD-1522A.

3.30 Nondestructive evaluation (NDE). See Standard NDE (3.43).

3.31 Payload organization. NASA installation, sponsoring agency, or commercial customer that is responsible for a payload at the Space Shuttle Payload Safety Reviews.

3.32 Pressure vessel. Container designed primarily for pressurized storage of gases or liquids, and:

1. That stores energy of 14,240 foot-pounds (19,310 Joules) or greater based on adiabatic expansion of a perfect gas; or

2. That holds a gas or liquid at an MDP in excess of 15 psia (103.4 kPa) which will create a hazard if released; or

3. That will experience an MDP greater than 100 psia (689.5 kPa).

3.33 Proof test. Load or pressure in excess of limit load or maximum operating pressure applied to verify the structural integrity of a part or to screen initial flaws in a part.

3.34 Responsible fracture control authority. The designated individual, panel, or group at the NASA Center or sponsoring institution responsible for fracture control methodology.

3.35 Responsible NASA Center. NASA Field Center acting as the sponsor or coordinator for the payload with the Space Shuttle Integration and Operations Office, JSC. For non-NASA payloads, JSC serves as the responsible NASA Center.

3.36 Responsible program authority. Program director/project manager at the NASA Center or sponsoring agency.

3.37 Safe-life. Design criterion under which a flaw is assumed to be consistent with the inspection process specified and under which it can be shown that the largest undetected flaw that could exist in the structure will not grow to failure in four service lifetimes when subjected to the cyclic and sustained loads in the environments encountered. Also, the period of time for which the integrity of the structure can be ensured in the expected operating environments.

3.38 Safe-life verification. Analysis or test of a fracture-critical component which demonstrates safe-life.

3.39 Sealed containers. Any single, independent (not part of a pressurized system) container, component, or housing that is sealed to maintain an internal non-hazardous environment and that has a stored energy of less than 14,240 foot-pounds (19,310 Joules) and an internal pressure of less than 100 psia (689.5 kPa).

3.40 Service life. Service interval for a part beginning with the determination of initial crack size for an analysis based on inspection or a flaw-screening proof test and extending through completion of its specified mission including testing, transportation, lift-off, ascent, on-orbit operations, descent, landing, and postlanding events.

3.41 Single-point direct catastrophic failure. Direct catastrophic failure resulting from fracture in a structural joint where the load path is transmitted through a single fastener or pin or other single structural element.

3.42 Special NDE. Formal crack-detection procedure using inspection techniques and/or equipment that exceeds common industrial standards, or where assumed detection capability exceeds that specified in Table I or II.

3.43 Standard NDE. Formal crack-detection procedures that are consistent with common industrial inspection standards. Standard procedures include penetrant, magnetic particle, eddy current, ultrasonic, and x ray.

3.44 Static fatigue. In glass, flaws grow as a function of stress, flaw size, environment, and time. Strength degradation with time resulting from the flaw growth is also referred to as static fatigue.

3.45 Threshold strain. Value of strain level below which catastrophic failure of the composite structure will not occur in the presence of flaws or damage under service load/environmental conditions.

4. REQUIREMENTS

4.1 Fracture control program.

4.1.1 Responsibilities. In addition to the oversight of the responsible fracture control authority (i.e., at the NASA Center or other Government agency), the prime contractor responsible for the design, development, and manufacture of a payload shall designate a specific fracture control individual or group to be responsible for directing the payload fracture control program and for ensuring its effectiveness. This designee shall be responsible for monitoring, reviewing, and approving fracture control activities performed both internally and by subcontractors or other contributors to the payload system. As appropriate, concurrence is required by other key organizations including engineering; manufacturing; and safety, reliability, and quality assurance.

4.1.2 Supporting data. Engineering data, which should be available for use in fracture control assessments as appropriate, shall include the following:

a. Definition of environments, load spectra history, and stress analysis results.

b. Detailed design and assembly drawings.

c. Mechanical and fracture properties of materials in the appropriate environments.

4.1.3 Fracture control plan.

a. For each payload (or payload element under separate responsibility), a fracture control plan shall be prepared by or for the payload organization, approved by the responsible program authority, and submitted to the Payload Safety Review Panel for approval as part of the Phase I Payload Safety Review.

b. The fracture control plan shall define the elements of the fracture control program and the responsibilities for managing and accomplishing them. As a minimum, it shall also describe the following methods and procedures to be used for implementing this document:

(1) Analysis and/or testing and inspection to determine fracture control classification and acceptability of hardware.

(2) Control of materials, manufacturing processes, testing, design changes, and transportation to ensure proper implementation of fracture control requirements.

(3) Overall review and assessment of the payload fracture control activities and results.

c. Changes to the fracture control plan that may be required as a result of the Phase I Payload Safety Review shall be incorporated into a revised fracture control plan. This plan must be resubmitted for approval by the program authority prior to the Phase II Payload Safety Review. Resubmission shall follow the process outlined in paragraph 4.1.3.a.

4.1.4 Traceability and documentation.

a. An appropriate level of traceability to ensure proper materials, processes, and inspections shall be maintained on all fracture-critical parts throughout the payload development, manufacturing, flight, and multiple-flight preparation program.

(1) Specific procedures, which shall be summarized in the fracture control plan, shall be established at the discretion of the primary organization responsible for developing the payload.

(2) A pressure history log shall be maintained for pressure vessels when vessel life is limited by safe-life fracture control requirements. The log, which shall begin with the proof test or inspection(s) used to define the starting flaw baseline, shall record pressure cycles and vessel contents for the service life of the vessel.

(3) Engineering drawings and equipment specifications for fracture-critical parts shall contain notes which identify the part as fracture-critical and specify the appropriate inspection or flaw-screening method to be used on the part.

b. As a minimum, changes in design or process specifications, manufacturing discrepancies, repairs, and finished part modifications for all fracture critical parts shall be reviewed by the designated fracture control individual or group (as defined in 4.1.1) to ascertain that the parts still meet fracture control requirements.

4.2 Fracture control classification and requirements.

4.2.1 General. Fracture control classification for all components of a payload shall be determined as shown in Figure 1. Components which are classified as low released mass, contained, fail-safe, or low-risk fracture shall meet the requirements specified in 4.2.2. These components may be classified as nonfracture critical and should be processed in accordance with other imposed standards to meet the design, analysis, inspection, testing, verification, quality control, and documentation requirements set forth for Space Shuttle payloads. Components classified as fracture critical shall have their damage tolerance and/or safe-life verified by either test or analysis in addition to meeting the standard aerospace requirements.

4.2.2 Nonfracture-critical components.

4.2.2.1 Low released mass part. For a payload component to be classified as a low released mass part, it shall meet requirements a, b, and c listed below:

a. The part satisfies one of the following two conditions:

(1) Total mass of the part or any other released part is less than 0.25 pounds (113 grams).

(2) Total mass in pounds (kilograms) supported by the part is not more than 14/h, where h is the part’s travel distance in feet (or 1.94/h, where h is in meters) to the aft bulkhead of the Space Shuttle cargo bay. When the installation location of a potential released mass is not known, a documented maximum travel distance estimate may be used. Total mass of the released part shall not exceed 2 pounds (0.9 kilograms).

b. It can be shown that the release of this component will not cause a catastrophic hazard to the Space Shuttle because of subsequent damage to the payload from which it came.

c. For parts which have low fracture toughness and are preloaded in tension, a fragment may be released at high velocity immediately following failure; therefore, the total released mass may not exceed 0.03 pounds (14 grams). A part shall be considered to have low fracture toughness when its material property ratio $K_{Ic}/F_{ty} < 0.33$ in.$^{1/2}$ (1.66 mm$^{1/2}$), where K_{Ic} is the plane strain fracture toughness and F_{ty} is the allowable yield tensile strength. If the part is a steel bolt and the K_{Ic} value is unknown, low fracture toughness shall be assumed when the specified minimum $F_{tu} > 180$ ksi (1240 mPa), where F_{tu} is the allowable ultimate tensile strength.

4.2.2.2 Contained part. For a payload component to be classified as a contained part, it shall be shown that all released pieces of the failed component that violate the low mass requirement (4.2.2.1) are completely contained in the payload and will not cause a catastrophic hazard to the Space Shuttle as a result of subsequent damage to the payload in which it was installed. One of the following methods shall be used to verify containment:

a. Engineering judgment supported by documented technical rationale may be used when it is obvious that an enclosure, a barrier, or a restraint exists that prevents the part from escaping into the Space Shuttle payload bay. Examples of such enclosures that have obvious containment capability include metallic boxes containing closely packed electronics, detectors, cameras, and electric motors; pumps and gearboxes having conventional housings; and shrouded or enclosed fans not exceeding 8 inches. (200 mm) diameter and 8000 revolutions per minute (rpm) speed.

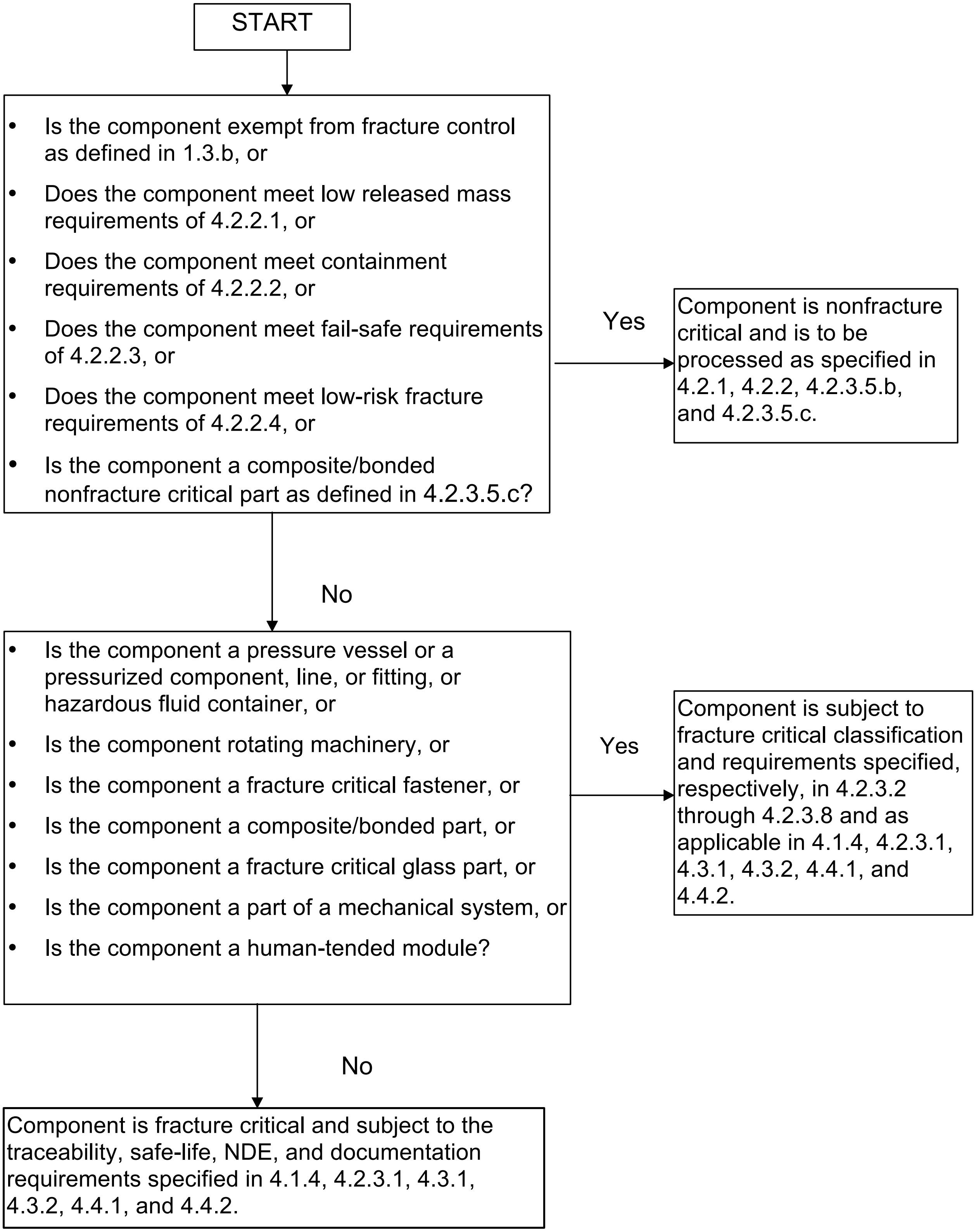


FIGURE 1. Fracture Control Classification/Processing of Payload Components

b. Documented testing or analysis shall be used to show containment when the ability of the enclosure, barrier, or restraint to prevent the part from escaping is not obvious. For enclosures with holes, only internal parts that cannot pass through the holes shall be considered contained. When enclosures are designed to be opened, they must be closed again to establish containment for a later phase of the mission. Closure devices shall be single failure tolerant.

4.2.2.3 Fail-safe part. For a payload component to be classified as a fail-safe part, it must meet requirements a and c or requirements b and c below:

a. It must be shown by analysis or test that, due to structural redundancy, the structure remaining after any single failure can withstand the redistributed limit loads with a safety factor of 1.0. In meeting these requirements, the effect of altered Space Shuttle/payload coupling shall be considered unless:

(1) Design loads are conservative with respect to Space Shuttle/payload dynamic coupling variations; or

(2) Failure of the component would not significantly alter payload dynamic response. Technical rationale to substantiate that there is no significant effect on payload dynamic response must be documented.

b. Alternatively, engineering judgment supported by documented technical rationale may be used when it is obvious there is sufficient structural redundancy for fail-safe classification, or failure of the part clearly would not create a catastrophic hazard.

c. Adequate quality control is implemented to ensure that generic or process defects are not present so that the remaining structure may be considered unflawed. For multi-mission payloads, it must be verified before reflight that the structural redundancy of a fail-safe part is still intact or sufficient fatigue life is available in the remaining structure to reach end-of-service life (e.g., 4.2.2.4.2.2). At a minimum, verification shall consist of a purposeful visual inspection for evidence of structural damage at the lowest level of planned disassembly between missions. If there is evidence of damage, the affected structure shall be repaired or sufficiently examined to verify intact redundancy.

4.2.2.4 Low-risk fracture part. A low-risk fracture part shall comply with the requirements of 4.2.2.4.1 and 4.2.2.4.2 except for fasteners and shear pins, which need comply only with 4.2.2.4.3.

4.2.2.4.1 Limitations on applicability. The part shall be all metal. It shall not be the pressure shell of a human-tended module or personnel compartment, pressure vessel, pressurized component in a pressurized system containing a hazardous fluid, or high-energy rotating machinery. A part whose failure will directly result in a catastrophic hazard is also excluded, except when the total (unconcentrated) tensile stresses in the part at limit load are no greater than 30 percent of the ultimate tensile strength for the metal used and all other requirements for low-risk classification are met. The intended use of low-risk fracture classification shall be presented at the Phase I Safety Review to show an adequate understanding of the requirements. Identification of low-risk fracture parts and compliance with these requirements shall be addressed in the Phase III Safety Review package and in the fracture control summary report.

4.2.2.4.2 Inherent assurance against catastrophic failure from a flaw. The part shall possess inherent assurance against catastrophic failure due to a crack-like flaw by compliance with the requirements of the following paragraphs (4.2.2.4.2.1 through 4.2.2.4.2.3, as applicable):

4.2.2.4.2.1 Remote possibility of significant crack-like defect. Assurance against the presence of a significant crack-like defect shall be achieved by compliance with the following criteria:

a. The part shall be fabricated from a well-characterized metal which is not sensitive to stress corrosion cracking as defined in either MSFC-SPEC-522 or MSFC-HDBK-527/JSC 09604. If other than Table I or A-rated materials – as classified, respectively, in these documents – must be used, suitability for the specific application shall be documented by a materials usage agreement (MUA). MUA forms contained in the cited documents, or equivalent, shall be used.

b. The part shall not be fabricated using a process that has a recognized risk of causing significant crack-like defects, such as welding, forging, casting, or quenching heat treatment (for materials susceptible to cracking during heat treatment quenching) unless specific NDE or testing, which has been approved by the responsible fracture control authority, is applied to sufficiently screen for defects. It may be assumed that significant crack-like defects do not occur during machining of sheet, bar, and plate products from materials that are known to have good machinability properties, do not have low fracture toughness (as defined in 3.27), and are metals or alloys produced in accordance with applicable military specifications and standards or equivalent grade specifications.

c. All parts classified as low-risk fracture parts shall meet inspection standards consistent with aerospace practices to ensure aerospace-quality flight hardware. At a minimum, low-risk fracture parts shall receive visual inspection. Inspection shall be made at the individual part level to assure maximum accessibility. Surface damage that could affect part life shall be cause for rejection.

4.2.2.4.2.2 Remote possibility of significant crack growth. Assurance against significant crack growth shall be achieved by compliance with any one of the following criteria:

a. The part shall not be subjected to fatigue loading beyond acceptance and/or normal protoflight testing (if any), transportation, and one mission.

b. The part shall be shown to possess a high safety margin on fatigue strength. This may be shown by either criteria 1 or 2 as follows:

(1) Limiting the local maximum cyclic tensile stress, S_{max}, for a metal part to S_{max} < endurance limit or, if data are not available, to

$$S_{max} \leq F_{tu}/(4(1-0.5R))$$

where R is the ratio of minimum to maximum stress in a fatigue cycle, and S_{max} is the local concentrated stress.

(2) A conventional fatigue analysis for crack initiation which conservatively accounts for the effects of notches and mean stress. The analysis must show a minimum of four complete service lifetimes with a safety factor of 1.5 on alternating stress.

c. The part shall be shown to possess acceptable resistance to crack growth from potential initial defects caused by machining, assembly, and handling. Assumed initial surface cracks of 0.025 in. (0.63 mm) depth and 0.05 in. (1.25 mm) length and corner cracks of 0.025 in. (0.63 mm) radius from holes shall not grow to failure in less than four complete service lifetimes.

4.2.2.4.2.3 Nonhazardous leak mode of failure. Pressurized components or sealed containers that have a nonhazardous LBB mode of failure (i.e., critical length of through crack is at least 10 times wall thickness and fluid release would not create a catastrophic hazard) may be classified as low-risk fracture parts if the component/container supports meet fracture control safe-life, fail-safe, or containment requirements and the component/container complies with the following requirements:

a. Requirements for sealed containers:

(1) Compliant with the definition for sealed containers in 3.39.

(2) Container is made from metal alloys typically used for sealed containers (e.g., aluminum, stainless steel, or titanium sheet) and contains a fluid whose release is not a catastrophic hazard.

(3) If compliant with criteria 1 and 2 and pressurized to 1.5 atmospheres or less, the containers are acceptable. If pressurized to more than 1.5 atmospheres, an analysis shall show that the safety factor is 2.5 or greater or that the container shall be proof-tested to a minimum of 1.5 times the MDP.

(4) In special cases, containers with pressure or contained energy exceeding the limits defined in 3.39 may be acceptable, but these containers shall be specifically approved by the responsible fracture control authority and by the Payload Safety Review Panel. At a minimum, an analysis shall show the safety factor is 2.5 or greater and that the container is an LBB design. In addition, the container shall be proof-tested to a minimum of 1.5 times the MDP.

b. Requirements for pressurized components:

(1) Components, lines, and fittings shall be in compliance with flight system safety factors as defined in NSTS 1700.7.

(2) Components are made from metal alloys (e.g., stainless steel, aluminum, Inconel) typically used for pressurized systems.

(3) Components that can sustain continued fatigue crack extension following leakage shall be shown by analysis to have safe-life-against-burst for the remaining possible cyclic pressurizations, or controls shall exist to detect leakage and prevent continued pressure cycles.

4.2.2.4.3 Fasteners and shear pins. Fasteners and shear pins may be classified as low-risk fracture parts when, though they are not shown to be compliant with 4.2.2.3, (a) fracture of the fastener does not result in a single-point direct catastrophic failure, and (b) they can meet the following requirements:

a. Be high-quality military standard, national aircraft standard, or equivalent commercial fasteners or pins that are fabricated and inspected in accordance with aerospace-type specifications. Fasteners, which require specific tensile preload and which are used in joints that are loaded primarily in tension, shall have rolled threads meeting aerospace or equivalent rigorous standards.

b. Be fabricated from well-characterized metal which is not sensitive to stress-corrosion cracking. Bolts in tension applications shall not be fabricated from low fracture toughness alloys (as defined in 3.27) or specifically, Ti-6A1-4V STA titanium.

c. Meet appropriate requirements for stress and fatigue analysis including torque/preload requirements for tension-loaded fasteners (i.e., sufficient preload to prevent gapping so that the cyclic loads are limited).

d. Be of equal aerospace quality and meet all applicable criteria in a, b, and c above when reworked or custom-made fasteners.

e. Have positive back-off prevention consistent with their criticality to assure the validity of fracture control of all fasteners.

4.2.3 Fracture-critical components.

4.2.3.1 Safe-life verification.

4.2.3.1.1 General.

a. A fracture-critical component is acceptable if it can be shown, by analysis or test, that the largest undetected flaw that could exist in the component will not grow to failure when subjected to the cyclic and sustained loads encountered in four complete service lifetimes. One complete service lifetime shall include all significant loadings that occur after flaw screening to establish minimum initial flaw size and shall include testing, transportation, lift-off, ascent, on-orbit operations, descent, landing, and postlanding events.

b. For limited life parts (as defined in 3.26), it shall be determined that at least four safe-lives remain before reflight. Renewed life predictions may be established by periodic inspection, proof-testing, or replacement; therefore, limited life parts shall be accessible for NDE inspection or replacement. Intervals between inspections, proof tests, and/or replacements are to be established by safe-life analysis. Accessibility for inspection, testing, and/or replacement shall be addressed in the fracture control summary report.

c. A specific, detailed, fracture mechanics analysis (or test) shall be performed to justify the use of any fracture-critical flight part with detected crack-like flaws. Approval of the responsible program authority must be obtained prior to the use of any fracture-critical flight part containing detected cracks or crack-like defects. Occurrences of detected crack-like flaws shall be included in the fracture control summary report along with the basis for acceptability.

4.2.3.1.2 Safe-life analysis.

a. When crack growth analysis is used to demonstrate the safe-life design of a part, an undetected flaw shall be assumed to be in the most critical area and orientation for that part. The size of the flaw shall be based on either the appropriate NDE techniques (4.3) or on proof testing. Table I (or Table II) lists flaw sizes representative of the capabilities of commonly used NDE techniques for geometries shown in Figure 2. Both the crack growth analysis and the proof test flaw screening logic, if utilized, shall be based on state-of-the-art fracture mechanics methodology. Use of proof testing as an alternative to NDE to support safe-life determination shall require prior approval of the responsible fracture control authority. For surface cracks in components including pressure vessels, both sets of values for “a” and “c” given in Table I (or Table II) must be considered.

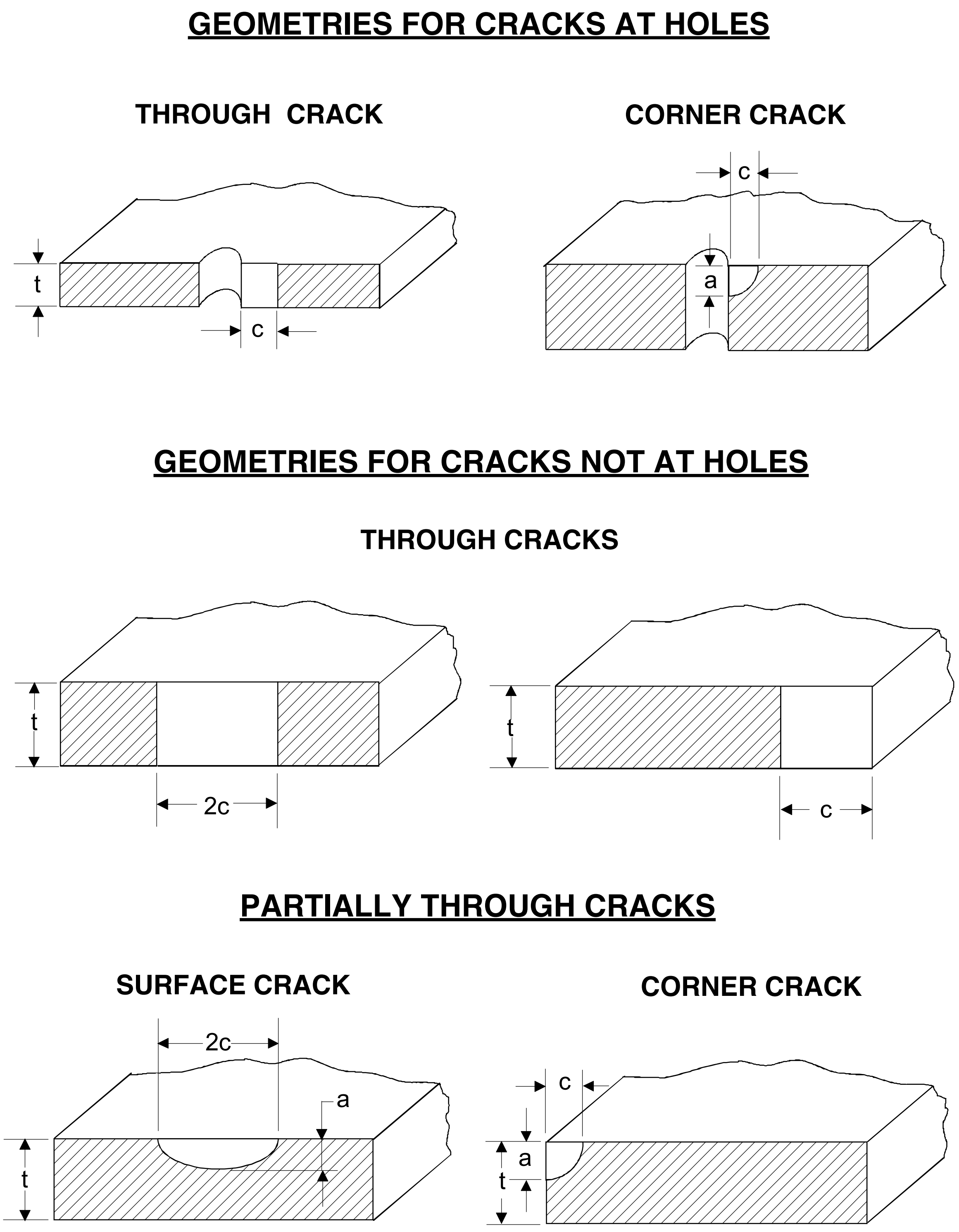
b. For components where it is necessary to consider the propagation of a crack into a hole, or from one hole to another hole, analysis shall assume that the crack is not arrested or retarded by the hole but continues on past the hole. In analyzing components or assemblies where drilling of numerous holes or the use of automatic hole preparation and fastener installation equipment at the assembly level makes NDE of holes impractical, an initial crack size can be assumed which is based on the maximum potential damage from hole preparation operations. With acceptable hole preparation (outlined in 4.2.3.1.2.c and in the restrictions of 4.2.3.1.2.d and 4.2.3.1.2.e), the maximum initial crack size can be assumed to be smaller than those sizes specified in Table I (or Table II).

c. Specifically, for drilled holes with driven rivets, the assumed defect (4.2.3.1.2.b) shall be a 0.005 in. (0.13 mm) length crack through the thickness at one side of the hole. For fastener holes other than those for driven rivets, where the material thickness is equal to or less than 0.05 in. (1.3 mm), the assumed fabrication defect shall be a 0.05 in. (1.3 mm) length crack through the thickness at one side of the hole. Where the thickness is greater than 0.05 in. (1.3 mm), the initial flaw size shall be a 0.05 in. (1.3 mm) radius corner flaw at one side of the hole.

d. The maximum fabrication defect sizes given in 4.2.3.1.2.c may be used for an analysis of holes only where (1) the holes are not punched, (2) the material is not prone to cracking during machining, (3) NDE is performed prior to machining of the holes, (4) no heat treatment or possible crack forming fabrication processes are performed subsequent to NDE, (5) analysis is performed with separate and additional flaws assumed at the most critical locations away from the holes and with sizes that are consistent with the specified NDE method, and (6) prior approval is obtained from the responsible fracture control authority.

e. Notwithstanding any of the options stated in 4.2.3.1.2.d, NDE of holes shall always be required for fracture-critical components where the load is transmitted through a single hole, such as for a fitting.

f. Either of two analysis approaches may be used to show that an NDE-inspected part meets safe-life requirements. The first or direct approach is to select the appropriate inspection technique and level indicated in Table I (or Table II) and to use the listed minimum initial flaw sizes in analyses to show that the part will survive at least four lifetimes. The alternate or iterative approach is to calculate the critical (i.e., maximum) initial crack size for which the payload can survive four lifetimes and to verify by inspection that there are no cracks greater than or equal to this size. Where the iteratively derived crack size is smaller than the value given in Table I (or Table II), use of the smaller size requires prior approval as per 4.3.2.



GEOMETRIES FOR CRACKS AT HOLES

THROUGH CRACK

CORNER CRACK

GEOMETRIES FOR CRACKS NOT AT HOLES

THROUGH CRACKS

PARTIALLY THROUGH CRACKS

SURFACE CRACK

CORNER CRACK

FIGURE 2. Standard Crack Geometries

TABLE I. Minimum Initial Crack Sizes for Fracture Analysis Based On NDE Method

U.S. Customary Units (in.)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
Eddy Current NDE				
Open Surface	t ≤ 0.050	Through	t	0.050
	t > 0.050	PTC[1]	0.020 0.050	0.100 0.050
Edge or Hole	t ≤ 0.075	Through	t	0.100
	t > 0.075	Corner	0.075	0.075
Penetrant NDE				
Open Surface	t ≤ 0.050	Through	t	0.100
	.050 < t < .075	Through	t	0.15-t
	t > 0.075	PTC	0.025 0.075	0.125 0.075
Edge or Hole	t ≤ 0.100	Through	t	0.100
	t > 0.100	Corner	0.100	0.100
Magnetic Particle NDE				
Open Surface	t ≤ 0.075	Through	t	0.125
	t > 0.075	PTC	0.038 0.075	0.188 0.125
Edge or Hole	t ≤ 0.075	Through	t	0.250
	t >0.075	Corner	0.075	0.250
Radiographic NDE[2]				
Open Surface	.025 ≤ t ≤ 0.107	PTC	0.7t	0.075
	t > 0.107		0.7t	0.7t
Ultrasonic NDE[3]				
Open Surface	t ≥ 0.100	PTC	0.030 0.065	0.150 0.065

Notes:
1 - Partly through crack (PTC).
2 - Sizes not applicable to very tight flaws (e.g., forging flaws or lack of full penetration in butt welds).
3 - Comparable to Class A quality level (MIL-STD-410)

TABLE II. Minimum Initial Crack Sizes for Fracture Analysis Based on NDE Method

SI Units (mm)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension a	Crack Dimension c
Eddy Current NDE				
Open Surface	t ≤ 1.27	Through	t	1.27
	t > 1.27	PTC[1]	0.51 1.27	2.54 1.27
Edge or Hole	t ≤ 1.91	Through	t	2.54
	t > 1.91	Corner	1.91	1.91
Penetrant NDE				
Open Surface	t ≤ 1.27	Through	t	2.54
	1.27 < t < 1.91	Through	t	3.81-t
	t > 1.91	PTC	0.64 1.91	3.18 1.91
Edge or Hole	t ≤ 2.54	Through	t	2.54
	t > 2.54	Corner	2.54	2.54
Magnetic Particle NDE				
Open Surface	t ≤ 1.91	Through	t	3.18
	t > 1.91	PTC	0.97 1.91	4.78 3.18
Edge or Hole	t ≤ 1.91	Through	t	6.35
	t > 1.91	Corner	1.91	6.35
Radiographic NDE[2]				
Open Surface	0.64 ≤ t ≤ 2.72	PTC	0.7t	1.91
	t > 2.72		0.7t	0.7t
Ultrasonic NDE[3]				
Open Surface	t ≥ 2.54	PTC	0.76 1.65	3.81 1.65

Notes:

1 - Partly through crack (PTC).

2 - Sizes not applicable to very tight flaws (e.g., forging flaws or lack of full penetration in butt welds).

3 - Comparable to Class A quality level (MIL-STD-410).

g. Appropriate crack models and material properties, including all contributions to crack growth, such as environmental effects, shall be included in the analysis. For sustained stresses, it shall be shown that the maximum stress-intensity factor in the fatigue cycle, K_{max}, is less than the stress corrosion or environmental cracking threshold, K_{Iscc}. Retardation effects on crack growth rates from variable amplitude loading shall not be considered without the approval of the responsible fracture control authority. The Fatigue Crack Growth Computer Program NASGRO (NASA/FLAGRO) is an approved computer code for crack growth analysis of Space Shuttle payloads. Other computer programs or analysis methods are acceptable if they are shown to give comparable results.

4.2.3.1.3 Safe-life testing. Testing is an acceptable alternative to safe-life analysis, but it is subject to prior approval of the test plan by the responsible program authority. Safe-life testing, which shall be performed in the appropriate environment on precracked specimens representative of the structural design of the part, shall demonstrate at least four lifetimes.

4.2.3.1.4 Fracture mechanics material data.

a. Where environmental effects on crack growth must be considered, as in pressure vessel applications, the lower bound values of K_{Iscc} for the relevant fluid and material combinations shall be used in fracture mechanics analysis.

b. When using assumed NDE initial flaw sizes for safe-life analysis of ordinary fracture-critical parts, the assumed fracture toughness values (the effective fracture toughness for a surface or elliptically shaped crack [K_{Ie}], K_{Ic}, or the critical stress-intensity factor for fracture [K_c]) as appropriate for predicting crack instability shall be average (i.e., typical) values. If conditions 1 and 2 are met, these average values may be obtained from data in literature, from actual testing, or from NASGRO as follows:

(1) The material is a standard mill product such as rolled sheet, plate, bar, extrusion, or forging.

(2) The material alloy composition, heat treatment, and environmental operating conditions are reliably known and correspond to those for which the literature or test data are available.

c. For parts that are specifically considered high risk (e.g., failure will clearly result in catastrophic occurrence) and are fabricated from an alloy having a wide variety of fracture toughness for the particular fabrication and heat treatment process used, strength and fracture toughness testing of actual representative material may be required. Testing for this case shall be explicitly required for low fatigue cycle applications (e.g., less than 1000 cycles) when an assumed lower bound value of fracture toughness results in an inadequate safe-,life. When these tests are not performed or when the conditions in 4.2.3.1.4.b cannot be met, material properties which are clearly conservative with respect to expected properties shall be documented and approved by the responsible fracture control authority.

d. If a proof test is used for initial flaw screening, upper bound fracture toughness values shall be used to calculate the crack size determined by the proof test. Upper bound values shall be determined by multiplying average properties by a factor of 1.2.

e. Average fatigue crack growth rate properties shall be used for crack growth calculations for the NDE initial flaw size approach. Average fracture toughness values may be used in crack growth rate equations which model growth rate approaching instability; however, for flaw sizes determined by a proof test, upper bound fracture toughness values used to determine the initial flaw size in condition d shall be used. Where the fatigue crack growth data sources are particularly sparse, conservative estimates of the growth rate shall be assumed and documented. All crack growth rate data shall correspond to the actual temperature and chemical environments expected or shall be conservative with respect to the actual environments. The crack growth rate data contained in NASGRO may be used if all the conditions in 4.2.3.1.4.b are met.

4.2.3.2 Pressurized systems and containers.

4.2.3.2.1 Pressure vessels.

a. Pressure vessels, as defined in 3.32, shall comply with the requirements in Sections 4 and 5 of MIL-STD-1522A (including revisions as of December 1984) that are modified as follows:

(1) Approach “B” of Figure 2 in MIL-STD-1522A is not acceptable.

(2) In addition to other required analyses, composite pressure vessels shall be assessed for adequate stress rupture life and damage tolerance.

(3) NDE of safe-life pressure vessels (i.e., safe life against hazardous leak or burst) shall include inspection of welds after proof testing to screen the initial NDE flaw size assumed for analysis.

(4) MDP, as defined in 3.28, shall be substituted for all references to MEOP in MIL-STD-1522A.

(5) For low cycle applications (< 50 pressure cycles), a proof test of each flight vessel to a minimum of 1.5 times MDP and a fatigue analysis showing the greater of 500 pressure cycles or 10 lifetimes may be used in lieu of testing a qualification vessel. This option may be used when the pressure vessel can be verified as otherwise compliant with the requirements of NSTS 1700.7 and MIL-STD-1522A, Approach A.

(6) An acceptable approach to LBB is to show that a through-the-thickness crack with a length 10 times the wall thickness will not result in an unstable fracture (i.e., $K_{max} < K_c$) at MDP or other relevant maximum pressure. If fracture mechanics data are not available, or if reliable conservative estimates of properties cannot be made, a vessel test shall be conducted to verify the LBB capability. LBB pressure vessels which are fabricated to acceptable requirements, qualified for their application, and used where release of contained fluid would not be a catastrophic hazard are acceptable without safe-life assurance. For the remote case where a pressure vessel may sustain continued fatigue crack extension subsequent to leakage, analysis shall show safe-life-against-burst for the remaining possible cyclic pressurizations, or controls shall exist to detect leakage and to prevent continued pressure cycles.

(7) For metal-lined pressure vessels that have an overwrapped composite structure, the fracture control for safe-life and failure mode shall be applied to the liner. In addition, the overwrap shall satisfy 4.2.3.5 of this document.

(8) In the event of a conflict in requirements between MIL-STD-1522A and this document, the requirements of this document shall take precedence.

b. Particular attention shall be given to ensure the compatibility of vessel materials with fluids used in cleaning, testing, and operation. Data requirements for pressure vessels are listed in NSTS 13830.

4.2.3.2.2 Lines, fittings, and components. Lines, fittings, and other pressurized components (equipment that is part of a pressurized system including valves, filters, regulators, heat pipes, heat exchangers, etc.) are to be considered fracture critical if they contain hazardous fluids or if loss of pressurization would result in a catastrophic hazard. All fusion joints in fracture critical systems shall be 100 percent inspected using a qualified NDE method(s) that will determine the presence of unacceptable lack of penetration or other unacceptable conditions both on the surface and within the weldment. Unless impractical, inspection of fusion joints shall be made after proof testing, and for lines and fittings after proof test of the final assembly. Concurrence of the responsible fracture control authority is required where full NDE is not considered practical. Any type of flaw indication in the final product that does not meet specification requirements shall be cause for rejection. In addition to proof testing of parts during individual acceptance, the complete pressure system shall also be proof-tested and leak-checked to demonstrate system integrity. Safe-life analysis is not required for fracture-critical lines, fittings, and other pressurized components which are proof-tested to a minimum of 1.5 times the MDP and meet the safety factor requirements of NSTS 1700.7

4.2.3.2.3 Hazardous fluid containers. Hazardous fluid containers as defined in 3.17 shall have safe-life against rupture or leakage when release of a fluid would cause a catastrophic hazard. Such containers shall be treated and certified the same as pressure vessels when the contained fluid has a delta pressure greater than one atmosphere. When approved by the responsible fracture control authority, an optional approach may be used for metallic or non-metallic containers (including those with a differential pressure of less than one atmosphere). Containers using this optional approach shall have a minimum safety factor of 2.5 times MDP and shall meet the fracture control requirements for pressurized components given in 4.2.3.2.2. When a proof test to a minimum factor of 1.5 is impractical, safe-life shall be assured by appropriate NDE applications and flaw growth analysis. Integrity against leakage shall be verified by test at a minimum pressure of 1.0 times MDP.

4.2.3.3 High-energy rotating machinery. For the purpose of fracture control, a rotating mechanical assembly that has a kinetic energy of 14,240 foot-pounds (19,310 Joules) or greater (based on $1/2I\omega^2$) is fracture critical by definition. In addition to other requirements for fracture-critical components, rotating machinery shall be proof-tested (spin-tested) to screen for flaws and shall be subjected to NDE before and after proof testing or shall be shown to be contained if failure occurs at maximum speed and if loss of function is not safety critical. The proof-test level shall be greater than or equal to the level derived by fracture mechanics analysis. Rotating mechanisms with lower kinetic energy levels are to be classified by the same criteria as other structural components.

4.2.3.4 Fracture-critical fasteners. Fasteners and shear pins shall be classified as fracture-critical parts when their fracture results in a single-point direct catastrophic failure. For this classification, all parts shall meet the requirements of low-risk fasteners in items a through e in 4.2.2.4.3, plus the additional requirements as follows:

a. Be the highest quality aerospace fasteners fabricated from A286 steel, Inconel 718, MP35N alloy, or similarly tough and environmentally compatible alloys.

b. Shear bolts and pins shall be designed or sized to carry shear in the shank area only. At a minimum, for the purpose of screening flaws, the shank area of shear bolts shall be NDE-inspected by the eddy current method and tension fasteners shall be similarly inspected in the shank, head fillet, and thread areas. If desired, this inspection may be performed by the fastener manufacturer or by one of the manufacturer's approved NDE houses. A safe-life analysis shall be conducted for shear loading (i.e., resulting bending stress) and for tension fasteners with an assumed "thumbnail" type surface crack given in JSC 22267. For a fastener diameter, D, that is less than 0.50 in. (12.7 mm), the initial crack length, 2c, shall be equal to 0.3 D. For a fastener diameter that is greater than 0.50 in. (12.7 mm), the crack length shall be 0.15 in. (3.8 mm). Analytical flaw location for shear fasteners and bolts shall be in the shank and shall be in the threads for tension fasteners. The depth, a, of the assumed crack may be calculated from the expression

$$a = r\left(1 + \tan\frac{c}{r} - \sec\frac{c}{r}\right)$$

where r is the radius of the shank or one-half the minor diameter of the thread.

c. For all fracture-critical fasteners smaller than 0.188 in. (4.8 mm) diameter, the fasteners and the methods for flaw screening and preload control shall be identified and specifically approved by the responsible fracture control authority.

d. All fracture-critical fasteners shall be identified and stored separately following NDE or proof testing. Installation of fracture-critical fasteners shall employ appropriate methods to apply required preloads accurately.

e. The use of fracture-critical tension fasteners shall be avoided, whenever reasonable, through the use of multiple fastener-type designs for which redundant load-carrying capability exists.

4.2.3.5 Composite/bonded structures.

a. For nonmetallic composite/bonded structures, analysis of damage tolerance by linear elastic fracture mechanics is generally agreed to be beyond the current state of the art. Therefore, fracture control of these structures must rely on the techniques of containment and fail-safe assessment, use of threshold strain levels for damage tolerance, verification of structural integrity through analysis and testing, manufacturing process controls, and nondestructive inspection.

b. All composite/bonded structures shall meet the structural verification requirements of NSTS 14046. Furthermore, the payload designer/manufacturer shall use only manufacturing processes and controls (coupon tests, sampling techniques, etc.) that are demonstrated to be reliable and consistent with established aerospace industry practices for composite/bonded structures. Supporting data shall be available to verify that as-built flight articles satisfy design and analysis assumptions, models, and all technical requirements. Test articles shall be designed and fabricated to the same requirements, drawings, and specifications as the flight article.

c. Composite/bonded structures or components may be classified as nonfracture critical if it is shown that one of the following conditions is satisfied:

(1) The structure or component in question meets the requirements of 4.2.2 for low released mass, contained, or fail-safe components.

(2) The strain level at limit load is less than the composite/bonded structure's damage-tolerance threshold strain level. The threshold strain level shall be determined by testing preflawed coupons or, if approved by the responsible fracture control authority, by using available data.

d. All composite/bonded structures deemed fracture critical (i.e., those which do not meet the fracture control screening criteria listed in 4.2.3.5.c) shall be shown to meet fracture control requirements by one of the following methods:

(1) A proof test (static or dynamic) to no less than 120 percent of the limit load. The proof test shall be conducted on the flight article. The test may be accomplished at the component or subassembly level if the loads on the test article duplicate those that would be seen in a fully assembled test article. Caution should be exercised when testing the flight article to 1.20 to prevent detrimental yielding to the metallic fittings and fasteners in the flight assembly and damage to the composite. Test loads on the composite should not exceed 80 percent of ultimate strength.

(2) A damage-tolerance test program to establish that these structures possess at least four service lifetimes. These tests shall be conducted on full-scale, flight-like elements of critical components and samples with controlled flaws or damage. The size and shape of the flaws or damage must correspond to the detection capability of the NDE to be imposed on the flight part. The type of flaws and damage considered must be representative of that which could occur on the flight part.

e. In particular cases where the requirements of 4.2.3.5.d cannot be met, flight hardware may be approved for fracture control based on special considerations. These special considerations include a formal quality control program and demonstrated past experience. Specifically, it must be shown that the manufacturer of the composite article has a successful history of building a similar design, certified and controlled process specifications are used, personnel are properly trained and certified, and proposed nondestructive testing techniques are adequate to validate the quality and integrity of the hardware. This information must be provided to the Payload Safety Review Panel and documented in the fracture control summary report. Use of this option must be approved by the responsible program authority.

f. For all fracture-critical composite/bonded components, procedures to prevent damage resulting from handling or final assembly shall be addressed in the fracture control plan and approved by the responsible program authority.

4.2.3.6 Fracture-critical glass components.

4.2.3.6.1 Classification criteria. A glass component shall be considered fracture critical if it is loaded by either external or pressure loads or if it fails to meet the "low release mass part" or "contained part" requirements specified in 4.2.2.1 and 4.2.2.2. If the only forces carried by the component are due to its own inertial loading and the requirements specified in 4.2.2.1 or

4.2.2.2 are met, the component shall be considered nonfracture critical. If a payload with a glass component is carried in the crew module, positive protection to the crew against any breakage or release of shatterable material is required.

4.2.3.6.2 Fracture control analysis.

a. Fracture-critical glass components that are load bearing, either from sustained loads or pressures, shall be analyzed for degradation from static fatigue (as defined in 3.44). This analysis shall include an evaluation of flaw growth under the conditions of limit stresses and actual environments. Since moisture contributes to flaw growth in glass, flaw growth calculations will be based on the total design life, with a life scatter factor of 4 and with average flaw growth properties derived for 100 percent moisture. This fracture mechanics analysis, which shall be performed for each fracture-critical glass component, must demonstrate that the component has an end-of-life factor of safety of at least 1.4. The life prediction will be based on K_{IC} nominal minus 3-sigma.

b. A proof test of flight hardware will be conducted to screen all manufacturing flaws larger than those assumed in the fracture mechanics analysis. The proof test will be conducted in an environment which does not promote flaw growth. Proof stress will be based on K_{IC} nominal plus 1-sigma.

c. If the fracture mechanics analysis predicts critical flaws which are much greater than the constraints of the analysis, or if stresses are very low with respect to test-verified allowables and a factor of safety of 5 or greater can be shown, a proof test is not required. The appropriate analysis should be submitted in lieu of test results.

d. If the component has only inertia loading during mission phases, including launch and landing, and does not meet either requirements of 4.2.2.1 and 4.2.2.2, a vibration test of the component, in excess of flight levels, followed by a rigorous visual inspection may satisfy fracture control requirements. Effects of humidity and/or cleanliness during the tests shall be considered. Use of this option shall be approved by the responsible fracture control authority.

e. For some payloads, a statistical analysis of flaw population in the glass components may be acceptable. The report ATR-93(3827)-1 may be helpful in these cases. Use of this option shall be approved by the responsible fracture control authority.

4.2.3.7 Fracture-critical mechanical systems. Structural parts of a mechanical system whose failure would result in a catastrophic hazard are defined as fracture critical. These systems, or critical parts within a system, shall be assured against failure from flaws using fracture mechanics methodology.

4.2.3.8 Human-tended modules. Human-tended modules are fracture critical and shall be assured against catastrophic failures from flaws using fracture control methodology. Human-tended modules shall be shown to be safe-life designs against flaw instability. If a module is an LBB design and leakage is not catastrophic and will be detected, this may be used as assurance against instability in lieu of safe-life assessment. All LBB modules shall have fusion joints inspected to verify design and quality requirements. If fusion joints are safe-life designs, they shall be inspected accordingly for flaws after proof testing, as a minimum.

4.3 NDE inspections.

4.3.1 Requirements and assumptions. The selection of NDE methods and level of inspection shall be based primarily on the safe-life acceptance requirements of the part. The NDE initial crack sizes used in safe-life analysis shall correspond to a 90 percent probability/95 percent confidence level of inspection reliability. Minimum detectable initial crack sizes for specific NDE methods are given in Table I (or Table II) for geometries shown in Figure 2. Except for fasteners and shear pins, these are the minimum sizes to be used for safe-life analysis. Use of initial crack sizes for other geometries or NDE techniques require the approval of the responsible fracture control authority. Where adequate NDE inspection of finished parts cannot be accomplished, NDE may be required by the responsible fracture control authority on the raw material and/or on the part itself at the most suitable step of fabrication.

4.3.2 NDE inspections. All fracture-critical parts shall be NDE inspected or proof-tested to screen for flaws. Prior approval of the responsible fracture control authority is required if flaws are to be screened by proof testing. NDE inspections shall be conducted according to standard aerospace quality procedures. Personnel conducting standard NDE shall be certified in accordance with MIL-STD-410 or ASNT-CP-189. The use of special NDE techniques (e.g., to justify the use of initial crack sizes smaller than those shown in Table I) requires prior approval by the responsible fracture control authority. Etching of parts prior to penetrant inspection shall be required on mechanically disturbed metallic surfaces to remove smeared or masking materials. Etching shall be performed in accordance with an approved procedure that precludes contamination of the part. Where etching cannot be performed on the finished part, the part shall be etched and penetrant-inspected at the latest practical stage of finishing (e.g., before final machining of parts with precision tolerances, or at the assembly level before holes are drilled). Previously etched and penetrant-inspected surfaces that are not subsequently mechanically disturbed require only chemical cleaning prior to reinspection by the penetrant method. Unaided visual inspection and visual inspection aided only by magnification are not generally acceptable methods for screening cracks. For transparent optical elements such as windows and lenses, visual inspection with 10× or higher magnification is acceptable for detecting surface and embedded flaws of 0.100 in. (2.54 mm) length or greater when proper lighting is applied at right angles to the actual flaw orientation.

4.4 Summary documentation.

4.4.1 Fracture control summary report. To certify fracture control compliance of a payload, the organization with primary responsibility for the payload development shall prepare a fracture control summary report on the total system for review and approval by the responsible fracture control authority and the Payload Safety Review Panel. As a minimum, this report shall include a listing of all fail-safe, fracture-critical (including limited life), and low-risk parts and shall be the basis for determining the acceptability of each part. This summary report shall be submitted to the responsible fracture control authority and the Payload Safety Review Panel prior to the Phase III Payload Safety Review.

4.4.2 Supporting data. Documents supporting the fracture control summary report shall be kept by the sponsoring installation for the life of the payload where return or reflight is anticipated and shall be available for audit by the responsible fracture control authority and the Space Shuttle Payload Safety Review Panel. The documents required to support the acceptability of a fracture-critical part shall include a crack growth analysis (or safe-life test) report and an NDE inspection (or proof-test) report. A documented description of the load spectrum and material crack growth properties used in the analysis shall be included in the safe-life analysis report. The NDE inspection report shall include the date of inspection, the serial or identification number of the part inspected, and the name of the inspector. If special NDE is used, additional data to ensure acceptability and traceability of the process shall be required in the inspection report.

4.5 Alternate approaches. In the event a particular requirement of this document cannot be met for a specific payload component, but an alternative or modified fracture control approach can be utilized to preclude a catastrophic hazard to the Orbiter and its crew, a hazard report describing this alternate approach shall be prepared by the organization with primary responsibility for development of the payload. The hazard report shall be in accordance with JSC-13830 for NASA payloads. The alternate approach shall be approved by the responsible fracture control authority and the Payload Safety Review Panel at the earliest possible time, but no later than the Phase II Payload Safety Review.

5. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

5.1 Key word listing:

Composites
Critical crack size
Critical initial crack size
Fail-safe
Fracture control
Fracture mechanics
Fracture toughness
Glass
Nondestructive evaluation (NDE)
Pressure vessels
Proof test
Safe-life
Sealed containers
Service life
Standard