Fracture Control Requirements for Space Station

International Space Station

Revision C

August 24, 2001

NASDA

National Space Development Agency of Japan

Canadian Space Agency | Agence spatiale canadienne

agenzia spaziale italiana (Italian Space Agency)

esa
european space agency

**National Aeronautics and Space Administration
Space Station Program Office
Lyndon B. Johnson Space Center
Houston, Texas**

REVISION AND HISTORY PAGE

REV.	DESCRIPTION	PUB. DATE
	BASELINE ISSUE (REFERENCE SSCBD NO. BB003052B EFF. 08–09–91)	08–91
A	Revision A (Reference SSCBD 000002 dated 2–7–94)	4–17–94
B	Revision B (Reference SSCBD 000008R1 dated 6–3–94)	9–30–94
	DCN 002 (SSCN 000256) Administrative Cancellation	
C	Revision C incorporates SSCNs 000256 and 001285.	11–16–01

ERU: /s/ M. Hehn 11–16–01

PREFACE

The Fracture Control Requirements for Space Station establishes control requirements for all International Space Station flight, experiment, and payload hardware. It also contains the requirements for metallic and nonmetallic structural components, except glass.

This document contains an introduction describing the purpose of the document, a list of applicable documents, a definition of the Fracture Control Program, and a discussion of fracture control classification and requirements, nondestructive evaluation inspections, summary reporting, and alternate approaches.

The contents of this document are intended to be consistent with the tasks and products to be prepared by NASA Centers and International Space Station (ISS) Program participants as defined in SSP 41000, System Specification for the Space Station. The Fracture Control Requirements for Space Station document shall be implemented on all new ISS contractual and internal activities and shall be included in any existing contracts through contract changes. This document is under the control of the Space Station Control Board, and any changes or revisions will be approved by the Program Manager through the SSCN process.

CONCURRENCE

INTERNATIONAL SPACE STATION PROGRAM

FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

24 AUGUST 2001

PREPARED BY:	ORiley McSpadden		AG–J312
	PRINT NAME		ORGN
	SIGNATURE		DATE
CHECKED BY:	Robert M. Foster		AG–J322
	PRINT NAME		ORGN
	SIGNATURE		DATE
SUPERVISED BY (BOEING):	Mark Mulqueen		5–5EEK
	PRINT NAME		ORGN
	SIGNATURE		DATE
SUPERVISED BY (NASA):	John J. Zipay		OB1
	PRINT NAME		ORGN
	SIGNATURE		DATE
DQA:	Adam Burkey		AG–J322
	PRINT NAME		ORGN
	/s/ Adam R. Burkey		11/7/01
	SIGNATURE		DATE

NASA/ASI

INTERNATIONAL SPACE STATION PROGRAM

FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

24 AUGUST 2001

For NASA DATE

For ASI DATE

NASA/CSA

INTERNATIONAL SPACE STATION PROGRAM

FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

24 AUGUST 2001

For NASA DATE

For CSA DATE

NASA/ESA

INTERNATIONAL SPACE STATION PROGRAM

FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

24 AUGUST 2001

For NASA DATE

For ESA DATE

ref: SSP 50019, Para. 3.1.4.1 and JESA 30000, Section 3, Appendix B

NASA/NASDA

INTERNATIONAL SPACE STATION PROGRAM

FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

24 AUGUST 2001

For NASA

DATE

For NASDA Concurrence

DATE

INTERNATIONAL SPACE STATION PROGRAM OFFICE
FRACTURE CONTROL REQUIREMENTS FOR SPACE STATION

LIST OF CHANGES
24 AUGUST 2001

All changes to paragraphs, tables, and figures in this document are shown below:

SSCBD	ENTRY DATE	CHANGE	PARAGRAPHS
256	08–24–01	2.0	APPLICABLE DOCUMENTS
1285		4.1	General
		4.2.1.3	Payload Component Release
		4.2.2.3	Rotating Device Containment
		4.2.3	Fail–Safe Part
		4.2.4.1	Limitation on Applicability
		4.2.4.2.1	Remote Possibility of Significant Crack–Like Defect
		4.2.4.2.2	Remote Possibility of Significant Crack Growth
		4.3.1.2.1	Crack Growth Analysis Assumptions
		4.9	Fracture Control for Habitable Modules
Editorial			All
			TABLES
1285	08–24–01	4.3.1.2–1	Minimum Crack Sizes for Fracture Analysis Based on NDE Method
			FIGURES
1285	08–24–01	4.1–1	Fracture Control Classification of Space Station Components
			APPENDIX
1285	08–24–01	Appendix B	Glossary

TABLE OF CONTENTS

TABLE OF CONTENTS – Continued

TABLE OF CONTENTS – Continued

TABLE OF CONTENTS – Continued

TABLES

TABLE OF CONTENTS – Continued

FIGURES

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to establish the fracture control requirements for all Space Station flight hardware including all Program Elements, Orbital Replacement Units, Orbital Support Equipment, Flight Support Equipment, and Payloads. All Space Station fracture control shall be in accordance with the requirements stated herein. Meeting these requirements implements the minimum fracture control requirements of SSP 41000. In addition to the requirements of this document, all Space Station hardware launched by the National Space Transportation System shall also meet the fracture control review and requirements of NASA NHB 8071.1.

1.2 GENERAL REQUIREMENTS

For all Space Station flight hardware systems, NASA requires full assurance of adequate 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 reliable inspection. For all Space Station flight hardware, it is specifically required that designs shall be based on fracture control procedures when structural failure from crack propagation can result in a catastrophic event.

1.3 APPLICABILITY

1.3.1 REQUIREMENTS APPLICABILITY

The requirements set forth in this document are the minimum fracture control requirements for all Space Station systems, payloads, and user provided equipment. The requirements apply to systems developed by NASA Centers, international partners, contractors, and outside organizations.

1.3.2 REQUIREMENT SCOPE

This document contains the requirements for metallic and non–metallic structural components with the exception of glass. Components that are exempt from fracture control are those that are clearly not susceptible to failure as a result of crack propagation, such as insulation blankets, electrical wire bundles, and elastomeric seals.

1.3.3 REQUIREMENT SEVERITY

Individual responsible contractors and international partners may establish more restrictive, project specific guidelines when necessary to meet clearly defined program requirements (e.g., use of fracture control to prevent a loss in redundancy of a safety critical function). In case of conflict in which this document is more restrictive, this document takes precedence over all other fracture control requirements for the Space Station except for structural glass. In case of conflict between this document and SSP 30560, the latter document takes precedence for glass structure.

1.4 RELATION TO OTHER REQUIREMENTS

Nothing in this document shall be construed as requiring 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 to the extent specified by the procuring organization or its designated representatives.

2.0 APPLICABLE DOCUMENTS

The following documents of the exact date and issue shown in SSP 50257 form a part of this document to the extent specified herein. Inclusion of applicable documents herein does not in any way supersede the order of precedence specified in 1.3.3.

DOCUMENT NO.	TITLE
SSP 30233	Space Station Requirements for Materials and Processes
Reference	Paragraphs 3.5, 5.2.5
SSP 30559	Structural Design and Verification Requirements
References	Paragraphs 4.4.2.1, 4.7.3
SSP 30560	Glass, Window, and Ceramic Structural Design and Verification Requirements
References	Paragraphs 1.3.3, 4.8
MIL–STD–410	Nondestructive Testing Personnel Qualification and Certification
Reference	Paragraph 5.2.1
MIL–STD–1522	Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
Reference	Paragraph 4.4.1.1
MIL–STD–8879	Screw Threads, Controlled Radius Root With Increased Minor Diameter; General Specification for
Reference	Paragraph 4.2.4.4

2.1 REFERENCE DOCUMENTS

The following documents are referenced in this specification as a guide for context and user convenience. The references to these documents may not be listed in SSP 50257.

JSC–22267	Fatigue Crack Growth Computer Program “NASA/FLAGRO”
References	Paragraphs 4.3.1.2.7, 4.3.1.4.2, and 4.3.1.4.5
MSFC–HDBK–527/JSC 09064	Materials Selection List for Space Hardware Systems
Reference	Paragraph 4.2.4.2.1
MSFC–SPEC–522	Design Criteria for Controlling Stress Corrosion Cracking
Reference	Paragraph 4.2.4.2.1
MSFC–STD–1249	NDE Guidelines and Requirements for Fracture Control Programs
Reference	Table 4.3.1.2–1
SSP 41000	System Specification for the Space Station
Reference	Paragraph 1.1

NASA NHB 8071.1	Fracture Control Requirements for Payloads Using the National Space Transportation System (NSTS)
Reference	Paragraph 1.1

3.0 FRACTURE CONTROL PROGRAM

3.1 RESPONSIBILITIES

Each Space Station contractor or hardware system developer shall designate a specific individual or group to be the responsible fracture control authority that will be responsible for direction and implementation of its Fracture Control Program and for assuring its effectiveness. The designee shall be responsible for monitoring, reviewing, and approving fracture control activities performed both internally and by subcontractors. These activities should be coordinated with other key organizations including engineering, manufacturing, safety, reliability, and quality assurance as required. The Fracture Control Program shall be subject to oversight and review by the prime contractor or international partner as required.

3.2 SUPPORTING DATA

Engineering data considered necessary for adequate fracture control assessments shall include the following:

A. Definition of environments, load spectrum history, and stress analysis results.

B. Detailed design and assembly drawings.

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

3.3 FRACTURE CONTROL PLAN

3.3.1 FRACTURE CONTROL PLAN APPLICABILITY

Each Space Station major element or experiment hardware system shall be governed by a Fracture Control Plan prepared by the contractor or system developer and approved by the responsible prime contractor or international partner. The plan shall be submitted for review at a date specified by the prime contractor or international partner. For hardware systems launched as payloads on the Space Shuttle, the Fracture Control Plan requirement can be met by including the Space Station requirements and the Space Shuttle payloads requirements in a single Fracture Control Plan.

3.3.2 FRACTURE CONTROL PLAN CONTENT

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 methods and procedures to be used for the following:

A. Fracture control classification of components.

B. Analysis and/or testing to determine fracture control acceptability of hardware.

C. Control of materials, manufacturing processes, nondestructive evaluation inspections, testing, design changes, and transportation.

D. Overall review and assessment of fracture control activities and results.

3.3.3 FRACTURE CONTROL PLAN REVISION

Changes to the Fracture Control Plan shall be incorporated into a revised Fracture Control Plan that must be resubmitted for prime contractor or international partner approval.

3.4 TRACEABILITY AND DOCUMENTATION

3.4.1 TRACEABILITY AND APPLICABILITY

Traceability shall be maintained on all fracture critical parts throughout their development, manufacturing, testing, and flight. Serialization shall be required for fracture critical pressure vessels and components of rotating machinery. In cases where it is impractical to serialize, all other fracture critical parts shall have traceability to material heat treat lot as a minimum. Alternatively, fracture critical parts (except pressure vessels and components of a high energy rotating part) designed to aerospace quality specifications whose calculated safe life, based on an initial flaw size of 1.5 times the standard Nondestructive Evaluation (NDE) flaw size, is greater than four shall have traceability to manufacturer’s lot as a minimum.

For each pressure vessel, a log shall be maintained to record all pressure cycles and associated environmental conditions occurring during the time period from fabrication to the end of the service life of the vessel. Engineering drawings and equipment specifications for fracture critical parts shall contain notes that identify the part as fracture critical and specify the appropriate inspection or flaw screening method to be used on the part.

3.4.2 DESIGN CHANGE REVIEW

As a minimum, changes in design or process specifications, manufacturing discrepancies, repairs, and finished part modifications for all fracture critical parts shall be reviewed according to criteria established by the responsible fracture control authority to ascertain that the parts still meet fracture control requirements.

3.5 MATERIALS AND PROCESSES

Materials, Processes, and Inspection requirements shall comply with SSP 30233.

4.0 FRACTURE CONTROL CLASSIFICATION AND REQUIREMENTS

4.1 GENERAL

Fracture control classification for all Space Station hardware components shall be determined as shown in Figure 4.1–1. Components which are classified as nonhazardous released parts, contained, fail–safe, or low risk shall meet the requirements specified in 4.2. These components may be considered nonfracture critical and are not required to be further evaluated for fracture control. Components classified as fracture critical shall have their damage tolerance and/or safe–life verified by test and/or analysis in addition to meeting the standard design, control and verification requirements for aerospace structures. As fracture control classification and analysis of parts are performed, an up to date list shall be maintained for fracture critical and low risk fracture parts showing part or drawing number.

4.2 NONFRACTURE CRITICAL COMPONENTS

4.2.1 NONHAZARDOUS RELEASED PART

4.2.1.1 NONHAZARDOUS PART DEFINITION

For a component to be classified as a nonhazardous released part, it shall meet the requirement that release of the part as a result of fracture will not cause a catastrophic hazard. In assessing the catastrophic hazard potential, both the Failure Modes and Effects Analysis normally required on mechanical systems and the initial velocity of a preloaded part resulting from energy release at fracture shall be considered.

4.2.1.2 NONHAZARDOUS PARTS RELEASED

For zero gravity flight, the maximum release velocity for a nonhazardous released part that may impact critical hardware or crew personnel shall be 35 feet/second (10.7 meters/second) and not exceed the momentum of a 0.25 pound (113.4 grams) mass having this velocity. Where it is realistic to do so, such as for pressure or spring loaded parts or pretensioned bolts made of low–fracture toughness alloy (as defined in appendix B), the release velocity shall be calculated by assuming 100 percent conversion of strain energy to kinetic energy at the time of fracture. For a steel bolt, if the K_{Ic} value is unknown, low–fracture toughness shall be assumed when $F_{tu} >$ 180 ksi (1241 MPa). For bolts that do not meet these low–fracture toughness criteria, zero release velocity may be assumed.

4.2.1.3 PAYLOAD COMPONENT RELEASE

During launch on Space Shuttle, released payload components in the cargo bay shall be normally considered nonhazardous for impact damage from launch accelerations if the total mass is less than 0.25 pounds. However, for payload metal parts which have low–fracture toughness properties and are highly preloaded in tension, a high release velocity at fracture may result; therefore, for these parts the total released mass during launch shall not exceed 0.03 pounds (13.6 grams). Unacceptable released mass can also be assessed using the formula $M=14/h$, where M is the weight in pounds and h is the travel distance in feet to the orbiter cargo bay aft bulkhead. M shall not exceed 2 pounds (908 gm). A part shall be considered to have low–fracture toughness using the same criteria as previously defined in appendix B.

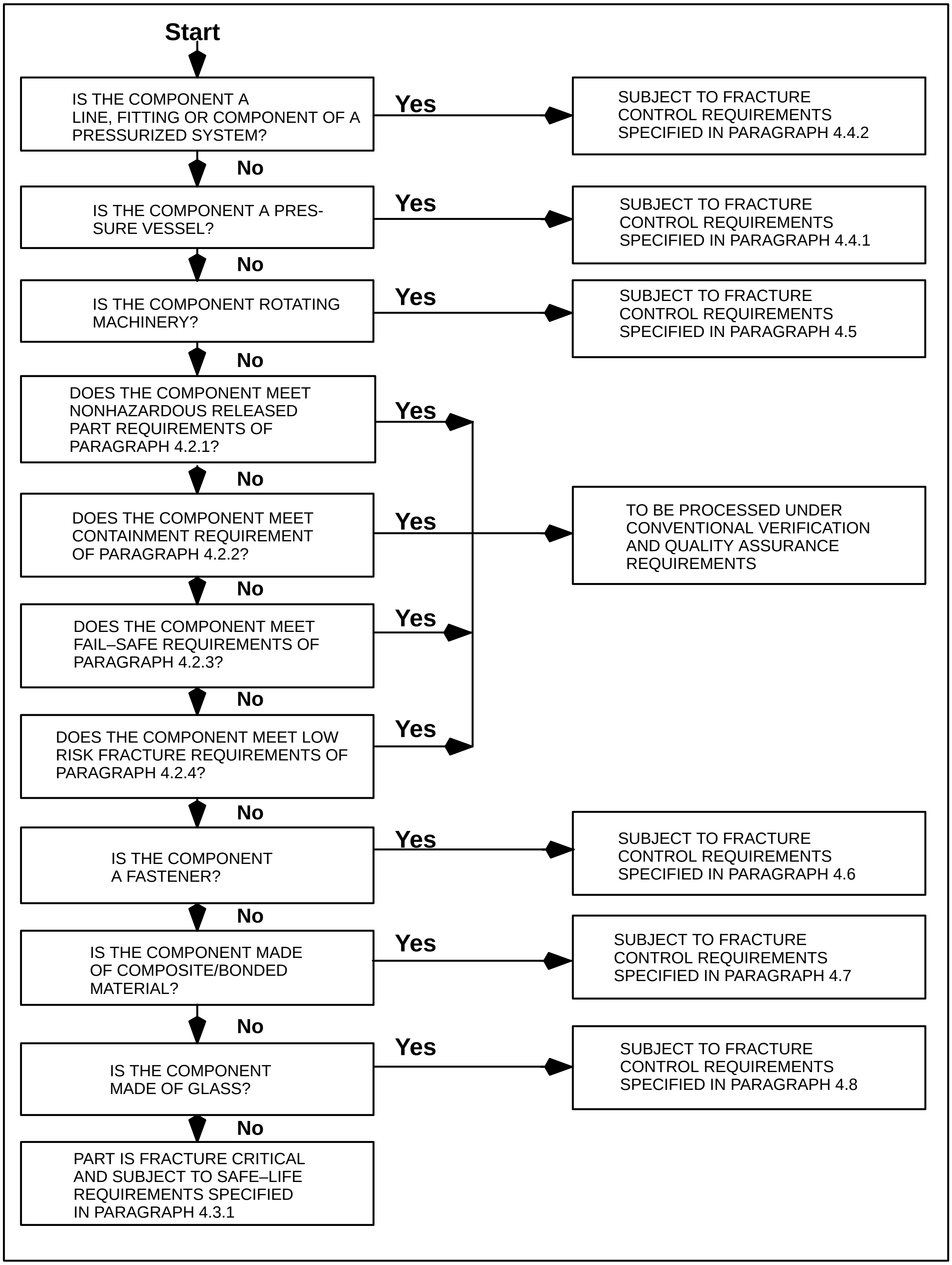

FIGURE 4.1–1 FRACTURE CONTROL CLASSIFICATION OF SPACE STATION COMPONENTS

4.2.2 CONTAINED PART

4.2.2.1 CONTAINED PART DEFINITION

For a component to be classified as a contained part, it shall meet two requirements: a) it can be shown that, if the part fails, all fragments of the part that violate the requirements of 4.2.1 are completely contained within the failed element or system; and b) it can be shown that the failure of the component will not cause a catastrophic hazard as a result of subsequent damage to the failed element or system itself. Containment within a housing/enclosure may be shown by documented engineering judgment/rationale where it is clear that containment exists, or it shall be shown by test or analysis where there is uncertainty. Examples of hardware which may be considered for containment by judgment/rationale include electronic boxes and other conventionally designed metallic components having relatively close–packed internal parts, such as radios, cameras, and similar components having enclosures.

4.2.2.2 LOOSE PARTS CONTAINMENT

More detailed containment requirements shall apply to payloads where internal loose parts resulting from fracture in a housing/enclosure may become free in the Space Shuttle cargo bay. When the housing/enclosure has holes, only those internal parts which cannot pass through the holes shall be considered to be contained. If a containment housing/enclosure is designed to be opened, and containment is required after closure, the door/cover/aperture, etc., shall be single fault tolerant against remaining open. If single fault tolerance does not exist, that portion of the internal hardware that can be shown by analysis or test as contained in the failed open container for the remainder of the mission is acceptable.

4.2.2.3 ROTATING DEVICE CONTAINMENT

Rotating devices that are not assured for safe–life by fracture control procedures shall have containment by either (1) associated housings/shrouds, etc., (2) containment shown by documented engineering judgment/rationale where it is clear that containment exists, or (3) containment demonstrated by analysis or test. Examples of hardware that may be considered for containment by judgment/rationale include conventional electric motors, shrouded or enclosed fans less than 8 inch diameter and 8,000 rpm, gear boxes, conventional pumps and similar components.

4.2.3 FAIL–SAFE PART

To be classified as a fail–safe part it shall be shown by analysis, test, or documented rationale that a component meets the following requirements:

A. Due to structural redundancy, the structure remaining after any single failure can withstand the resulting redistributed flight or service loads with a minimum ultimate factor of safety of 1.0. To meet this requirement, the possible changes in dynamic characteristics of the remaining structure (e.g., due to the failure of a major element of a minimally redundant structure) and its post failure effects on dynamic loads shall be considered unless:

(1) the design loads are sufficiently conservative to envelop dynamic load variations caused by expected changes in frequency responses (e.g., a low stress design controlled by high stiffness or fabricability requirements).

(2) or failure of the component clearly would not significantly alter the frequency response (e.g., a single failure in a highly redundant structure).

B. Failure of the part is readily detectable, and there is a plan to repair or replace the part. If repair or replacement is not an alternative, a fatigue or durability analysis (see paragraph (c)) shall demonstrate no failure of the remaining structure in four service lifetimes.

C. For multimission systems, it shall be verified by inspection to the extent practical before reflight that the structural redundancy of a fail–safe part is still intact.

4.2.4 LOW–RISK FRACTURE PART CRITERIA

A low–risk fracture part shall comply with the requirements of 4.2.4.1 and 4.2.4.2 or 4.2.4.3 or 4.2.4.4.

4.2.4.1 LIMITATION ON APPLICABILITY

The part shall be all–metal and shall not be a pressure vessel, habitable module pressure boundary (shell), pressurized component in a pressurized system containing a hazardous fluid, or high energy rotating equipment. A part whose failure will directly result in a catastrophic hazard is also excluded, except when the total (far field) tensile stresses in the part at limit load are not 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 II Safety Review to show adequate understanding of the requirements. Identification of low–risk fracture parts and compliance with these requirements shall be addressed in the Fracture Control Summary Report.

4.2.4.2 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 4.2.4.2.1 and 4.2.4.2.2 as follows:

4.2.4.2.1 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 that is not sensitive to stress corrosion cracking as defined in 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 which are susceptible to cracking during heat treatment quenching) unless specific NDE or testing, 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, extruded and plate products from materials that are known to have good machinability properties, do not have low fracture toughness (as defined in appendix B), 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 insure 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.

4.2.4.2.2 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 credible damage from fatigue loading beyond acceptance and/or normal protoflight testing (if any), transportation, and one Space Shuttle mission.

B. The part shall be shown to possess a high safety margin on fatigue strength. This may be shown by either (1) , (2) or (3) as follows:

(1) The part shall be shown to possess a high safety margin on fatigue strength. This may be shown by limiting the maximum stress, S_{max}, for a metal part with a theoretical elastic stress concentration factor K_t and stress Ratio R to

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

where R is the ratio of minimum stress to maximum stress in a fatigue cycle.

(2) Alternatively, a fatigue analysis may be performed which conservatively accounts for the effects of notches and mean stress and shows a minimum safety factor of 1.5 on alternating stress as compared to mean fatigue strength data for either 10^8 cycles or else a minimum of 10 complete service lifetimes.

(3) The maximum stress, S_{max}, acting in the part satisfies the following relationship:

$$S_{max} < S_c / 1.5$$

where S_c is the stress level at which a standard NDE flaw multiplied by 1.5 produces four calculated lives. This method is recommended for parts fabricated using a process that has a recognized risk of crack–like defects.

C. The part shall be shown to possess acceptable resistance to the crack growth of potential limit defects caused by machining, assembly, and handling. Assumed initial surface cracks of 0.025 inch (0.63 mm) depth and 0.05 inch (1.25 mm) length and corner cracks of 0.025 inch (0.633 mm) radius from holes shall not grow to failure in less than four complete service lifetimes.

4.2.4.3 NONHAZARDOUS LEAK MODE OF FAILURE

Pressurized components or sealed containers having a nonhazardous leak–before–burst (LBB) mode of failure (i.e., critical length of through crack is at least 10 times the wall thickness and fluid release would not create a 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 criteria.

A. Criteria for sealed containers:

(1) Maximum internal pressure above external pressure is not greater than 2.0 atmospheres.

(2) Proof pressure tested to at least 1.25 times maximum design pressure differential if design safety factor based on ultimate strength is less than 2.0 or total internal volume is greater than 3.4 ft^3 (0.10 m^3).

(3) Container is made from metal alloys typically used for sealed containers such as aluminum, stainless steel, or titanium sheet.

B. Criteria for pressurized components:

(1) Component is a system part other than a pressure vessel which is designed to flight system safety factors as defined in SSP 30559.

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

4.2.4.4 FASTENERS AND SHEAR PINS

Fasteners and shear pins may be classified as low–risk fracture parts when

A. their fracture does not result in a single point catastrophic failure and

B. they can meet the following requirements:

(1) Be high quality MS, NAS, or equivalent commercial fasteners or pins fabricated and inspected in accordance with aerospace type specifications. Fasteners requiring specific tensile preload that are used in joints that are loaded primarily in tension shall have rolled threads meeting MIL–STD–8879, (Appendix B, Reference 9) or a metric equivalent.

(2) 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, particularly Ti–6AI–4V STA titanium, or alloys with K_{Ic} / F_{ty} ratios equal to or less than 0.33 $in^{1/2}$ (1.66 $mm^{1/2}$).

(3) Meets appropriate requirements for stress and fatigue analysis including torque/preload requirements for tension loaded fasteners.

(4) Reworked or specially fabricated fasteners shall be of equal aerospace quality and meet all applicable criteria in (1), (2), and (3) above.

4.3 FRACTURE CRITICAL COMPONENTS

4.3.1 SAFE–LIFE VERIFICATION

4.3.1.1 GENERAL ANALYSIS CRITERIA

4.3.1.1.1 FAIL–SAFE PARTS

A fracture critical component shall be 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 service lifetimes. One service lifetime, as defined in appendix B, shall include all significant loadings occurring after flaw screening to establish minimum initial flaw size and shall include testing, transportation, lift–off, ascent, on–orbit operations, or any other loadings considered relevant.

Structure that will remain permanently on–orbit, and that is fail–safe during on–orbit application, and that is delivered to orbit intact, may use loading events in safe–life analysis that the part experiences up to on–orbit delivery.

The on–orbit life for parts that are fail–safe during on–orbit application can be determined by conventional fatigue or durability analyses. The fatigue/durability analyses should include all loading events in the spectrum (prelaunch, launch/abort, as well as on–orbit). The rationale for categorization of structure as fail–safe shall be documented.

4.3.1.1.2 LIMITED LIFE PARTS

For limited life parts (as defined in appendix B), the predicted crack propagation life shall be at least four times the limited service life. Renewed life predictions for further use may be established by periodic inspection; therefore, limited life parts shall be accessible for NDE inspection or replacement. Intervals between inspections shall be established by safe–life crack growth analysis.

4.3.1.1.3 FRACTURE CRITICAL FLIGHT PARTS

A specific, detailed, fracture mechanics analysis (or test) shall be performed to justify the use of any fracture critical flight part with known crack–like flaws. Approval of the responsible fracture control authority shall be obtained prior to the use of any fracture critical flight part containing known cracks or crack–like defects. The approval shall be based on acceptance criteria that are approved by the Prime Contractor or international partner. All such parts shall be documented, and the data kept as required in 6.2.

4.3.1.2 SAFE–LIFE ANALYSIS CRITERIA

4.3.1.2.1 CRACK GROWTH ANALYSIS ASSUMPTIONS

When crack growth analysis is used to demonstrate safe–life design of a part, an undetected flaw shall be assumed to be in the most critical area and orientation for each part. The size of the undetected flaw shall be based on either the appropriate NDE techniques as covered in 5.0 or on proof testing. Table 4.3.1.2.1–1 and 4.3.1.2.1–2 lists flaw sizes representative of the capabilities of commonly used NDE techniques. For surface cracks in components both sets of values for “a” and “c” given in Table 4.3.1.2.1–1 and 4.3.1.2.1–2 shall be considered. If a proof test is used to define initial crack size for a safe life determination, it shall be demonstrated by analysis or test that the proof test will ensure the required life is obtained. Flaws screened by proof test shall have aspect ratio a/c from 0.2 to 1.0. The demonstration shall consider all effects which may affect the proof test life prediction such as: stable crack growth during the proof test, anomalous behavior of cracks approaching a surface boundary, weld and parent material inhomogeneities if welds are present, and environment if testing and operations are at different environmental conditions.

TABLE 4.3.1.2.1–1 Minimum Crack Sizes for Fracture Analysis Based on NDE Method – U.S. Customary Units

U. S. Customary Units (Inches)				
Crack Location	Part Thickness, t (inches) (1)	Crack Type	Crack Dimension, a (Inches)	Crack Dimension, c (Inches)
		Eddy Current NDE		
Open Surface	t ≤ 0.050 t > 0.050	Through PTC	t 0.020 0.050	0.050 0.100 0.050
Edge or Hole	t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.100 0.075
		Penetrant NDE		
Open Surface	t ≤ 0.050 0.050 < t ≤ 0.075 t > 0.075	Through Through PTC	t t 0.025 0.075	0.100 0.15 – t 0.125 0.075
Edge or Hole	t ≤ 0.100 t > 0.100	Through Corner	t 0.100	0.100 0.100
		Magnetic Particle NDE		
Open Surface	t ≤ 0.075 t > 0.075	Through PTC	t 0.038 0.075	0.125 0.183 0.125
Edge or Hole	t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.250 0.250
		Radiographic NDE		
Open Surface	0.025 ≤ t ≤ 0.107 t > 0.107	PTC	0.7t 0.7t	0.075 0.7t
		Ultrasonic NDE Comparable to a Class A quality level (See MSFC–STD–1249)		
Open Surface	t ≥ 0.100	PTC	0.030 0.065	0.150 0.065
Note: (1) 1 inch = 25.4 mm (2) 1 mm = 0.0394 inch				

TABLE 4.3.1.2.1–2 Minimum Crack Sizes for Fracture Analysis Based on NDE Method – SI Units

SI Units (mm)				
Crack Location	Part Thickness, t (mm) (2)	Crack Type	Crack Dimension, a (mm)	Crack Dimension, c (mm)
		Eddy Current NDE		
Open Surface	t ≤ 1.27 t > 1.27	Through PTC	t 0.50 1.27	1.27 2.5 1.27
Edge or Hole	t ≤ 1.91 t > 1.91	Through Corner	t 1.91	2.5 1.91
		Penetrant NDE		
Open Surface	t ≤ 1.27 1.27 < t ≤ 1.91 t > 1.91	Through Through PTC	t t 0.63 1.91	2.5 3.82 – t 3.2 1.91
Edge or Hole	t ≤ 2.5 t > 2.5	Through Corner	t 2.5	2.5 2.5
		Magnetic Particle NDE		
Open Surface	t ≤ 1.91 t > 1.91	Through PTC	t 0.96 1.91	3.2 4.6 3.2
Edge or Hole	t ≤ 1.91 t > 1.91	Through Corner	t 1.91	6.30 6.30
		Radiographic NDE		
Open Surface	0.635 ≤ t ≤ 2.72 t > 2.72	PTC	0.7t 0.7t	1.91 0.7t
		Ultrasonic NDE Comparable to a Class A quality level (See MSFC–STD–1249)		
Open Surface	t ≥ 2.5	PTC	0.76 1.65	3.8 1.65

Note:
(1) 1 inch = 25.4 mm
(2) 1 mm = 0.0394 inch

4.3.1.2.2 CRACK GROWTH PROPAGATION AROUND HOLES

For components where it is necessary to consider the propagation of a crack into a hole, or from one hole to another hole, the analysis shall assume that the crack is not arrested or retarded by the hole but continues on past the hole. In the analysis of cases where automatic drilling and fastener installation or drilling on assembly of multiple holes makes NDE of hole surfaces impractical, an initial crack size may be assumed which is based on the maximum potential damage from hole preparation operations. With acceptable hole preparation, as outlined in 4.3.1.2.3 and with the restrictions of 4.3.1.2.4 and 4.3.1.2.5 the initial crack size may be assumed to be smaller than those specified in Table 4.3.1.2.1–1.

4.3.1.2.3 HOLE DEFECT ASSUMPTIONS

Specifically, for drilled holes with driven rivets, the assumed defect, as outlined in 4.3.1.2.2, shall be a 0.005 inch (0.13 mm) crack through the thickness at one side of the hole. For fastener holes other than for driven rivets where the material thickness is equal to or less than 0.05 inch (1.3 mm), the assumed fabrication defect shall be a 0.05 inch (1.3 mm) length crack through the thickness at one side of the hole. Where the thickness is greater than 0.05 inch (1.3 mm), the initial flaw size shall be a 0.05 inch (1.3 mm) radius corner flaw at one side of the hole.

4.3.1.2.4 DEFECT SIZE CRITERIA

The maximum fabrication defect sizes given in 4.3.1.2.3 may be used for analysis of holes only where all of the following apply:

A. the holes are not punched,

B. the material is not prone to cracking during machining,

C. NDE is performed prior to machining of the holes,

D. no heat treatment or possible crack forming fabrication processes are performed subsequent to NDE,

E. 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

F. control procedures and requirements for producing adequate fastener hole quality are presented in the Fracture Control Plan.

4.3.1.2.5 HOLE NONDESTRUCTIVE EVALUATION

Notwithstanding any of the options stated in 4.3.1.2.4, 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.

4.3.1.2.6 SAFE–LIFE REQUIREMENT ANALYSIS

Either of two analysis approaches may be utilized 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 4.3.1.2.1–1 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 part can survive the required lifetimes and to verify by inspection that there are no cracks greater than or equal to this size. If any cracks are found in the structure, they shall not be acceptable regardless of size unless they meet the requirements of 4.3.1.1.3.

4.3.1.2.7 ANALYSIS COMPONENTS

Appropriate crack models and materials 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 $K_{max} < K_{Iscc}$. Load interaction or retardation effects on crack growth rates from variable amplitude loading shall not be considered without approval of the Prime Contractor or international partner. The Fatigue Crack Growth Computer Program “NASA/FLAGRO, JSC–22267” is an approved computer code for crack growth analysis of Space Station components. Other computer programs or analysis methods are acceptable if they are shown to give comparable results.

4.3.1.3 SAFE–LIFE TESTING CRITERIA

Testing to predict life shall be an acceptable alternative to safe–life analysis, when approved by the responsible fracture control authority. Safe–life testing shall be performed on precracked specimens representative of the structural design of the part and shall demonstrate at least four lifetimes. Safe–life tests and analysis shall include the consideration of worst–case dimensions, tolerances, material properties and environmental conditions to demonstrate safe–life under worst–case circumstances.

4.3.1.4 FRACTURE MECHANICS MATERIAL DATA

4.3.1.4.1 FRACTURE MECHANICS ANALYSIS

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

4.3.1.4.2 FRACTURE TOUGHNESS VALUES

When using assumed NDE initial flaw sizes for safe–life analysis of fracture critical parts, the assumed fracture toughness values (K_{Ie}, K_{Ic}, or K_c as appropriate) for predicting crack instability shall be average (i.e., typical) values. If the following conditions (a) and (b) are met, these average values may be obtained from data in literature, from actual testing, or from NASA/FLAGRO, JSC–22267:

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

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

4.3.1.4.3 STRENGTH AND FRACTURE TESTING OF MATERIALS

For parts that are considered high risk, i.e., failure will result in a catastrophic occurrence, and are fabricated from an alloy having a wide variation of fracture toughness for the particular fabrication and heat treatment process used, the 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) where the failure mode is brittle fracture, and when an assumed lowest possible value of fracture toughness results in inadequate safe–life. When these tests are not performed or when conditions in 4.3.1.4.2 cannot be met, material properties which are clearly conservative with respect to expected properties shall be documented and approved by the Prime Contractor or international partner.

4.3.1.4.4 DETERMINATION OF PROOF TEST FACTOR

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

4.3.1.4.5 CRACK GROWTH RATE

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 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 encountered or shall be conservative with respect to the actual environments. The crack growth rate data contained in NASA/FLAGRO, JSC–22267 may be used if all of the conditions in 4.3.1.4.2 (a) and (b) are met.

4.4 PRESSURIZED SYSTEMS

4.4.1 PRESSURE VESSELS

4.4.1.1 PRESSURE VESSEL COMPLIANCE

Pressure vessels, as defined in appendix B, shall comply with requirements in MIL–STD–1522, Sections 4 and 5, modified as follows:

A. In the event of conflict in requirements between MIL–STD–1522 and this document, the requirements of this document shall take precedence.

B. Approach “B” of Figure 2 in MIL–STD–1522 is not acceptable and shall not be used.

C. Pressure vessels whose failure at Maximum Design Pressure (MDP) would not be leak before burst, or would release a hazardous fluid, or whose loss of pressure would be potentially catastrophic, shall be safe–life vessels. All other pressure vessels shall be either safe–life or leak before burst at MDP.

D. MDP, as defined in appendix B, shall be substituted for all references to Maximum Expected Operating Pressure in MIL–STD–1522.

E. For metal lined pressure vessels having an overwrapped composite structure, the fracture control for safe–life and failure mode shall be applied to the liner. The overwrap shall in addition satisfy 4.7.4.

F. In addition to other required analyses, composite pressure vessels shall be assessed for adequate stress rupture life and effects of atomic oxygen.

G. NDE of safe–life pressure vessels shall include inspection of welds before and after proof testing.

H. Controls shall be implemented to ensure compatibility of vessel materials with fluids used in cleaning, test, and operation.

I. An acceptable approach to LBB is to show that a through the thickness crack of length ten times the wall thickness is stable (i.e., $K_{max} < K_c$) at MDP. If fracture mechanics data are not available, or reliable conservative estimates of properties cannot be made, a vessel test shall be conducted to verify leak–before–burst capability.

J. For low cycle applications a proof test of each flight pressure 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 certification vessel to qualify a vessel design that in all other respects meets the requirements of SSP 30559 and MIL–STD–1522, Approach A.

4.4.2 PRESSURE SYSTEM COMPONENTS

4.4.2.1 PRESSURE SYSTEM COMPONENT EXCEPTIONS

Pressure system components (or equipment) not meeting the definition of pressure vessels given in appendix B, shall be considered fracture critical if they contain hazardous fluids or if loss of pressurization would result in a catastrophic hazard. All fusion welded joints on Fracture Critical components shall be inspected using a qualified NDE method. In instances where NDE is not feasible, or is incapable of being dealt with successfully, the manufacturer will employ a verification by sampling procedure for establishing the quality of uninspectable welds. This option requires NASA and/or International Partner approval. Cracks or any other type of flaw indication not meeting specification requirements shall be cause for rejection of these components. Safe–life analysis is not required for fracture critical pressurized lines, fittings and components that are proof tested to the factor of safety requirements of SSP 30559, section 3.3. In addition to proof testing of parts during individual acceptance, pressure integrity shall be verified at the system level.

4.5 ROTATING MACHINERY

4.5.1 FRACTURE CRITICAL DEFINITION FOR ROTATING MACHINERY

For the purposes of fracture control, a rotating mechanical assembly that has a kinetic energy of 14,240 ft–lbs (19,307 Joules) or greater (based on $I\omega^2/2$) shall be considered, by definition, fracture critical. In addition to other requirements for fracture critical components, rotating machinery shall be proof (spin) tested to design RPM, as a minimum, and subjected to NDE before and after proof testing. Rotating mechanisms with lower kinetic energy levels shall be classified by the same criteria as other structural components.

4.6 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 1–4 in 4.2.4.4 (b), plus the additional requirements as follows:

A. Be highest quality aerospace fasteners fabricated from A286 steel, Inconel 718, MP55N alloy or similarly tough and environmentally compatible alloys.

B. Fracture critical tension fasteners shall meet the analysis (and/or test) requirements for verification of safe–life as given in 4.3.1. Fasteners with any detected crack–like flaws shall be rejected. The rationale for the use of fracture critical fasteners smaller than 3/16 inch (0.48 cm) diameter, including the methods for flaw screening and preload control, shall be identified in the Fracture Control Plan and approved by the prime contractor or international partner.

C. Fracture critical shear pins and shear bolts shall be NDE inspected in the shank area but analysis limited to showing only adequate durability as defined in 4.2.4.2.2 (c).

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

4.7 FRACTURE CRITICAL COMPOSITE/BONDED STRUCTURES

4.7.1 DAMAGE TOLERANCE ANALYSIS

For 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, 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.

4.7.2 NONFRACTURE CRITICAL CLASSIFICATION

Except as otherwise directed by hazard analyses, composite/bonded structures or components shall be classified as nonfracture critical only if it is shown that one of the following conditions is satisfied:

A. The structure or component in question meets the requirements of 4.2 for nonfracture critical components.

B. The strain level at limit load is less than the composite/bonded structure's demonstrated damage tolerance threshold strain level. The threshold strain level shall be determined by testing preflawed coupons or, if approved by the responsible prime contractor or international partner, by using available data.

4.7.3 FRACTURE CRITICAL REQUIREMENTS

All composite/bonded structure classified as fracture critical shall meet the requirements for composite/bonded structure specified in SSP 30559.

4.7.4 DAMAGE PREVENTION

For all fracture critical composite/bonded components, the prevention of damage resulting from handling or final assembly shall be addressed in the Fracture Control Plan.

4.8 FRACTURE CRITICAL GLASS COMPONENTS

The design and analysis of all structural glass shall be in accordance with the requirements specified in SSP 30560.

4.9 FRACTURE CONTROL FOR HABITABLE MODULES

For habitable modules, the pressure shell, which includes associated hatches, windows, and closeout or feedthrough panels, shall comply with the design and structural verification requirements of SSP 30559. In addition, pressure shells shall be designed to meet LBB criteria. Pressure shells, or areas of pressure shells, that do not meet LBB criteria shall be verified as safe–life using fracture mechanics methodology. All structural welds shall be inspected with suitable NDE to assure quality and compliance with weld requirements. Welds in safe–life structure shall also be inspected for crack–like flaws after proof testing. The results of the inspection after proof testing shall be used as the baseline for safe–life analysis.

5.0 NONDESTRUCTIVE EVALUATION INSPECTIONS

5.1 REQUIREMENTS AND ASSUMPTIONS

All fracture critical parts shall be subjected to Nondestructive Evaluation (NDE) inspection or proof testing to screen flaws. The selection of NDE methods and level of inspection shall be based primarily on the safe–life acceptance requirements of the part. The initial crack sizes 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 4.3.1.2.1–1 for the geometries shown in Figure 5.1–1. These are the minimum sizes which shall be used for safe–life analysis. Use of initial crack sizes for other geometries or NDE techniques shall require the approval of the prime contractor or international partner. Where adequate NDE inspection of finished parts cannot be accomplished, NDE may be required on the raw material and/or on the part itself at the most suitable step of fabrication.

5.2 PERFORMANCE OF NONDESTRUCTIVE EVALUATION INSPECTIONS

5.2.1 NDE INSPECTIONS

NDE inspections for fracture critical hardware shall be conducted in accordance with standard aerospace quality standards. Personnel conducting standard NDE shall be certified per MIL–STD–410. The use of special NDE techniques (e.g., to justify the use of initial crack sizes smaller than those shown in Table 4.3.1.2.1–1) shall require prior approval by the responsible fracture control authority identified as required by 3.1.

5.2.2 PART ETCHING

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 to preclude 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).

5.2.3 UNACCEPTABLE INSPECTIONS

Unaided visual inspection and visual inspection aided only by magnification are not generally acceptable methods for screening cracks.

5.2.4 CRACK GROWTH ANALYSIS USE

The use of crack growth analysis for predicting replacement needs of critical structures based on NDE shall be addressed in the Fracture Control Plan.

5.2.5 NONDESTRUCTIVE INSPECTION REQUIREMENTS

NDE Inspection requirements for fracture critical hardware shall be included in the Nondestructive Inspection (NDI) Plan in accordance with SSP 30233, paragraph 4.4.

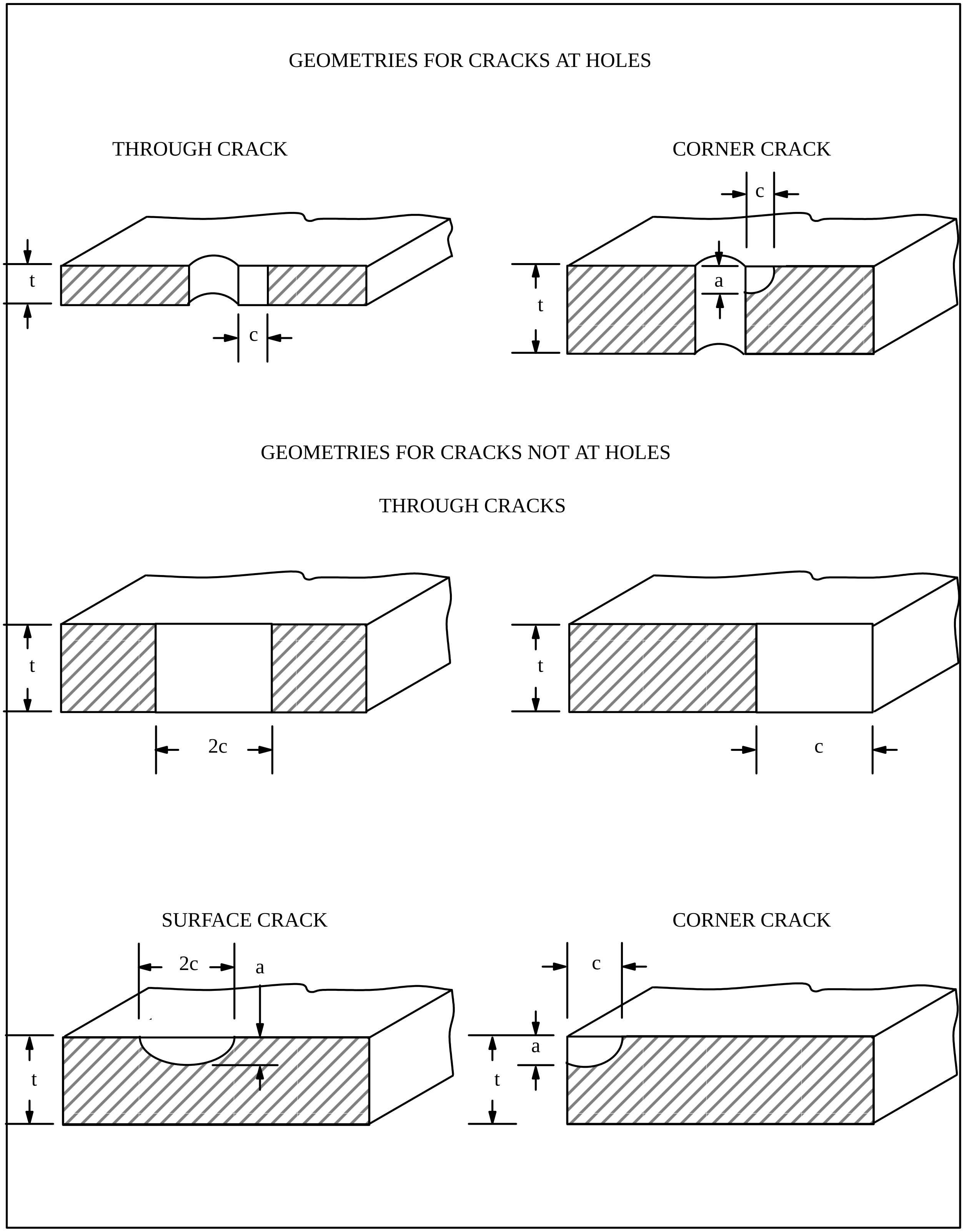

FIGURE 5.1–1 STANDARD CRACK GEOMETRIES

6.0 SUMMARY DOCUMENTATION

6.1 FRACTURE CONTROL SUMMARY REPORT

To certify compliance with fracture control requirements, the prime contractor or subcontractor responsible for the subsystem development shall provide input to the Prime Contractor and/or International Partner to prepare a fracture control summary report on the total system for review and approval at the Design Certification Review by NASA and/or the international partner. As a minimum, the report shall include:

A. Identification of fracture critical and low risk fracture parts showing the material and heat treatment used and the basis for acceptability (safe–life analysis, test, acceptable durability, insignificant fatigue loading, etc.). Fracture critical parts that are limited life will be specifically noted. For experiment system hardware to be launched as a payload on the Space Shuttle and flown on the Space Station, the summary report requirement may be met by including the Space Station usage in the Space Shuttle payload fracture control summary report.

B. Identification of the NDE and/or tests applied for fracture control purposes to each fracture critical part and to each low risk part requiring specific inspection.

6.2 SUPPORTING DATA

Documents or analysis supporting the fracture control summary report and the fracture control classification of components shall be kept for the life of the system and shall be available for audit. The documents required to support the acceptability of a fracture critical part shall include a crack–growth analysis (or safe–life test) report and a 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, serial number or identification of part inspected, and name of the inspector. If special NDE was used, additional data may be required in the inspection report to assure acceptability and traceability of this process.

7.0 ALTERNATE APPROACHES

7.1 REQUIREMENTS

In the event that a particular requirement of this document cannot be met for a specific component, but an alternative or modified fracture control approach can be utilized to preclude a direct or indirect catastrophic hazard, a report describing the alternate approach shall be prepared by the contractor or component developer and submitted to the Prime Contractor or international partner for approval by the time of the final design review of the component.

APPENDIX A ABBREVIATIONS AND ACRONYMS

cm	centimeter
ft	feet
FLAGRO	Fatigue Crack Growth Computer Program
in	inch
ISS	International Space Station
JSC	Johnson Space Center
kPa	Kilo Pascal
ksi	thousand pounds per square inch
LBB	Leak–Before–Burst
lbs	pounds
m	meter
MDP	Maximum Design Pressure
mm	millimeter
mPa	Mega Pascal
MSFC	Marshall Space Flight Center
MUA	Materials Usage Agreement
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
psia	Pounds per square inch absolute
PTC	Part Through (Surface) Crack
RPM	Revolutions per Minute

APPENDIX B GLOSSARY

ANALYTICAL LIFE

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

CATASTROPHIC FAILURE

Failure that results in loss of the Space Shuttle, Space Station, life of personnel, or major injury to personnel that results in incapacitation of flight crew.

CATASTROPHIC HAZARD

The presence of a potential risk situation caused by an unsafe condition that can result in a disabling or fatal personnel injury, or loss of one of the following: launch or servicing vehicle, ISS, or major ground facility.

COMPONENT

A component is a hardware item that is considered as a single entity in fracture control classification. The terms ”component” and ”part” are interchangeable in this document.

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.

CRITICAL INITIAL CRACK SIZE

Largest crack that can exist at the beginning of the service life of a structure that has an analytical life greater than or equal to four service lives.

DAMAGE TOLERANCE THRESHOLD STRAIN LEVEL

The strain level below which catastrophic failure of flawed/damaged composite structure will not occur when subjected to expected load/environmental conditions.

FAIL–SAFE

A structural design criterion in which it must be shown that the structure remaining, after failure of any single structural member, can withstand the resulting redistributed internal limit loads without failure.

FASTENER

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

FRACTURE CONTROL

The 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.

FRACTURE CONTROL PLAN

The plan which specifies fracture control activities to be imposed on the design, analysis, testing, change control, and documentation of 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.

FRACTURE CRITICAL COMPONENT (OR PART)

A classification which assumes that fracture or failure of the part resulting from the occurrence of a crack will result in a catastrophic hazard. Such classification is required on structural components unless the contrary is demonstrated using the criteria of 4.2.

FRACTURE MECHANICS

An engineering discipline which describes the behavior of cracks or crack like flaws in materials under stress.

$\mathbf{F_{tu}}$

Allowable tensile ultimate strength.

$\mathbf{F_{ty}}$

Allowable tensile yield strength.

HABITABLE MODULE

A pressurized, life–supporting enclosure or module that is normally intended to support life without the need for spacesuits or special breathing apparatus. The enclosure may be one that is continuously inhabited, or one that is used for crew transference, or for crew accessible stowage so long as life support is a requirement for the design. Single mission or multi–mission module designs are included.

HAZARDOUS FLUID

Any liquid or gas which, if released, could result in the potential for personnel injury, loss of Space Station, loss of Orbiter, or loss of launch or ground facilities.

$\mathbf{I\omega^2/2}$

The rotational energy of a rotating component where "I" is the mass moment of inertia and ω is the rotational frequency.

$\mathbf{K_c}$

Critical stress intensity factor for fracture.

$\mathbf{K_{Ic}}$

Plane strain fracture toughness.

$\mathbf{K_{Ie}}$

Effective fracture toughness for surface or elliptically shaped crack.

K_{Iscc}

Stress corrosion or environmental cracking threshold for no crack growth under sustained stress conditions.

LEAK–BEFORE–BURST (LBB)

A fracture machanics design concept in which it is shown that any initial flaw will grow through the wall of a pressure vessel and cause leakage rather than burst (catastrophic failure).

LIMITED LIFE PART

A multimission part which has a predicted safe life less than four times the service life required.

LIMIT LOAD

Maximum expected load on a structure during its service life.

LOW FRACTURE TOUGHNESS

A 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 $F_{ty} > 180$ ksi (1241 MP_a).

MAXIMUM DESIGN PRESSURE

The Maximum Design Pressure (MDP) for a pressurized system is the highest pressure defined by the maximum relief pressure, maximum regulator pressure, maximum temperature, and transient pressure excursions.

PRESSURE VESSEL

A container designed primarily for pressurized storage of gases or liquids and:

A. Contains stored energy of 14,240 foot–pounds (19,307 joules) or greater based on adiabatic expansion of a perfect gas; or

B. Contains a gas or liquid in excess of 15 psia (103.4 kPa) which will create a hazard if released; or

C. Stores a gas which will experience a MDP greater than 100 psi (689.5 kPa).

PROOF TEST

A load or pressure in excess of limit load or maximum design pressure applied in order to verify the structural integrity of a part or to screen initial flaws in a part.

SAFE–LIFE

A design criterion under which a flaw is assumed consistent with the inspection process specified, and 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.

SAFE–LIFE VERIFICATION

An analysis (or test) of a fracture critical component which demonstrates that the largest undetected flaw that could exist in the part will not grow to failure when subjected to the cyclic and sustained loads and environments encountered in at least four complete service lifetimes of the part.

SEALED CONTAINERS

In general, individual components and/or containers (not part of a pressurized system) that are sealed to maintain an internal nonhazardous environment at approximately one atmosphere psia or less. “Approximately one atmosphere” applies to the practice of limited internal pressurization above an external pressure of one atmosphere to assure a positive internal environment.

SERVICE LIFE

The interval beginning with determination of initial crack size for analysis based on inspection or flaw screening proof test of a part through completion of its specified mission including testing, transportation, lift–off, ascent, on–orbit operations, and descent and landing as applicable.

SINGLE POINT DIRECT CATASTROPHIC FAILURE

A direct catastrophic failure resulting from fracture in a structural part where the load is transmitted through a single fastener, pin or other structural element.

SPECIAL NONDESTRUCTIVE EVALUATION

Formal crack detection procedure using approved inspection techniques and/or equipment that exceed common industrial standards.

STANDARD NONDESTRUCTIVE EVALUATION

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

STRESS RUPTURE LIFE (COMPOSITE)

The minimum time during which the composite maintains structural integrity during the required service life considering the combined effects of stress level(s), time at stress level(s), and associated temperatures.

THRESHOLD STRAIN

The 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.