

JSC 25863B

FRACTURE CONTROL PLAN FOR JSC SPACE-FLIGHT HARDWARE

JSC Fracture Control Board

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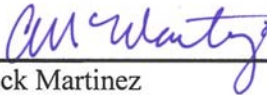
**JSC 25863, FRACTURE CONTROL PLAN FOR
JSC SPACE-FLIGHT HARDWARE, REVISION B
[APRIL, 2009]**

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1.0 Introduction

Any part or component whose individual structural failure would be a catastrophic event will be evaluated for Fracture Control. These parts will be treated with appropriate Fracture Control rigor to assure that a catastrophic failure is not caused by manufacturing and service-induced flaws, damage, or cracks existing in the materials of construction.

This Fracture Control Plan (FCP) presents the JSC implementation methodology for compliance with Fracture Control requirements on all manned space-flight programs.

Many projects may be relatively small and generation of an FCP for each individual project, as required by applicable specifications, may be overly demanding of available resources. The project may accept this FCP or other FCP that is approved by the JSC Fracture Control Monitor (FCM). The NASA/JSC FCM may be contacted for assistance with programmatic implementation of Fracture Control.

Experience has shown that relatively few parts or components will be truly "fracture-critical". Some hardware will have no fracture-critical parts. Use of this plan will simplify classification of parts and systems. Designers and analysts are encouraged to develop a working familiarity with this FCP to minimize Fracture Control implementation problems and/or costs. Terms defined in Appendix A of this document and in glossary sections of applicable requirements documents will be consulted for proper understanding and implementation of this FCP.

A viable Fracture Control program relies on proper design and analysis and on high quality of parts/components in-flight structures and pressurized or mechanical systems. Design and quality requirements for critical-flight hardware are expected to be consistent with aerospace standards. It is beyond the scope, or intent, of this FCP to specify requirements of flight hardware that already exist. Fracture Control supplements well-designed, high-quality hardware with significant additional assurance against catastrophic failures resulting from unexpected and/or undetectable flaws.

Fracture Control does not replace other applicable requirements for flights such as vibration testing, strength, structural life/fatigue, etc.

Basic assumptions that underlie Fracture Control implementation include:

- (a) All individual structural parts contain flaws or crack-like defects. The minimum service life capability of the part may be determined by considering one and only one flaw in the most critical area of the part and in the most unfavorable orientation.
- (b) The use of Non-Destructive Evaluation (NDE) techniques does not negate the above assumption. The NDE techniques establish a probable upper bound on the size of the assumed initial flaw at a specified confidence level.
- (c) All space-flight hardware will be of good design, certified for the application, acceptance tested as required, and manufactured and assembled using high-quality processes.

There are no differences between in-house and contracted efforts as to when Fracture Control is required.

Fracture Control is not intended to compensate for poor design, analytical errors, misuse, or poor quality. Implementation of Fracture Control enhances the safety and mission reliability of the flight hardware by reducing the risk of catastrophic failure. Although Fracture Control can be effective in assuring mission success, it is not specifically required for that purpose and is up to the discretion of the Hardware Developer (HD) to use for that purpose.

Fracture Control of the hardware will implement the required rigor based on the 'hazard' criticality evaluation and agreement. The FCM will verify that acceptable Fracture Control has been implemented on JSC flight hardware. The FCM does not normally determine the criticality of a structural failure on given hardware, but is available to both the project and safety organizations for consultation in such determinations and does have the prerogative to question classifications. Since Fracture Control is implemented to assure safety, the FCM will respect the Safety and Mission Assurance (S&MA) position.

NASA-HDBK-5010, Fracture Control Implementation Handbook for Payloads, Experiments, and Similar Hardware, provides useful guidelines and examples in meeting the Fracture Control requirements.

With the approval of the FCM, individual provisions of this document may be tailored based on application specific experience and sufficient technical rationale. If there are any discrepancies between this document and applicable Fracture Control requirements, the requirements take precedence over this FCP.

2.0 Purpose

The purpose of this document is to provide a general FCP for implementation of Fracture Control programs on NASA/JSC controlled space-flight hardware to meet the requirements specified in NASA-STD-5019. This plan will also meet the intent of NASA-STD-5007, NASA-STD-5003, SSP 30558C, and SSP 52005C.

3.0 Applicability

This plan is applicable to all JSC controlled space-flight hardware that is the responsibility of NASA/JSC. Other NASA centers or agencies may adopt this plan with the concurrence of the responsible Fracture Control group.

Additionally, all hardware that deviates from the certified design configuration will require an update to the existing Fracture Control analysis and classification in accordance with this FCP.

4.0 Responsibilities

4.1 Program/Project

It will be the responsibility of the Hardware Developer (HD) or specifically designated Fracture Control Coordinator (FCC) to provide for implementation of Fracture Control on the respective hardware. The HD/FCC will assure that Fracture Control is properly implemented in a timely manner. Fracture Control responsibilities will be established prior to the project formulation or Project/System Requirements Review (P/SRR).

The HD/FCC have the following responsibilities:

- (a) Fracture Control classification of parts.
- (b) Identification and specification of required NDE inspections or proof-test or any other special requirements to screen for flaws on fracture-critical parts.
- (c) Testing or fatigue/fracture mechanics analyses for all low-risk and fracture-critical parts.
- (d) Implementation of traceability and documentation showing compliances, adherence of flight hardware to approved drawings, specifications, plans and procedures.
- (e) Assessment of anomalies on low-risk and fracture-critical parts and decisions regarding questions or issues relating to Fracture Control.
- (f) Compilation of the Fracture Control Summary Report (FCSR).

Designers and analysts will conduct a hardware assessment to determine the extent of Fracture Control to be applied. The HD/FCC will assure that the Fracture Control activity is coordinated to the extent necessary with the FCM and will expedite the generation of a Fracture Control Summary Report (FCSR) for the program/project per Fracture Control requirements. For good design practices, the following are encouraged:

- (a) Design parts with redundancy. Avoid single-point catastrophic failures in joints and structures when it is reasonable to do so.
- (b) Design parts so they can be inspected. Avoid welds that are not inspectable on all sides.
- (c) Avoid processes that tend to be prone to cracking such as welding, custom-forging, casting, etc.
- (d) Use well-characterized standard aerospace materials for which the strength, fatigue, and fracture properties are known, or provide for adequate material testing.

4.2 JSC Fracture Control Monitor (FCM)

The responsibilities of the JSC FCM include:

- (a) Review and approve FCP.
- (b) Interpretation of Fracture Control requirements.
- (c) Support Safety Review Panels (SRP, PSRP, FESRRP, etc.) at JSC.
- (d) Present off-nominal cases to the JSC Fracture Control Board (FCB).
- (e) Review FCSR to support Safety Review Panels and issue Fracture Control certification of JSC integrated flight hardware.

4.3 Fracture Control Milestones

The Hardware Developer (HD) will meet the following milestones for Fracture Control Data Submittal to the FCM.

Preliminary Design Review (PDR) or Phase I Safety Review:

- (a) Submission of a FCP.
- (b) Pressure vessel(s) design and qualification, as applicable.
- (c) Identification of Damage Threat Assessment (DTA) and Damage Control Plan (DCP) for structural composite/bonded structures and Composite Overwrapped Pressure Vessel (COPV).

Critical Design Review (CDR) or Phase II Safety Review:

- (a) Fracture Control status and categorization of the hardware.
- (b) Any unique or alternate approaches used in Fracture Control that require the approval of the FCM.

System Acceptance Review (SAR) or Phase III Safety Review:

- (a) FCSR or certification of compliance from a center or agency with whom an inter-center agreement has been established.

4.4 JSC Fracture Control Board (FCB)

The JSC FCB is an assembly of experts in various aspects of Fracture Control including fracture mechanics, Fracture Control methodology, structures, materials, NDE and S&MA.

The FCB will be available to assess and resolve Fracture Control issues and/or provide Fracture Control directions and recommendations.

The JSC FCM and cognizant Project/Program personnel will determine when action by the FCB is warranted and will solicit specific FCB action.

In addition, the FCB will assure that the latest Fracture Control data and methodology consistent with NASA Fracture Control policy are implemented in JSC programs. This will be achieved by participation in NASA inter-Center Fracture Control meetings and activities, periodic internal meetings and discussions, and the determination of when revision in Fracture Control implementation is warranted.

5.0 Applicable Documents

The latest issuances of cited documents will be used unless otherwise approved by the FCM. The applicable documents are accessible via the NASA Technical Standards System at <http://standards.nasa.gov>, directly from the Standards Developing Organizations, or from other document distributors.

NASA-STD-5007; General Fracture Control Requirements for Manned Spaceflight Systems

NASA-STD-5019; Fracture Control Requirements for Spaceflight Hardware

NASA-STD-5003; Fracture Control Requirements for Payloads Using the Space Shuttle

SSP 30558C; Fracture Control Requirements for Space Station

SSP 52005C; Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures

NASA-HDBK-5010; Fracture Control Implementation Handbook for Payloads, Experiments, and Similar Hardware

NASGRO[®]; Fracture Mechanics and Fatigue Crack Growth Analysis Software Reference Manual, www.nasgro.swri.org

NASA-STD-5009; Non Destructive Evaluation Requirements for Fracture-Critical Metallic Components

NASA-STD-6008; NASA Fastener Management and Control Practices

NASA-STD-6016; Standard Materials and Processes Requirements for Spacecraft

JSC 20793, Crewed Space Vehicle Battery Safety Requirements

NSTS 1700.7B; Safety Policy and Requirements for Payloads Using the Space Transportation System

NSTS 1700.7B, ISS ADDENDUM; Safety Policy and Requirements for Payloads Using the International Space Station

JSC 62550; Strength Design and Verification Criteria for Glass, Ceramics and Windows in Human Space Flight Applications

DoT Title 49, United States Government Code, Department of Transportation

ANSI/AIAA S-080-1998; Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components

ANSI/AIAA S-081A-2006; Space Systems - Composite Overwrapped Pressure Vessels (COPVs)

API-RP 579-1; Fitness For Service, Section 9

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or 2, September 2004; Rules for Construction of Pressure Vessels, Section VIII, Division 1 or Division 2, Alternative Rules

ES4-02-050; Levels of Containment Guidelines For Payloads Utilizing Hazardous/Toxic Materials

ES4-07-031; Fracture Control of Mechanisms

6.0 Fracture Control Classification of Parts

Where feasible, Fracture Control will be initiated by a structure/system screening for potential fracture-critical parts/components, based on structural failure modes, consequence of failure, applicable requirements, and experience. The list of potential fracture-critical parts will serve as a contributing base for establishing the necessary Fracture Control rigor in the program according to the methodology in this FCP.

Hardware may be classified as:

- (a) Exempt, or
- (b) Non-fracture-critical, or
- (c) Fracture-critical.

Exempt hardware typically includes items such as insulation blankets, switches, sensors, enclosed electrical circuit components/boards, electrical connectors, pins, tangs, lock wire, etc. used for fastener back-off prevention, wire bundles, seals, etc.

Non-fracture-critical hardware generally includes the classifications of low-released mass, contained, fail-safe, non-hazardous leak-before-burst (NHLBB) pressurized lines, fittings & components, low-speed/low-energy and low-momentum rotating machineries, low-strain composite parts, low-risk parts and fasteners, and protected glasses. Section 6.1 gives a

detailed explanation of each of these classifications and suggestions for classifying specific hardware items.

Fracture-critical hardware includes pressure vessels, high-energy or high-momentum rotating equipments, hazardous material containers, habitable modules, solid rocket motor cases and propellant tanks and any remaining hardware that do not fit the first two categories of exempt or non-fracture-critical. All fracture-critical hardware will be shown to meet damage-tolerant requirements through analysis or test or fleet-leader testing. Section 6.2 provides criteria for classifying and assessing specific types of fracture-critical hardware.

The assessment of hardware criticality will examine the different phases of application including launch, on-orbit, and return-to-ground (including a contingency abort without ground services) to determine the applicability and extent of Fracture Control. For example, a part may not be fracture-critical during the launch phase, but could be fracture-critical for on-orbit service. In this case Fracture Control assessments will address the on-orbit phase as well as potential effects of other phases on the on-orbit performance.

Fracture-critical parts will be identified as such on the drawings. This alerts all who use the drawing as to the criticality of the part. Designers and analysts will work together to assure that required notations, including NDE and/or proof-test requirements, etc., are provided on the drawing for any fracture-critical part.

6.1 Non-Fracture-Critical Parts/Components

If the structural failure of a part/component is clearly not a catastrophic hazard, no further Fracture Control assessment is required. If the hazard is unclear, it could be classified as non-fracture-critical if it can be shown to meet one of the following categories addressed in Section 6.1.1 thru Section 6.1.11. These parts will be processed under conventional aerospace verifications and quality assurance procedures.

6.1.1 Low-Released Mass

Potential mass releases as a result of a single-point structural failure will be examined for hazard potential. Any part of any size in this category whose release would not be a catastrophic hazard either to the source of the mass or to any other structures, systems, or crew that could be impacted by the mass during any phase of launch/reentry or flight can be classified non-fracture-critical. A released mass may either be internal or external to the spacecraft.

The released mass inside the habitable module will not be able to achieve (for example, via contact with crew or release during launch) a velocity of more than 10.7 m/sec (35 ft/sec) or a momentum of more than 1.24 kg-m/sec (8.75 ft-lb/sec).

Fasteners pre-loaded in tension which have a low-fracture toughness, $K_{Ic}/F_{ty} < 1.66 \sqrt{\text{mm}}$ (0.33 $\sqrt{\text{in}}$), will be limited to 14 gm (0.03 pound) potential free mass.

For steel bolts with unknown K_{Ic} , low-fracture toughness is assumed when $F_{tu} > 1240$ MPa (180 ksi).

Parts/components whose single-point failure would exceed low-released mass limits would, preferably, be shown to be contained (Section 6.1.2), or meet the low-risk criteria (Section 6.1.11) and, therefore, be classified as non-fracture-critical. Otherwise, applicable requirements of fracture-critical parts must be applied.

6.1.2 Contained

A part confined in a container or housing, or otherwise positively restrained from free release, and whose failure would not result in a catastrophic event, can be classified non-fracture-critical.

Pressurized components and rotating devices within stowed or contained hardware will be assessed independently, as delineated in this FCP, to assure against explosion and/or release of fragments, hazardous fluids, over-pressurization and catastrophic failure of the container/compartiment.

Containment of rotating devices will consider the combined effect of rotational speed and potential for mass release to determine classification. Guidance for calculating containment of high-energy rotating devices is given in Appendix B of NASA-HDBK-5010.

Hardware not in lockers/containers but having internal parts will be assessed on their individual merit for containment of loose internal parts. Enclosures with openings will be assessed for containment of parts larger than accessible openings.

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.

Typical electronic boxes and related equipment such as radios, cameras, recorders, personal computers, and similar close-packed and enclosed hardware can be regarded as acceptable containers of internal parts without further assessment.

Release of a free mass from a fastener that is safety-wired will be assumed non-credible. All safety wired fasteners can be classified non-fracture-critical if failure does not result in a catastrophic event due to loss of structural integrity of the fastener.

When containment is furnished by a compartment with doors or other opening hardware, the closure design will be one-fault tolerant of accidentally opening, i.e., hinges, latches, etc., will be redundant (e.g., fail-safe) for keeping a door closed in the event one fails.

6.1.3 Fail-Safe

For purposes of Fracture Control, structures (including fasteners, latches, and mechanisms) will be identified as fail-safe and classified non-fracture-critical when it can be shown that, due to structural redundancy, structure remaining (assumed unflawed) after any credible

single structural failure can withstand the redistributed loads with a minimum safety factor of 1.0 on limit load for metallic structure or 1.15 on limit load for composite/bonded structure.

Failures that are classified fail-safe will not result in release of an unacceptable free mass (Section 6.1.1).

In doing a fail-safe analysis of an assembly of several similar parts with a common function, such as fasteners in a bolted joint or struts in a truss, the part with the highest load and the part with the lowest margin (these may not be the same) will be removed separately to assess fail-safe capability.

When determining redundancy the effect of altered coupling will be considered unless: (a) the design loads are conservative with respect to dynamic coupling variations, or, (b) failure of the part would not significantly alter dynamic response of the hardware.

For composite/bonded structure, the structural models and analytical methodology used in the fail-safe analysis will be test-verified for the intact/nominal configuration. All fail-safe composite/bonded structures will be subjected to Task 1 of the Damage Threat Assessment (DTA) (Section 8.2.1) and Damage Control Plan (DCP) (Section 8.2.2).

In some cases, fail-safe categorization will be a matter of engineering judgment based on high-structural margins, design experiences, materials characteristics, overall configurations, etc. When engineering judgment is used in lieu of a detailed analysis or testing, the criteria for the judgment will be coordinated with the FCM and documented in the FCSR.

In cases of significant cyclic loading potential, the remaining structure will be assessed for fatigue or durability and coordinated with the FCM. Joint gapping is allowed under fail-safe or emergency or abort landing conditions as they are unlikely events.

All rivet applications will be designed fail-safe and are subject to conventional verification and quality assurance requirements only. Fracture Control for damage-tolerant rivets is impractical and not realistically implemented.

For multi-mission flight hardware, it will 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. This will be accomplished by a close visual inspection (aided by cameras, boroscopes, or other assistance if necessary) of the hardware for signs of damage. If damage is indicated, a more rigorous inspection will be made as warranted including NDE or other applicable analysis for the verification of fail-safe parts.

An alternative to reverification of structural redundancy by inspection is to show the remaining structure has sufficient fatigue capability demonstrated by a fatigue or damage-tolerant analysis or test to reach end-of-service life with minimum factor of four (4) on life.

6.1.4 Non-Hazardous Leak-Before-Burst (NHLBB) Pressurized Lines, Fittings and Components

This section addresses pressurized membranes where flaws cannot grow to instability before a sizable leak has developed, and release of contained fluid is not a catastrophic event.

Pressurized lines, fittings, and components such as regulators, valves, filters, bellows, etc. are accepted as NHLBB designs and they can be classified as non-fracture-critical provided all of the following are met:

- (a) They do not contain a hazardous fluid and loss of pressure in the system will not result in a catastrophic event.
- (b) The critical length of through-crack is at least 10 times the wall thickness OR the crack opening of the critical flaw size at typical operating pressures is large enough to allow a stable leak that reduces the internal pressure, thereby demonstrating LBB design.
- (c) The leak is automatically detected and further pressure cycling is prevented, or there is no repressurization.
- (d) System supports and brackets are evaluated per Fracture Control.

Catastrophic hazards for LBB assessment include unacceptable dilution or toxicity of breathing environment, increases in oxygen or flammable material beyond flammability limits, or loss of a safety-critical function.

Hardware meeting required design factors and utilizing common materials of construction that typically exhibit LBB failure modes may be considered acceptable in lieu of analysis with the approval of the FCM.

NHLBB will not be applied to habitable module and enclosures.

To be classified NHLBB, the components will not have coatings, barriers, liners, or other means that prevent or inhibit leakage through a flaw. Pressure vessels may also be of NHLBB design, but they are always considered fracture-critical.

The methodology given in API-RP-579-1, Fitness-for-Service (Section 9) may be used as a guideline in calculating the leakage requirement for LBB design.

6.1.5 Low-Energy Rotating Machineries

This section addresses rotating machineries that do not possess sufficient energy or momentum to present a catastrophic hazard risk and will be classified as non-fracture-critical.

Rotating machinery that has kinetic energy less than 19,310 Joules (14,240 foot-pounds) and angular momentum less than 136 Newton-meter-seconds (100 pound-foot-seconds) and does not present a catastrophic hazard risk can be classified as non-fracture-critical.

The low-energy and low-momentum rotating equipment will be examined for protection against a catastrophic occurrence resulting from release of fragments. Rotating equipment whose failure results in release of fragments will be shown to be contained by analysis or test.

The mounts and brackets for rotating machinery will be addressed as standard structure for Fracture Control.

Shrouded or enclosed fans [50265.5 rad/s (8000 rpm) and 20.4 cm (8 in) diameter maximum], electric motors, shafts, gearboxes, recorders, conventional pumps (including roughing pumps), and similar devices are accepted as inherently meeting containment requirements, or the full intent of requirements, and can be classified non-fracture-critical without further assessment.

6.1.6 Fasteners and Shear Pins

Designers are encouraged to design parts with redundancy and avoid single-point catastrophic failures in joints and structures when it is reasonable to do so.

Fasteners and shear pins that cannot be categorized fail-safe, may be classified as low-risk if the following are met:

- (a) Fastener will be in a local pattern of two or more similar fasteners.
- (b) Fastener will be fabricated and inspected in accordance with military standard, national aircraft standard, or equivalent commercial aerospace specifications.
- (c) Fastener will be fabricated from well-characterized metal not sensitive to stress-corrosion cracking as defined in NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft.
- (d) Tensile-loaded fastener will not be made from a low-fracture toughness alloy [$K_{Ic}/F_{ty} < 1.66 \sqrt{\text{mm}}$ (0.33 $\sqrt{\text{in}}$)] or, Ti-6Al-4V STA titanium.
- (e) Fasteners will have rolled threads.
- (f) Fasteners will meet appropriate pre-loads and fatigue requirements with no joint gapping (gapping is allowed under fail-safe and/or emergency conditions only) using one of the following approaches:
 - (i) A fracture mechanics damage-tolerant analysis of the thread root, shank and head/shank transition using a 0.127 mm (0.005 in) initial crack and shows a minimum of four (4) complete service lifetimes on alternating stress with a safety factor of 1.0.
 - or,
 - (ii) A conventional fatigue analysis (e.g., Miner's rule) of the thread root, shank and head/shank transition and shows a minimum of four (4) complete service lifetimes on alternating stress with a safety factor of 1.0.

(g) Re-worked or custom-made fasteners require FCM approval.

6.1.7 Shatterable Components and Structures

Internal and external shatterable components that are prone to brittle mode of failures (e.g., glass, ceramics, etc.) and/or subjected to impact or sustained loading can be classified as non-fracture-critical if they meet the criteria specified in Section 6.1.7.1 or Section 6.1.7.2.

6.1.7.1 Shatterable Components and Structures Inside Habitable Module

Shatterable components in habitable module can be classified as non-fracture-critical by meeting the requirements of contained parts (Section 6.1.2).

With the approval of the FCM, small shatterable parts can be accepted for use based on vibration environmental testing, inspection, and functional tests that verify the integrity.

Camera lenses and similar pieces that are recessed or protected during non-use periods are considered protected and can be classified non-fracture-critical.

6.1.7.2 External Shatterable Components and Structures

Any components or structures that are on the external surface of a spacecraft, including thermal protection systems, which are manufactured from a material that has limited ductility such that it is prone to brittle failures when cracked and/or subjected to impact, can be classified as non-fracture-critical by meeting the following two requirements.

(a) A Damage Threat Assessment (DTA) and Damage Control Plan (DCP), as defined in Section 8.2.1 and 8.2.2 respectively, will be developed to mitigate catastrophic hazards due to credible impacts from vehicle loss of external surface mass, crew exposure, Micrometeoroid and Orbital Debris (MMOD), Extra Vehicular Activity (EVA) inadvertent contacts, and EVA tool impact hazards.

(b) The design will be redundant in function and strength such that loss of a primary member does not result in catastrophic loss of function or required strength that prevents the spacecraft from safely completing the mission.

6.1.8 Sealed Containers

This section addresses inherently pressurized hardware (e.g., a sealed electronic box) that is not a part of a pressure system.

The pressure of the sealed container is less than 689.5 KPa (100 psia) and stored energy is less than 19,310 Joules (14,240 foot-pounds).

Sealed containers do not contain a hazardous fluid and loss of pressure in the system will not result in a catastrophic hazard.