Teamwork & Innovation RELATIVITY MISSION SPACE VEHICLE

GRAVITY PROBE B SPACE VEHICLE DEVELOPMENT

# ENGINEERING MEMORANDUM

| TITLE: Fracture Control Plan (GP-B Science Payload) | | EM NO. SMS 270<br>DATE: 20 Nov 1998<br>REVISED: |
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# 1. INTRODUCTION

## 1.1. PURPOSE AND SCOPE

This document establishes fracture control process requirements for the GP-B Science Payload. This document describes the method and procedures to be used for fracture classification of components, analysis, inspection, and structural verification. The requirements set forth in this document are the minimum fracture control requirements for metallic and nonmetallic structural components of the GP-B Science Payload. This document supersedes EM #428 (Ref. 1). This document will be released in the Stanford Document Control System as P0130.

## 1.2. SCIENCE PAYLOAD DEFINITION (PLSE-12, Ref. 2)

The Science Payload consists of the Science Instrument Assembly (SIA), Probe-C, Science Mission Dewar (SMD), Gas Management Assembly (GMA), Forward Equipment Enclosure (FEE), and the support electronic boxes.

## 1.3. GENERAL REQUIREMENTS

Design shall be based on fracture control procedures based on good design, manufacturing, test, and operational practices. Materials, analytical method, factors of safety, testing, adequate inspections shall be selected based on good engineering practices and judgment.

## 1.4. FRACTURE CONTROL CLASSIFICATION

Fracture control classification for all Science Payload components shall be determined as shown in the flow chart of Figure 1.

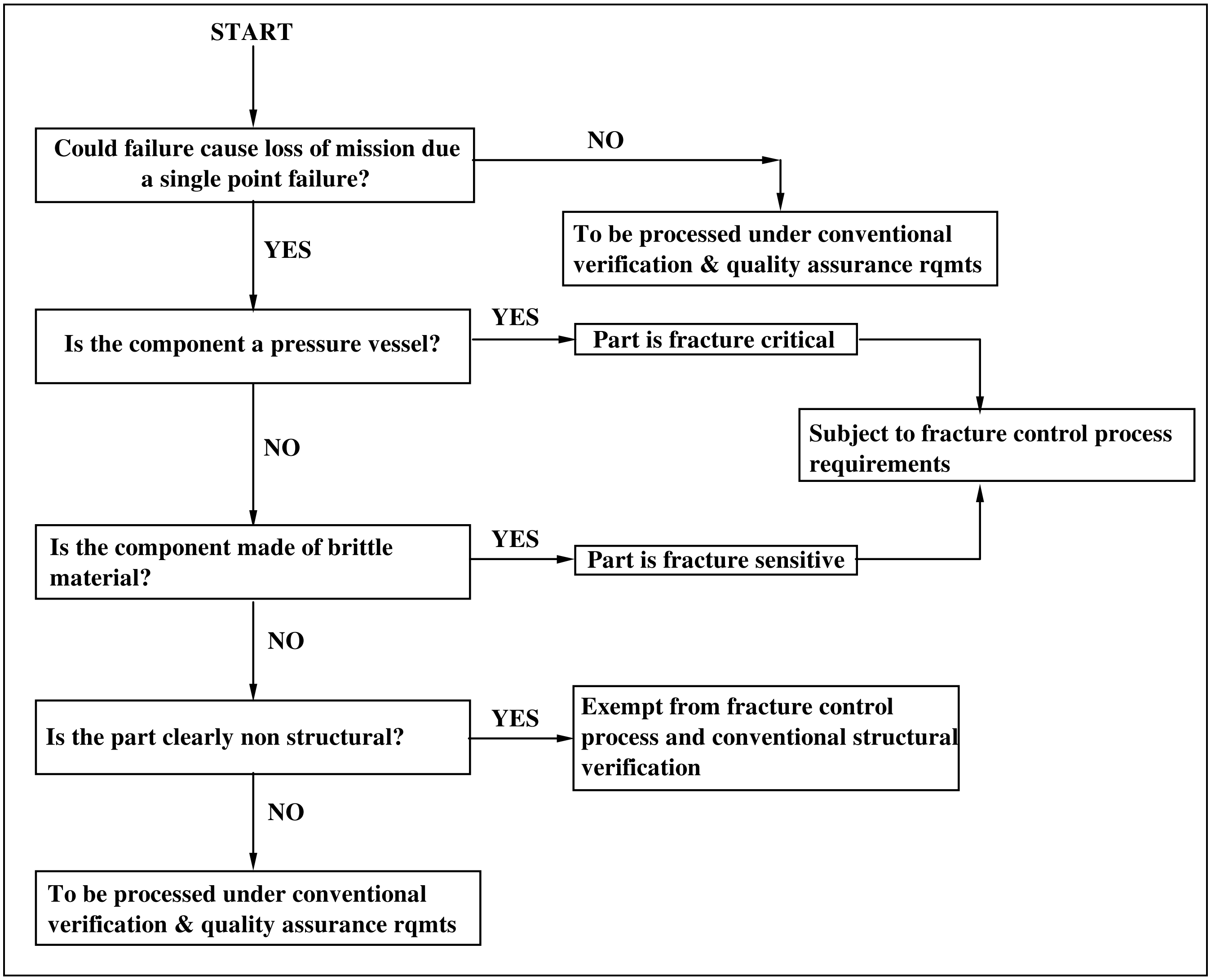


**Figure 1 GP-B Payload Fracture Control Classification**

## 1.5. TRACEABILITY

An appropriate level of traceability shall be maintained on all fracture critical and fracture sensitive parts as indicated in Section 4.1 throughout the GP-B development, manufacturing, testing, and flight preparation program.

# 2. FRACTURE CONTROL PROCESS

A fracture control process shall be applied to all flight hardware classified as fracture critical or fracture sensitive.

## 2.1. FRACTURE SENSITIVE COMPONENTS

Structural components that exhibit brittle failure behavior and would cause failure of the mission by a single point failure are considered fracture sensitive parts. If the structural reliability is to be demonstrated by fracture control, the process shown in Figure 2 shall be applied. The Figure 2 process is derived from NASA GEVS-SE (Ref. 3).

The "prescribed level for material" indicated in Figure 2 is threshold maximum stress level below which, fracture mechanics analysis is not required. The threshold levels as defined in Ref. 3 are:

- All metal elements except beryllium: 25% of their ultimate tensile strength
- All composite elements: 25% of their ultimate tensile strain or ultimate compressive strain
- All glass elements (including fused Quartz):10% of their ultimate tensile strength

Stress shall review all drawings to identify fracture sensitive components and determine if any nondestructive evaluation (NDE) inspection is required. Appropriate inspection notes shall be specified on the design drawings of parts classified as fracture sensitive.

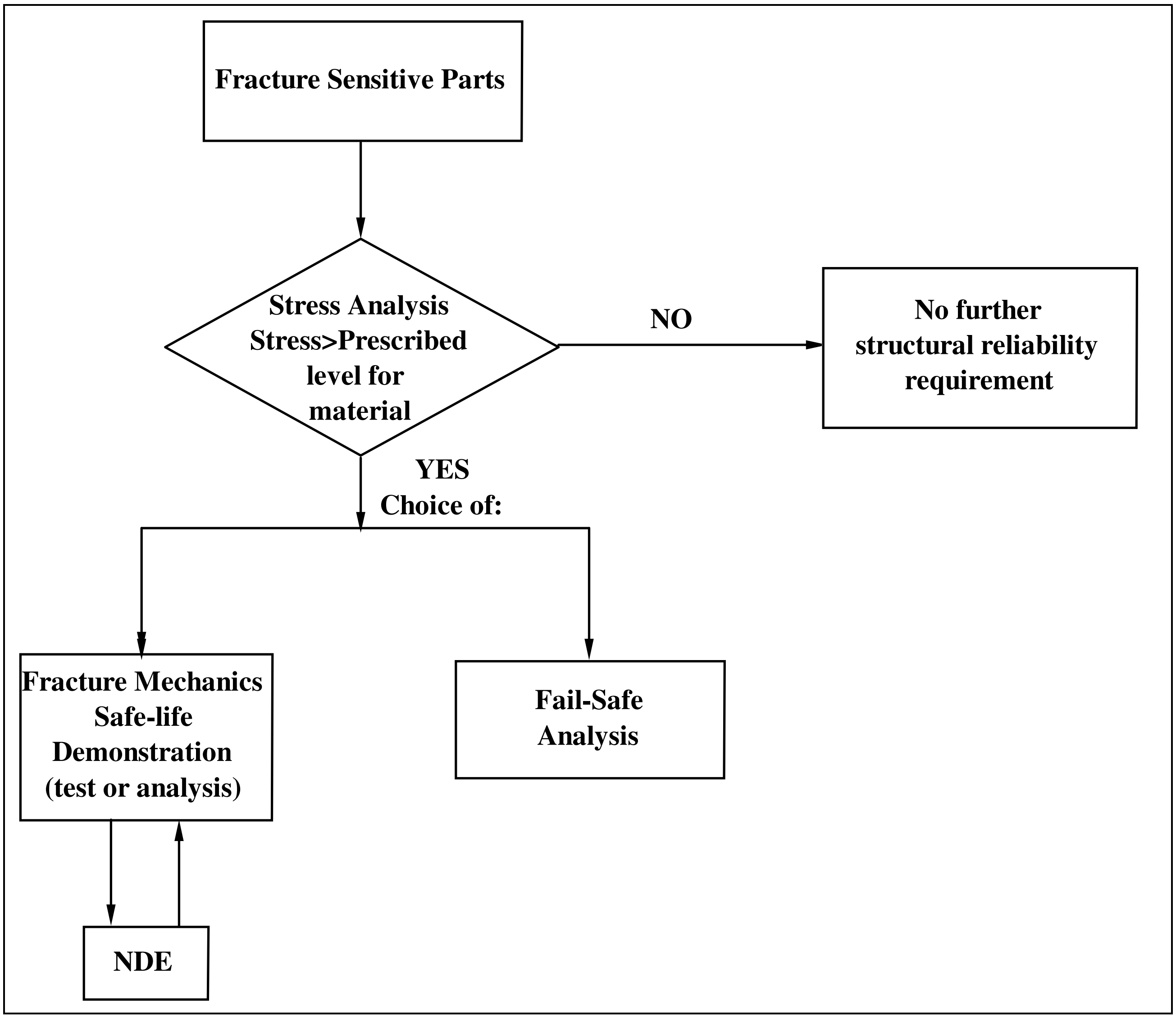


**Figure 2 Fracture Control Process for Fracture Sensitive Parts**

## 2.2. FRACTURE CRITICAL PARTS (PRESSURE VESSELS)

A pressure vessel as defined by MIL-STD-1522 (Ref. 4) is a component of a pressurized system designed primarily as a container that stores pressurized fluids and:

1. Contains stored energy of 14240 foot-pounds (19310 joules) or greater based on adiabatic expansion of a perfect gas
2. Contains a gas or liquid which will create a mishap if released; or
3. Will experience a design limit pressure greater than 100 psi

Pressure vessels are considered fracture critical and therefore subject to fracture control (MSFC-HDBK-505, Ref 5). Figure 3 illustrates the offered approaches (derived from Ref. 4) for the design, analysis, and verification of pressure vessels. Approach “A” illustrates verification requirements for a pressure vessel designed with burst factor ≥1.5 and approach “B” illustrates verification requirements for a pressure vessel designed with a burst factor ≥2.0. Approach “C” illustrates the steps required for verification of a pressure vessel designed to the ASME Boiler and Pressure Vessel Code. Appropriate inspection notes shall be specified on the design drawings of parts classified as fracture critical.

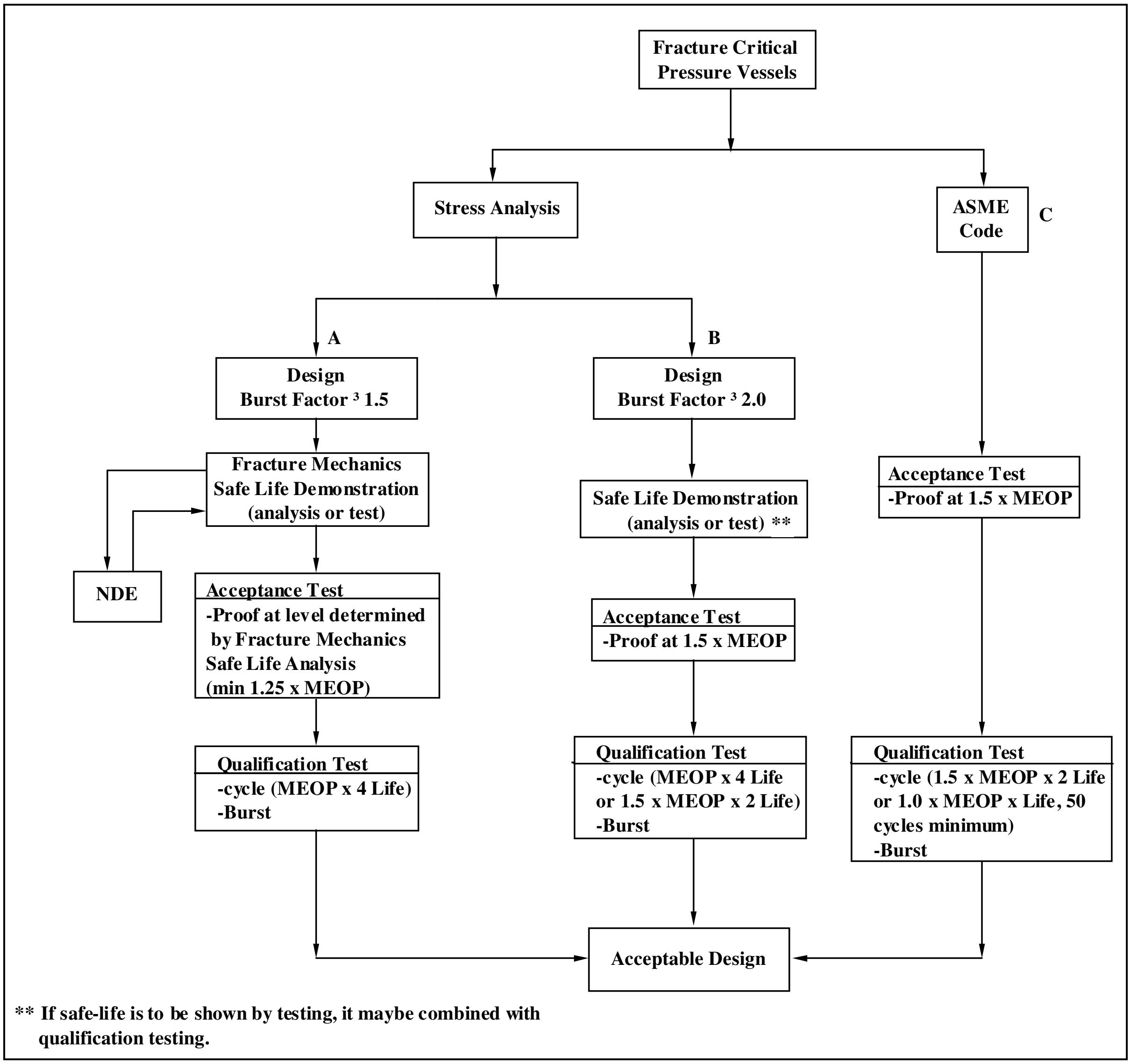


**Figure 3 Fracture Control Process for Fracture Critical Pressure Vessels**

### 2.2.1. PRESSURE VESSELS DESIGNED USING FRACTURE MECHANICS (REF. 4), APPROACH "A"

For Approach "A", both composite and non-composite pressure vessels may be designed and verified utilizing fracture mechanics. The pressure vessel is to be designed to a burst factor of 1.5 x MEOP . In addition to the stress analysis conducted, safe-life shall be demonstrated using fracture mechanics techniques covering the maximum expected operating loads and environments. Proof test (Acceptance Test) shall be conducted as determined by fracture mechanics safe-life analysis (minimum of 1.25 x MEOP).

### 2.2.2. PRESSURE VESSELS DESIGNED USING STRENGTH OF MATERIALS (REF. 4) APPROACH "B"

For Approach "B", both composite and non-composite pressure vessels may be designed and verified utilizing the criteria of Section 5.1.3 of MIL-STD-1522 (Ref. 4) which does not employ fracture mechanics techniques. The pressure vessel is to be designed to a minimum proof pressure of 1.5 x MEOP and a minimum design burst pressure of 2.0 x MEOP. Proof test shall be conducted at 1.5 x MEOP (Acceptance Test).

### 2.2.3. PRESSURE VESSELS DESIGNED USING THE ASME BOILER CODE (REF. 4), APPROACH "C"

For Approach "C", non-composite pressure vessels may be designed and manufactured per the rules of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or 2. Composite pressure vessels may be designed and manufactured per the rules of the ASME Boiler and Pressure Vessel Code, Section X. Both composite and non-composite pressure vessels shall be proof pressure tested at 1.5 x MEOP(Acceptance Test).

## 3. STRESS/FRACTURE MECHANICS ANALYSIS

Detailed structural analysis shall be performed and documented to determine the maximum stress fields resulting from mechanical loads, pressures, temperatures and temperature gradients, launch and on-orbit loads, and other environmentally induced loads. Fracture mechanics shall be performed using NASA FLAGRO, or other similar programs to determine safe-life of the fracture critical and fracture sensitive parts.

### 3.1. NONDESTRUCTIVE EVALUATION INSPECTIONS

When NDE is required, the NDE method chosen shall be capable of detecting flaws as small as the determined critical flaw size. Where adequate NDE inspection of the finished part cannot be accomplished, NDE may be performed on the raw material and/or the part itself at the most suitable step of fabrication. Flaws shall be mapped on the fracture critical and fracture sensitive parts, identifying type, location, size, and depth. All inspections done on the part shall be properly documented.

## 4. SUMMARY DOCUMENTATION

### 4.1. Fracture Control Summary List

To certify fracture control compliance, a fracture control summary list shall be prepared (see Table 1). This list shall include information such as drawing number, title, revision, part name, material, Fracture control classification, inspection type, and analysis results.

**Table 1 Fracture Control Summary List Format**

| Drawing | Title | Revision | Part Name | Material | FC Classification | Inspection/ Testing | Analysis Results/Comments |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

### 4.1.1. SUPPORTING DATA

Documentation supporting the fracture control summary list shall be kept for the life of the system. The documents required to support the acceptability of a fracture sensitive part shall include a detailed analysis and inspection report to assure acceptability and traceability of this process. Inspection report shall include the date of inspection, identification number of part inspected, and name of inspector.

Detailed design and assembly drawings shall be part of the Engineering data used in fracture control assessments. Analysis shall be clearly documented including assumptions, rationales, significant test results, methods, and references.

## 5. REFERENCES

1 *EM #428 , GPB-100477, "Gravity Probe-B Fracture Control Plan", 4/11/95.*
2 *CDRL No. PLSE-12, "Science Payload Specification", March 31, 1998.*
3 *NASA GEVS-SE, Structural Reliability (Residual Strength Verification)*
4 *MIL-STD-1522,"Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems".*
5 *MSFC-HDBK-505, "Structural Strength Program Requirements"*

# APPENDIX A: DEFINITIONS

The following definitions and terms shall be used for design and analysis of fracture critical candidate parts and in all documentation to establish uniform nomenclature with respect to loads, safety factors, fracture mechanics, testing, etc.

Burst Factor - The burst factor is a multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure. It is synonymous with ultimate pressure factor.

Critical Flaw Size - The flaw size which, for a given applied stress, causes unstable flaw propagation.

Fail-Safe - Ensures that a structural elements, because of structural redundancy, will not cause collapse of the remaining structure or have any detrimental effects on mission performance.

Flaws or Crack-like Defects - Defects which behave like cracks that may be initiated during material production, fabrication, or testing or developed during the service life of a component.

Fracture Critical Part - A part which, by fracture mechanics analysis has a service life factor of less than 4.0 times the vehicle life cycle requirements and failure of which would cause loss of vehicle. Also a part that is a pressure vessel.

Fracture Mechanics – An engineering discipline which relates the influence of loading, geometry, material parameters, and environment on the fracture of a material caused by flaw propagation from initial flaws or crack–like defects.

Fracture Sensitive Part – Any structural components which is susceptible to brittle fracture and would cause loss of mission by a single point failure.

Initial Flaw Size - The maximum size flaw, as defined by proof test or nondestructive inspection, which could exist in parts without failure in proof test or detection in NDE.

MEOP – Maximum expected operating pressure.

NDE - Nondestructive Evaluation

Pressure Vessel - A component of a pressurized system designed primarily as a container that stores pressurized fluids and:

- Contains stored energy of 14240 foot-pounds (19310 joules) or greater based on adiabatic expansion of a perfect gas
- Contains a gas or liquid which will create a mishap if released; or
- Will experience a design limit pressure greater than 100 psi

Proof Test – The test of a flight structure at proof load or pressure which will give evidence of satisfactory workmanship and material quality or will establish the initial flaw size prior to acceptance of the structure for flight.

Safe-Life - Ensures that the largest flaw that could remain undetected after non destructive examination will not grow to failure during the mission.

Ultimate Pressure or Load – The pressure or load at which an unflawed structure should fail if all the sizing allowables (material strength thickness, etc.) are at their minimum specified levels.

Ultimate Strength – Corresponds to the maximum load or stress that a structure or material can withstand without incurring rupture or collapse.

Yield Strength – Corresponds to the maximum load or stress that a structure or material can withstand without incurring detrimental deformation.