



National Aeronautics and
Space Administration

MSFC-HDBK-1453
October 1987

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Fracture Control Program Requirements

MSFC-HDBK-1453

FRACTURE CONTROL PROGRAM REQUIREMENTS

10/6/87
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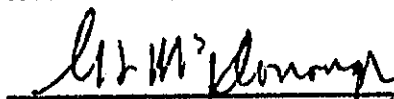
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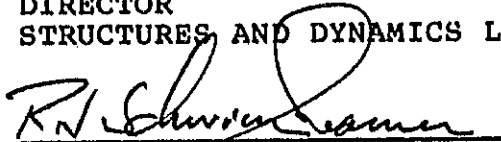
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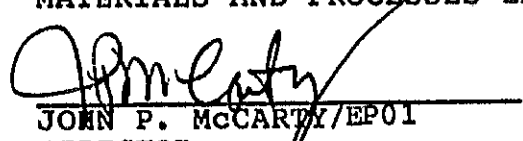
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TABLE OF CONTENTS

	<u>PAGE</u>
1. General Policy.....	1
2. Scope.....	1
3. Prerequisites.....	1
4. Fracture Control Board.....	2
5. Fracture Control Plan.....	3
6. Fracture Control Selection and Disposition of Parts.....	3
6.1 Low Mass.....	3
6.2 Contained/Restrained.....	4
6.3 Fail-Safe.....	4
6.4 Damage-Tolerant.....	4
6.5 Safe-Life.....	4
7. Fracture Mechanics Analyses/Tests.....	5
7.1 Low Mass Analyses.....	5
7.2 Containment/Restraint Analyses.....	5
7.3 Fail-Safe Analyses.....	5
7.4 Damage-Tolerant Tests.....	5
7.5 Safe-Life Analyses.....	6
8. Pressure Vessels and Rotating Machinery.....	6
9. Fasteners.....	7
10. Design.....	7
11. Materials and Processes.....	8
11.1 Material Properties for Fracture Mechanics Analyses.....	8
11.2 Preparation of Material Specifications.....	9
11.3 Tooling.....	9
12. Nondestructive Evaluation (NDE).....	10
13. Safety, Reliability and Quality Assurance.....	11
13.1 Personnel Certification.....	11
13.2 Safety, Reliability, and Quality Review Reporting.....	11
13.3 Failure Documentation.....	12
13.4 Traceability.....	12
13.5 Actual Service Accumulation.....	12
14. Environmental Control.....	13

	<u>PAGE</u>
15. Tests.....	13
15.1 Fracture Control/Verification Tests.....	13
15.2 Structural Strength Qualification Tests:.....	13
15.3 Service Testing.....	13
15.4 Proof Testing.....	14
16. Loads Spectra.....	14
17. Documentation.....	15-17
18. References.....	18
19. Definitions.....	19-21
Figure 1. Relationship of the MSFC Fracture Control Board to Other MSFC Elements.....	22
Figure 2. Fracture Control Selection and Disposition of Parts.....	23
Figures 3a. through 3h. Sample Data Requirements.....	24a-h

1. GENERAL POLICY

It is the policy of NASA and MSFC to produce space systems with a high degree of safety. This is accomplished through good engineering practices in the design, analyses, inspections, testing, fabrication, and operation of space flight structures. In conjunction with references 1 and 2 and MSFC policy, it is required that if structural failure of a part in a space vehicle system would cause a catastrophic event, then that part must be subjected to fracture control.

2. SCOPE

This document establishes the fracture control requirements for all flight structures for which MSFC is responsible. All activities influencing fracture control and selection of parts for fracture control of space flight structures are subject to the requirements of this document. These activities include-- but are not limited to--design, analysis, and test; materials selection, purchase and storage; fabrication process control; quality assurance tests and nondestructive evaluation; and operations and maintenance. These requirements are applicable to MSFC in-house activities as well as all related contractor activities and subcontractor efforts. In the event that this document is found to be in conflict with references 1 or 2 or any other level 1 requirements, then the most stringent requirements are to take precedent.

3. PREREQUISITES

Appropriate engineering data shall be generated for all components and made available as a basis for fracture control classification, as well as for the determination of low mass, containment/restraint, fail-safe, damage-tolerant, or safe-life of individual components. These data shall include the following as a minimum.

- a. Definition of external loads, environments, and test and operating cycles.
- b. Hardware design drawings.
- c. Mechanical and fracture mechanics properties of materials, including heat treatment specifications.
- d. Assembly details, including torque specifications for fasteners.
- e. Stress analysis results.
- f. Level of inspection (for crack detection) performed on parts.

4. FRACTURE CONTROL BOARD

The MSFC Fracture Control Board (FCB) is responsible for ensuring preparation, maintenance, review, and approval of all fracture control plans, procedures, and requirements. Board members are responsible for ensuring implementation of the fracture control program and board directives within their own organizations and for maintaining board awareness of fracture control progress or problems arising within these organizations. The FCB oversees all projects at MSFC. Within each project, the technical leads, chief engineers, and project offices are responsible for implementing fracture control as required by this document and for carrying out FCB directives. The technical leads support the FCB meetings and are directly responsible for monitoring and ensuring that fracture control requirements are fulfilled in their technical areas and on the project for which they are technically responsible (figure 1).

Fracture control related data are to be developed during the engineering design process per the following schedule:

<u>Type Review</u>		<u>Data Requirement</u>
Preliminary Requirements Review (PRR)	-	Fracture Control Plan
Preliminary Design Review (PDR)	-	Fracture Control Plan Update
	-	Preliminary Fracture Mechanics Analysis Results
Critical Design Review (CDR)	-	Fracture Control Plan Update
	-	Fracture Mechanics Analysis Results Update
Design Certification Review (DCR)	-	Fracture Control Plan Update
	-	Fracture Mechanics Analysis Results Update
Phase III Safety Review	-	Complete Fracture Control Report

The chief engineers office is responsible for scheduling contractor meetings with the FCB for review and approval of all contractor fracture control activities. The FCB chairman may call for meetings to review the data listed above plus other meetings that he may deem necessary to carry out the requirements of this document. All fracture control activities are to be completed in time to support the Phase III Safety Review.

5. FRACTURE CONTROL PLAN

The contractor, or technical leads for in-house projects, shall prepare a Fracture Control Plan. The plan shall be submitted for approval at the PRR and shall be updated in time to support the Phase I Safety Review. The plan shall define responsibilities, criteria, and procedures for the prevention of structural failures associated with the initiation and propagation of flaws or crack-like defects during fabrication, testing, handling, transportation, and operational life. The plan shall contain a tabulation and disposition of all parts to show that they meet fracture control requirements. The plan is to be updated and maintained throughout the life of the program and is to evolve into a complete Fracture Control Report showing all fracture control analyses and inspection results.

6. FRACTURE CONTROL SELECTION AND DISPOSITION OF PARTS

All space flight structures and components shall be examined to determine their fracture control requirements. All parts shall undergo an evaluation as shown in figure 2. The MSFC PCB has final approval authority for selection of the parts subject to the fracture control process.

NOTE: The criteria for selecting parts for fracture control are based on safety rather than mission success. The option for enforcing fracture control based on mission success, i.e., all parts must function within specification, resides with each program manager. Fracture control based on safety is mandatory, whereas fracture control based on mission success is the option of the program manager.

A determination must be made for all parts as to whether or not their structural failure will cause a catastrophic event (first question box in figure 2). Any structural failure must be assumed to lead to a catastrophic event unless it is shown otherwise. The exit "no" path may be chosen for those parts which are clearly low mass, contained/restrained, or fail-safe. The exit "yes" path must be chosen for all other parts. The parts in the "yes" path are termed fracture sensitive and they must be dispositioned by rigorous analyses and/or tests. Each fracture sensitive part must be dispositioned by one of the following methods: Low mass, contained/restrained, fail-safe, damage tolerant, or safe-life.

6.1 LOW MASS

A part is defined as low mass if it can be shown that its mass is sufficiently low so that its release or functional loss due to structural failure will not cause a catastrophic event. In addition for Space Transportation System (STS) payloads, the part must weigh less than or equal to 0.25 pounds.

6.2 CONTAINED/RESTRAINED

A part is defined as contained/restrained if it can be shown by analysis or test that structural failure of the part will not result in separation from the spacecraft or cause a catastrophic event. The containment/restraintment must be accomplished with an ultimate factor of safety of 1.0 and the contained/restrained system must have sufficient fatigue life to complete the mission. In addition, the failure of a part shall not release fragments in violation of 6.1.

6.3 FAIL-SAFE

A part is defined as fail-safe if it can be shown by analysis or test that, due to structural redundancy, the structure remaining after failure of the one part can sustain the new limit loads with an ultimate factor of safety equal to or greater than 1.0 and the remaining structure has sufficient fatigue life to complete the mission. In addition, the failure of a part shall not release fragments in violation of 6.1 or cause a catastrophic event. For multimission spacecraft, a fail-safe part shall be inspected prior to being reflown to ensure that its structural redundancy is intact.

6.4 DAMAGE-TOLERANT

A composite or nonmetallic part other than glass is defined as damage-tolerant if it is demonstrated by tests 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 four complete mission lifetimes. All structures and parts classified as damage-tolerant require nondestructive evaluation (NDE) to the level determined by a damage-tolerant test program.

6.5 SAFE-LIFE

A metallic or glass part is defined as safe-life if it can be shown 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 four complete mission lifetimes. All structures and parts classified as safe-life require a fracture mechanics analysis and NDE to ensure that no flaws (cracks) exist which will grow to critical size in four lifetimes. Two approaches are available to show a part is safe-life. The first is to calculate the critical initial flaw size to survive four lifetimes and inspect to insure that all flaws are less than this size. The second is to inspect to the levels given in reference 9 and use these as the initial flaw sizes in the analysis to show that the part will survive four lifetimes. The approach chosen and its implementation must be included in the fracture control plan and submitted to the FCB for approval.

7. FRACTURE MECHANICS/ANALYSES/TESTS

Analyses and/or tests shall be done on all fracture sensitive parts. As a minimum, these shall consist of analysis or test to show low mass, containment/restraint, fail-safe, damage-tolerant, or safe-life. In cases where analyses are not feasible nor adequate, tests shall be required. All test plans shall be submitted to the MSFC FCB for review and approval before such tests are performed.

7.1 LOW MASS ANALYSES

Low mass analyses shall evaluate the potential for loose low mass parts to cause a catastrophic event. Consideration shall be given to the part's velocity, energy, shape and other components which the part may contact or impact. Analytical methods must be submitted to MSFC for approval.

7.2 CONTAINMENT/RESTRAINT ANALYSES

Containment/restraint analyses shall consider such factors as the velocity and energy of the part, worst case sharpness/minimum area, and the elastic and/or plastic deformation and the resulting stresses in the enclosure/tether. Any analytical methods utilized to show containment or restraint shall be submitted to the MSFC FCB for approval.

7.3 FAIL-SAFE ANALYSES

Fail-safe analyses are to consider the results of failure of each element of the redundant structure. Only one failure at a time must be considered; hazards caused by the failure of two or more parts in series need not be considered. The analysis shall consider the higher loads on the remaining structure caused by [Aredistribution of loads following failure of the part and/or the altered dynamic characteristics of the structure caused by failure of the part.

7.4 DAMAGE TOLERANT TESTS

A damage-tolerant test program shall be implemented for composite structures and nonmetallics other than glass that are not classified as low mass, contained/restrained or fail-safe. These parts shall be shown to be damage-tolerant through a test program to establish that they possess at least four service lifetimes. These tests shall be conducted on full scale flight-like components and samples with controlled flaws or damages. The location of these controlled flaws/damages must be determined by thorough stress analyses or tests and their size and shape must correspond to the detection capability of the NDE to be imposed on the flight part. The flaws/damage used in these tests shall include broken fibers, resin crazing, delaminations, and cracks, particularly in regions of stress concentration.

7.5 SAFE-LIFE ANALYSES

Fracture mechanics analysis shall be performed on all safe-life parts to demonstrate that the maximum size flaw or crack-like defect that could exist after proof testing and/or NDE will not grow to critical size in four complete lifetimes. Current state-of-the-art fracture mechanics analytical techniques shall be used. These methods shall be presented to the MSFC FCB for approval at PRR. Flaws shall be assumed in the most critical location and orientation. All crack shapes in the range of $0.1 \leq a/2c \leq 0.5$ (where a is the crack depth and $2c$ is the surface crack length) shall be considered. The material property data requirements to be used in the safe-life analysis is given in section 11.1. Stress concentration factors shall be included, when appropriate, in the mean and cyclic stresses. The load spectra requirements to be considered are given in section 16. Data from flight tests shall be analyzed to improve the prediction of maximum service stresses, environmental spectrum, and critical flaw sizes. Any benefits of crack growth retardation shall not be considered without approval of the MSFC FCB.

For components where it is necessary to consider the propagation of a crack into a fastener hole or away from a fastener hole toward the edge of a panel or plate, the following analysis assumptions shall be implemented.

- a. When a crack grows to a hole or panel/plate edge, its length increases immediately by an amount equal to the diameter of the hole.
- b. The predictive life analysis is then continued using the new crack length that includes the hole diameter.
- c. The component's total life is obtained by summing the load cycles prior to and subsequent to reaching the hole or panel/plate edge.

8. PRESSURE VESSELS AND ROTATING MACHINERY

Pressure vessels and rotating elements are given special attention by the FCB due to the potential for catastrophic failure. The FCB may require a safe-life analysis and NDE for these items even if they are contained or fail-safe. These items must be described and presented to the FCB for disposition as shown in figure 2.

These items shall have a complete fracture mechanics analysis or damage-tolerant test program and be proof tested per section 15.4. In cases where proof testing does not screen all areas of the item, internal and surface NDE must be done during the fabrication process. The compatibility of fluids

used in cleaning, test, and operation of pressure vessels or rotating elements shall be ensured. These items which experience sustained stresses shall have an applied stress intensity during operation less than the stress corrosion threshold stress intensity in the appropriate environment or analyses must show that the items will not fail during four times the time interval that the items are under load.

9. FASTENERS

Fasteners must be dispositioned for fracture control purposes per the standard structure requirements of this document. In addition, the following requirements apply.

A safe-life fastener shall be shown by analysis and/or test to meet four lifetimes when assumed to contain a crack size screened by the methods of MSFC-STD-1249. Fasteners with machined threads shall be etched prior to penetrant inspection. Fasteners smaller than 3/16-inch in diameter shall not be used in fracture critical applications.

10. DESIGN

All fracture sensitive parts shall be designed using sound and established design practices. These practices shall include the following:

- a. Minimizing eccentricities and stress concentrations that could act as fatigue crack initiators.
- b. Providing access, conditions, and clearance to implement inspection, test, and maintenance.
- c. Selecting materials and their design operating stress levels so that the required life for a given component can be verified by analysis and available NDE techniques/proof test.
- d. Selecting materials such that problems with stress corrosion (reference 10), hydrogen embrittlement, environmental effects, temper embrittlement, creep, general and galvanic corrosion, radiation damage, and eutectic melting are prevented or minimized.
- e. Providing contained/restrained or fail-safe designs where practical. Any part of a redundant structure which may be loose after failure (such as a fastener) shall meet the requirements of 6.1.
- f. Fracture critical (damage tolerant or safe-life) parts shall be clearly identified in all design documents (engineering drawings, EO's, etc.) and shall be identified by serial number to facilitate accumulation and retrieval of fracture control information by part, material, and process. All fracture

critical parts shall be identified on the engineering drawings and NDE requirements specified in the drawing notes. A summary listing of all fracture critical parts subject to fracture control shall be maintained and distributed to the members of the FCB.

11. MATERIALS AND PROCESSES

Fracture control considerations shall be an integral part of the material and processes task to ensure that the characteristics of the selected material are adequately defined and are available on a timely basis to support the structural analysis. Materials shall meet the requirements of references 8 and 10. In addition to normal functional requirements, material characteristics to be considered include:

a. Fracture toughness and other fracture related properties such as flaw growth rate, threshold stress intensity, stress corrosion cracking susceptibility, effects of fabrication and joining processes, and effects of temperature and other environmental considerations.

b. The adequacy and validity of data for candidate materials under particular usage requirements.

c. The effects of processes, geometric configuration, fiber or grain orientation, and manufacturing tolerances on flaw initiation and growth.

d. Selection of nonsensitive materials and/or providing for environmental control to prevent stress corrosion, dissimilar metal corrosion, and other environmental effects leading to crack nucleation or growth.

e. For composite structures, particularly nonmetallic composites, the fracture toughness of the actual build-up shall be evaluated through testing and/or analysis as appropriate. This evaluation shall consider any and all types of crack-like defects inherent to composite structures such as voids, broken fibers, resin crazing, delaminations, and cracks in the composite, particularly in regions of stress concentration.

11.1 MATERIAL PROPERTIES FOR FRACTURE MECHANICS ANALYSES

The lower-bound values of stress-corrosion-cracking threshold data shall be used in fracture mechanics analysis. Fracture toughness data used for safe-life analysis shall be the average values obtained from the literature or actual testing. If a proof test is used for initial-flaw-size screening, the upper-bound toughness values shall be used to determine the proof test factor.

Average crack growth rate data may be used for crack growth calculations. When the data sources are particularly sparse, conservative estimates of the crack growth rate shall be assumed and documented. All crack growth rate data used shall correspond to the actual temperature and chemical environments that are to be encountered or shall be conservative with respect to the actual environments.

11.2 PREPARATION OF MATERIAL SPECIFICATIONS

Material specifications shall be prepared when fracture property data requirements are not adequately defined by existing Government or industry specifications. The specifications shall incorporate any special requirements for fracture control. It shall also specify test method, test specimen configuration, and material sampling requirements to verify compliance with these requirements. Requirements for special environmental control of fracture sensitive parts during inactive periods of operational service (maintenance, standby, inspection, and storage) shall be determined to prevent general corrosion and stress-corrosion cracking.

The material specification shall include any special nondestructive evaluation techniques and inspection standards to be used to verify the quality of the mill product.

Fracture properties used in the materials selection process and their sources shall be documented and maintained.

Test programs to determine the fracture properties of materials when sufficient data do not exist shall be implemented.

Material suppliers shall be surveyed before procurement to evaluate their ability to produce materials that meet fracture control requirements.

11.3 TOOLING

The designs for tooling, fixtures, and manufacturing aids used on fracture critical parts shall be reviewed for compatibility with fracture control requirements and objectives. Fracture control aspects to be considered in the design of tooling, fixtures, etc., shall include the following:

a. Protection of components from damage during hoisting, positioning, transporting, etc.

b. Elimination or minimizing or residual stresses during processing.

c. Maintenance of satisfactory and consistent control over critical process variables that are a function of the tooling, such as diffusion-bond tooling, welding chill, and backup bars.

d. Maintenance of tolerances and meeting of surface finish requirements.

12. NONDESTRUCTIVE EVALUATION (NDE)

All fracture critical parts shall be subjected to NDE to screen for flaws and crack-like defects. NDE employed shall be in accordance with reference 9. The NDE shall provide a 90 percent probability and a 95 percent confidence of the nonexistence of flaw sizes greater than the specified inspection levels. Data that permit the confidence of flaw detection to be expressed quantitatively, with a statistical basis, shall be made available to the MSFC FCB. NDE shall be done to detect both internal and external flaws. Generally the optimum internal flaw inspections are obtained on the raw stock before the part is made. The finished parts shall be NDE'd to assure that surface flaws greater than the specified size do not exist. All fracture critical parts shall be identified on the engineering drawings along with the flaw size inspection criteria for internal and surface flaws.

In accordance with reference 9, personnel conducting NDE shall be certified per MIL-STD-410. Personnel engaging in NDE techniques other than those defined in MIL-STD-410 shall demonstrate their capability to effectively perform that technique.

Etching of parts prior to penetrant inspection shall be implemented on mechanically disturbed metallic surfaces to remove smeared masking materials. Previously etched and penetrant-inspected surfaces not subsequently mechanically disturbed require only chemical cleaning prior to reinspection by the penetrant method. Unaided visual inspection and visual inspection aided only by magnification shall not be used for screening cracks. However, for transparent optical elements such as windows and lenses, visual inspection with 10X or higher magnification is considered reliable for detecting surface and embedded flaws of lengths greater than 0.1 inch when proper lighting is applied at right angles to the critical flaw orientation.

Proof test may be used with MSFC FCB approval as an NDE enhancement or as a method for screening flaws. Proof test shall meet the requirements of section 15.4.

Flaws greater than the critical initial flaw size are not allowed under any circumstances. Detected flaws less than critical initial flaw size shall be recorded then repaired and/or dispositioned by MRB action.

13. SAFETY, RELIABILITY, AND QUALITY ASSURANCE

It shall be verified that material, production processes, and parts conform to the fracture control requirements. Source and/or receiving inspection shall be conducted on all raw materials procured for use in the fabrication of fracture critical hardware. Tests, as required, shall be conducted to ensure compliance with materials processing specification requirements and to ensure that line inspection points and methods are adequately established to verify all significant processing steps for fracture critical parts. Pertinent properties, measured as a part of inspection requirements, shall be maintained and kept available for review. Significant fracture data on production operations of fracture critical parts shall be collected and maintained to determine which inspection points shall be adjusted during the remainder of the production program.

13.1 PERSONNEL CERTIFICATION

Any special qualification levels required to ensure that critical operations are performed and that skills match fracture control requirements shall be identified. Personnel engaged in nondestructive inspection of fracture control items shall be qualified in accordance with MIL-STD-410D.

13.2 SAFETY, RELIABILITY AND QUALITY REVIEW AND REPORTING

Inspection data indicating nonconformance with specifications associated with fracture critical parts shall be compiled and reported to the Fracture Control Board. A summary assessment shall be prepared and reported to the Fracture Control Board. These data shall include the following:

- a. Incidence of material defects, including range of size, character, location, and cause.
- b. Incidence of weld defects including size, location, and cause.
- c. Incidence of flaws caused by fabrication processes.
- d. Departures from required values for fracture toughness, mechanical properties, critical dimensions, and surface finishes.

13.3 FAILURE DOCUMENTATION

A complete documentation shall be made of fracture significant failures involving fracture critical components during manufacture, qualification testing, and acceptance testing. Other parts that fail should be assessed for fracture control. The cause of failure and any contributing factors shall be documented to the extent possible, and the document shall include recommendations for corrective actions required in the control of material procurement, fabrication processes, quality assurance methods, or operational procedures.

A report of failure evaluation results and recommended corrective action shall be prepared and disseminated to the Fracture Control Board.

A metallurgical failure analysis based on flaw topology, material microstructure, and other supporting laboratory investigations shall be provided where necessary to identify the cause of failure.

13.4 TRACEABILITY

Traceability is required to assure that the materials used in the construction of hardware have properties equivalent to those used in the analysis or verification tests and to identify faulty hardware when a problem is discovered in a fabricated part. Traceability is required for all fracture critical parts and shall include the following:

a. Each item (part, subassembly, assembly) requires a unique serial number (S/N), marked directly on the item or in the accompanying data package.

b. Engineering drawings and specifications shall include S/N and traceability requirements.

c. Materials shall be certified by test or inspection to meet all of the specified requirements. Traceability to manufacturer's heat or lot number and to records of subsequent processing (e.g., heat treatment and mix records) shall be maintained at all stages of fabrication and assembly for each S/N item.

13.5 ACTUAL SERVICE ACCUMULATION

An accurate record of actual service experience shall be maintained for each fracture sensitive part to permit early

identification of problem areas and development of corrective action for the remainder of the operational articles. All elements of the load spectra as given in section 16 shall be considered in this record.

14. ENVIRONMENTAL CONTROL

Requirements for special environmental control of fracture sensitive components during inactive periods of operational service (maintenance, standby, inspection, and storage) shall be implemented to protect against environmental effects on parts. Particular attention shall be devoted to any areas that are inaccessible for inspection during normal inactive periods. Responsibility for implementation of special environmental controls during inactive periods of operational service shall depend on specific contractual requirements of the program.

15. TESTS

Structural testing of fracture sensitive parts, when required, shall be done in a manner compatible with fracture control requirements.

15.1 FRACTURE CONTROL/VERIFICATION TESTS

Damage-tolerant tests shall be done in accordance with section 7.4. In other cases where analysis is insufficient to provide confidence that the structure meets fracture control requirements, verification testing shall be required.

15.2 STRUCTURAL STRENGTH QUALIFICATION TESTS

Data obtained through structural strength qualification tests shall be reviewed to determine if changes to design or materials of fracture sensitive parts are required. Where possible, test loading and environmental simulation shall reproduce critical design conditions established for fracture sensitive parts.

Anticipated critical sections of fracture sensitive parts or components shall be identified prior to start of testing. These sections shall be given particular attention during the test to identify crack propagation characteristics and rates.

15.3 SERVICE TESTING

Fracture control requirements shall be considered in the planning of in-service structural tests and/or evaluation programs.

The resulting test data shall be evaluated and its impact on the fracture control program determined.

15.4 PROOF TESTING

Current state-of-the-art fracture mechanics analytical techniques shall be used in establishing proof test requirements.

Proof testing of all pressure vessels and rotating machinery is mandatory. Other proof test requirements are:

- a. For tankage wherein conventional proof testing (i.e., pressure loading only) does not include all critical flight-load conditions, a combined pressure and external loading test shall be conducted unless it can be demonstrated to be unnecessary because of adequate NDE.
- b. Proof testing of unpressurized and nonrotating structures may be done if the proof test adequately screens flaws to guarantee four service lifetimes or if proof testing is required to enhance inspectability and/or reliability.
- c. Pre- and posttest NDE must be done when flight articles are proof tested. Exceptions to the postproof test NDE requirement may be considered provided appropriate substantiating data is submitted to the FCB for approval.
- d. The proof test factor shall be the larger of the values determined by fracture mechanics analysis/proof test requirements to meet service life or those specified in the factor of safety requirements (reference 7).
- e. Proof testing shall be performed in the actual expected environment (temperature and media) when feasible. When this is not feasible, environmental correction factors shall be used to adjust the values in d above.
- f. In no case shall the adjusted proof test factor be less than 1.05 without MSFC approval.
- g. Factors of safety must be chosen so that proof testing will not subject the flight article to detrimental deformations beyond the elastic limit.

16. LOADS SPECTRA

Loads spectra shall be developed to specify the load levels, the number of cycles at each level, and the order of occurrence for each event that the structural parts will experience. The events considered shall include fabrication, testing, transportation, handling, lift-off, ascent, on-orbit, descent, landing, and postlanding events. Loads considered are to include both low and high cycle fatigue, sustained, preloads, residual, and assembly loads. Sources considered for these loads

shall include mechanical, thermal, pressure, and atmospheric sources. All loads spectra applicable to a part shall be arranged and superimposed in the order in which they occur to constitute one lifetime for that part. Four of these lifetimes shall be used in the damage-tolerant tests and safe-life analysis described in sections 7.4 and 7.5.

17. DOCUMENTATION

As stated in section 5, the Fracture Control Plan is to evolve into a Fracture Control Report. This report must demonstrate that the spacecraft meets the fracture control requirements of this document. As a minimum, the report shall include:

a. A list of all parts along with their disposition for fracture control.

b. Fracture control components shall have detailed sketches defining the material, material process specifications, regions of maximum stress, direction of maximum stress, and size, character, and orientation of initial flaws that must be detected during inspection.

c. The design material mechanical properties, fracture toughness, cyclic crack growth rates, threshold stress intensity, and stress-corrosion cracking susceptibility.

d. The nature and extent of coupon sample tests used to verify the design material properties for the materials, when applicable.

e. The stress analysis results that led to the definition of the fracture sensitive components and the rationale for exclusion of the remainder of the structure; the cyclic flaw growth predictions; where pertinent, the crack arrest techniques; and the analysis that predicts the structural suitability of the design for the total service life.

f. The NDE methods and results for raw material stock from the supplier through sizing, machining, forming, welding, fastening, and assembly operations. Rationale for acceptance of any detected flaws.

g. Current records of the loads imposed upon the structure.

h. The repair techniques employed in welds or parent material.

i. Method of fracture control implementation.

- j. Description of responsibilities.
- k. Low mass analyses.
- l. Containment/restraintment analyses.
- m. Fail-safe analyses.
- n. Damage-tolerant tests results.
- o. Safe-life analyses.
- p. Record keeping for safety, reliability, and quality assurance provision including traceability, service accumulation and failure documentation.
- q. Methods of meeting environmental control.
- r. Structural/proof test descriptions and results.

In addition to the above, the report shall contain a summary for each fracture sensitive part that shall include:

- a. Sufficient diagrams and sketches that clearly show where and how the part is used in subassemblies and assemblies so the part function is clearly described (figures 3a and 3b).
- b. A summary of the fracture control analytical and NDE results for the assembly (subassembly) described in a above. This summary shall include (figure 3c):

- (1) Part name.
- (2) Part number.
- (3) Part size, i.e., size used in the fracture control analysis or tests.
- (4) Material and condition.
- (5) Flaw depth, length, and type upon which analysis or test is based. Acronyms for crack type may be the choice of the contractor and shall be defined in the notes. Low mass, contained/restrained, or fail-safe items are identified under these columns as such.
- (6) Type of NDE done on the part. Acronyms for type of NDE shall be per reference 9.
- (7) Lifetime based on level of NDE done on the part. The lifetime must be four or greater. If the lifetime is exactly

four then the flaw size is the critical initial flaw size. For fail-safe or constrained/restrained items, lifetime is the fatigue life remaining in the failed-safe or contained/restrained condition.

(8) The maximum stress which occurs in the load spectra. For fail-safe and contained/restrained items this stress is for the failed-safe or contained/restrained condition.

(9) The ultimate safety factor (S.F.) which corresponds to the maximum stress.

(10) The key refers to a location on the part where the flaw is assumed to be located. This key is identified on subsequent diagrams of the part.

c. A set of keyed diagrams and sketches that show flaw locations (see b.10 above) and part dimensions (figures 3.d. through 3.h.).

The latest version/update of the summary data described above shall be included in each presentation to the FCB.

18. REFERENCES

The following documents of the latest released version form a part of this document to the extent specified herein.

Other listed documents not referenced herein are given to provide background information only.

1. NHB 1700.7A Safety Policy and Requirements For Payloads Using the Space Transportation System (STS)
2. NHB 8071.1 Fracture Control Requirements for Payloads Using the Space Transportation System (STS)
3. NASA SP 8095 Fracture Control of Space Shuttle Structures
4. NASA SP 8040 Fracture Control of Metallic Pressure Vessels
5. NSS/HP-1740.1 NASA Aerospace Pressure Vessel Safety Standard
6. MIL-STD-1522A Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
7. MSFC-HDBK-505A Structural Strength Program Requirements
8. MSFC-STD-506B Standard Materials and Processes Control
9. MSFC-STD-1249 Standard NDE Guidelines and Requirements for Fracture Control Programs
10. MSFC-SPEC-522A Design Criteria for Controlling Stress Corrosion Cracking

19. DEFINITIONS

Catastrophic Event - An event which results in the loss of life, personal injury, or vehicle destruction.

CDR - Critical Design Review.

Contained/Restrained - See Section 6.2.

Crack 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.

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

Critical Initial Flaw Size - The maximum preexisting flaw size for which the part would survive exactly four lifetimes.

Damage-Tolerant - See section 6.4.

DCR - Design Certification Review

Fail-Safe - See section 6.3.

Flaw - See crack or crack-like defect.

Fracture Control - The rigorous application of those branches of engineering, assurance management, manufacturing, and operations technology dealing with the understanding and prevention of crack propagation leading to catastrophic failure.

Fracture Control Plan - A plan for establishing responsibilities, criteria, and procedures for the prevention of structural failures associated with the initiation and propagation of flaws or crack-like defects. The plan evolves with program maturity into a Fracture Control Report.

Fracture Control Report - A report which demonstrates that the spacecraft meets the fracture control requirement of this document. The report evolves from the Fracture Control Plan.

Fracture Critical Part - A part that is classified as damage-tolerant or safe-life.

Fracture Mechanics - An engineering concept used to predict fracture and flaw-growth behavior in materials and structures under load.

Fracture Sensitive Part - Those parts which require as a minimum, analysis and or test to satisfy fracture control requirements. Fracture sensitive parts must be dispositioned as low mass, contained/restrained, fail-safe, damage-tolerant, or safe-life.

Fracture Toughness - An inherent material property which describes the resistance to fracture.

Lifetime - The total load history that a part will be exposed to, including load level and number of cycles. This history may include loadings due to fabrication, testing, transportation lift-off, ascent, on-orbit, descent, landing, and postlanding events.

Limit Load or Stress - The maximum load or stress expected to act on a structure in the expected operating environments including fabrication, testing, transportation, ground handling, and flight.

Load Spectrum - A representation of the cumulative static and dynamic loadings including load level and number of cycles anticipated for a structural component or assembly under all expected operating, transportation, testing, manufacturing, and flight environments.

Low Mass - See Section 6.1.

MRB - Material Review Board

Nondestructive Evaluation (NDE) - Inspection techniques that do not cause physical or chemical changes to the part being inspected, or otherwise impair its adequacy for operational service, and that are applied to materials and structures to verify required integrity and detect characteristic flaws. NDE method refers to the specific technique used such as dye penetrant, x-ray, etc.

PDR - Preliminary Design Review.

Pressure Vessel - Any component designed for the storage of pressurized gases or liquids.

Proof Factor - A multiplying factor applied to either limit load or limit pressure to obtain either proof load or proof pressure.

Proof Test - The test which a part must sustain to give evidence of satisfactory workmanship and material quality. Proof test load is the product of maximum operating load times the proof factor.

PRR - Preliminary Requirements Review.

Residual Stress - A stress that exists in a structure as manufactured, due to processing, fabrication, or prior loading.

Rotating Machinery - Any rotating part whose fracture could result in a catastrophic event.

Safe-Life - See section 6.5.

Service Life - One lifetime.

Service Life Factor - A factor of four times the complete mission lifetime including all the cyclic and sustained loads and environments encountered during fabrication, testing, transportation, lift-off, ascent, on-orbit, descent, landing, and postlanding events, as applicable. This factor accounts for the uncertainties in the observed measured material crack growth properties and fracture mechanics analysis, and shall be applied to all mission phases in the damage-tolerant tests and safe-life analyses.

STS - Space Transportation System.

Traceability - A procedure for identifying the complete history of a part with regard to material and property verification, fabrication, testing, use, and deviation from specification.

Ultimate Factor of Safety - A specified factor which when multiplied by the limit load results in a product which must be less than or equal to the ultimate strength.

Ultimate Strength - The maximum load (or stress) that an unflawed structure can withstand without incurring rupture or collapse.

Yield Factor of Safety - A specified factor which when multiplied by the limit load results in a product which must be less than or equal to the yield strength.

Yield Strength - The maximum load (or stress) that an unflawed structure can withstand without incurring material yielding.

ORGANIZATION	FUNCTIONS/RESPONSIBILITIES
<div style="border: 1px solid black; padding: 2px; display: inline-block;"> MSFC FRACTURE CONTROL BOARD </div>	<ul style="list-style-type: none"> • OVERSEES AND APPROVES ALL FRACTURE CONTROL ACTIVITIES FOR <u>ALL</u> MSFC PROJECTS • BOARD MEMBERS PROVIDE INTERFACE WITH PARENT ORGANIZATION
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="border: 1px solid black; padding: 2px; display: inline-block; width: 15%;"> PROJECT OFFICE </div> <div style="border: 1px solid black; padding: 2px; display: inline-block; width: 25%;"> CHIEF ENGINEER'S OFFICE </div> <div style="border: 1px solid black; padding: 2px; display: inline-block; width: 20%;"> TECHNICAL LEADS </div> </div> <ul style="list-style-type: none"> • STRESS • DESIGN • LOADS • MATERIALS • NDE • SAFETY, RELIABILITY, MAINTAINABILITY, QUALITY 	<ul style="list-style-type: none"> • OVERSEE AND IMPLEMENT FRACTURE CONTROL FOR A <u>PARTICULAR</u> PROJECT • SCHEDULE AND SUPPORT FCB MEETINGS • INSURE THAT DAY-TO-DAY FRACTURE CONTROL ACTIVITIES ARE IN COMPLIANCE WITH THIS DOCUMENT • INTERFACE WITH COUNTERPARTS AT CONTRACTOR FACILITIES

FIGURE 1. RELATIONSHIP OF THE MSFC FRACTURE CONTROL BOARD TO OTHER MSFC ORGANIZATIONAL ELEMENTS

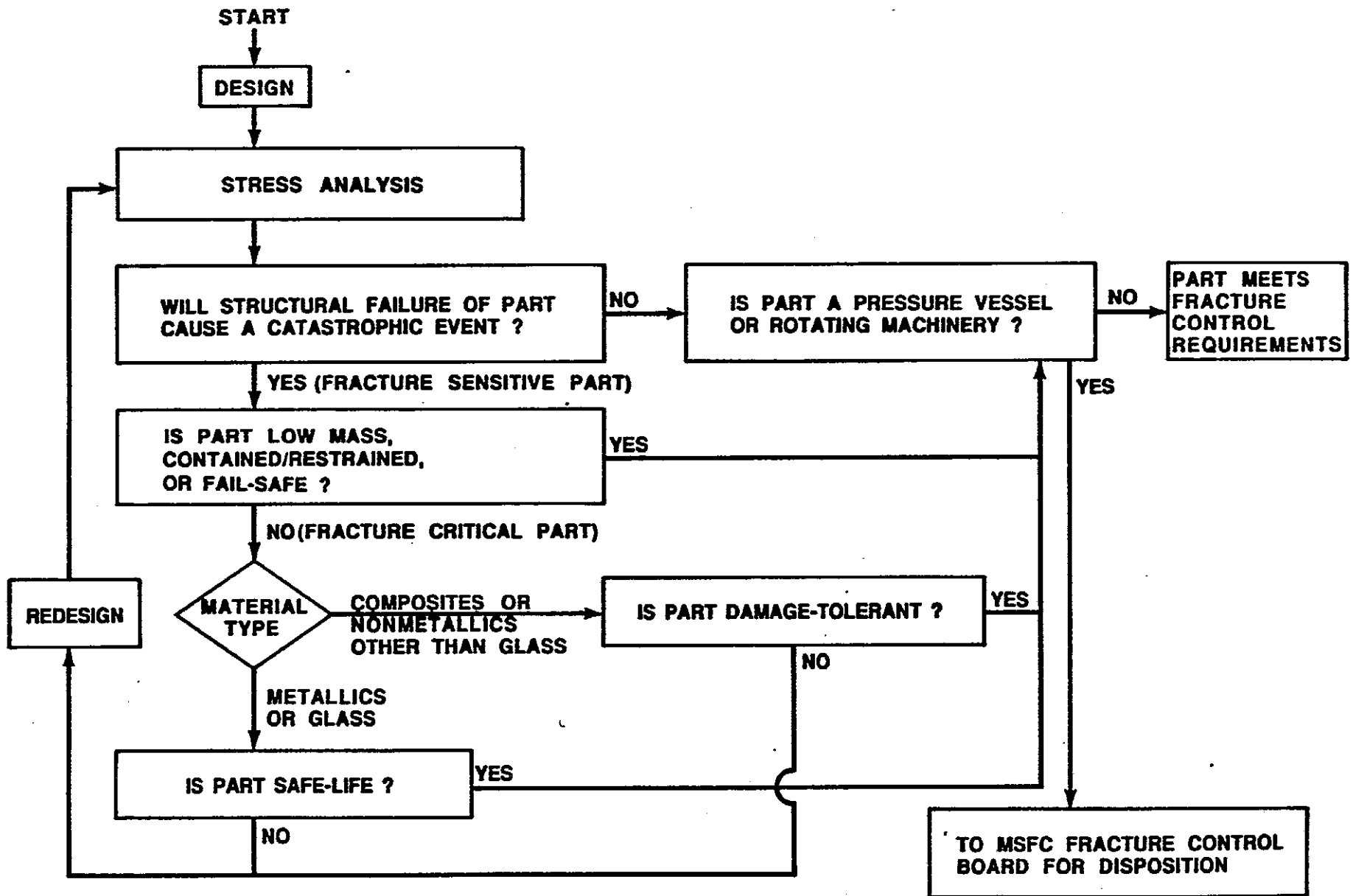


FIGURE 2. FRACTURE CONTROL SELECTION AND DISPOSITION OF PARTS

KINEMATIC MOUNT LOCATIONS

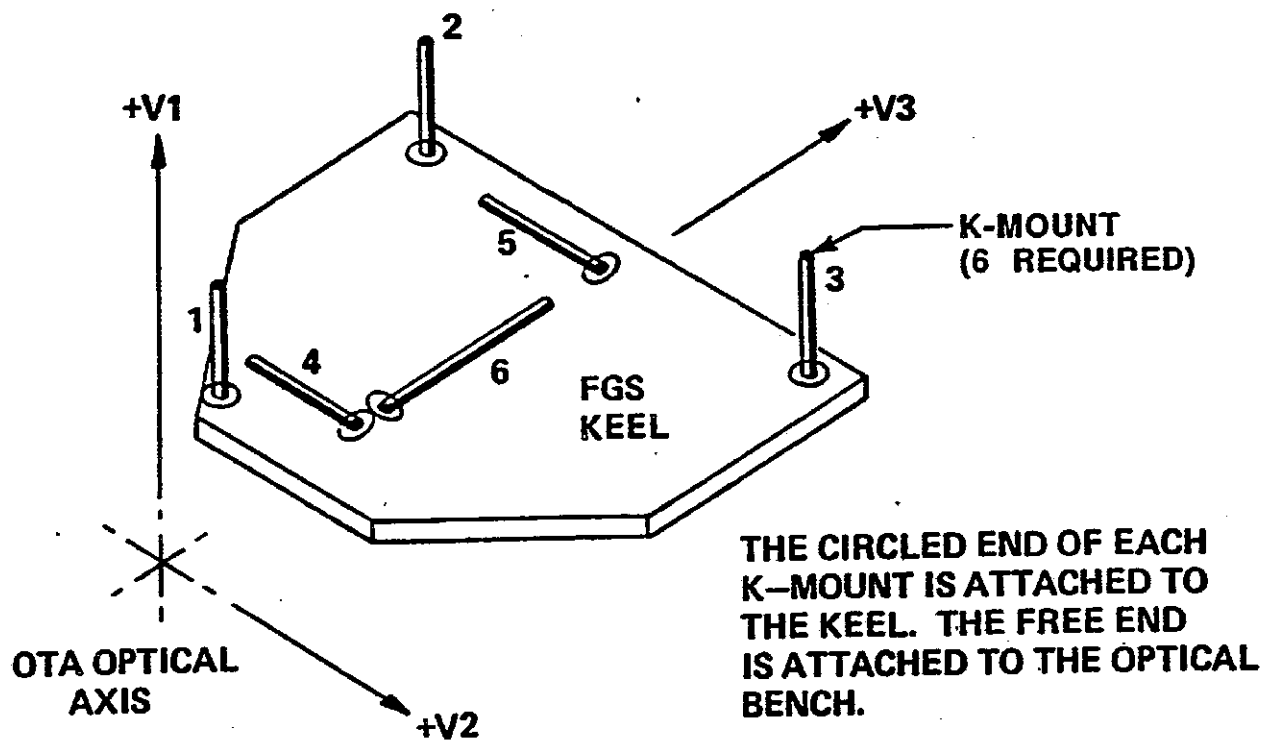
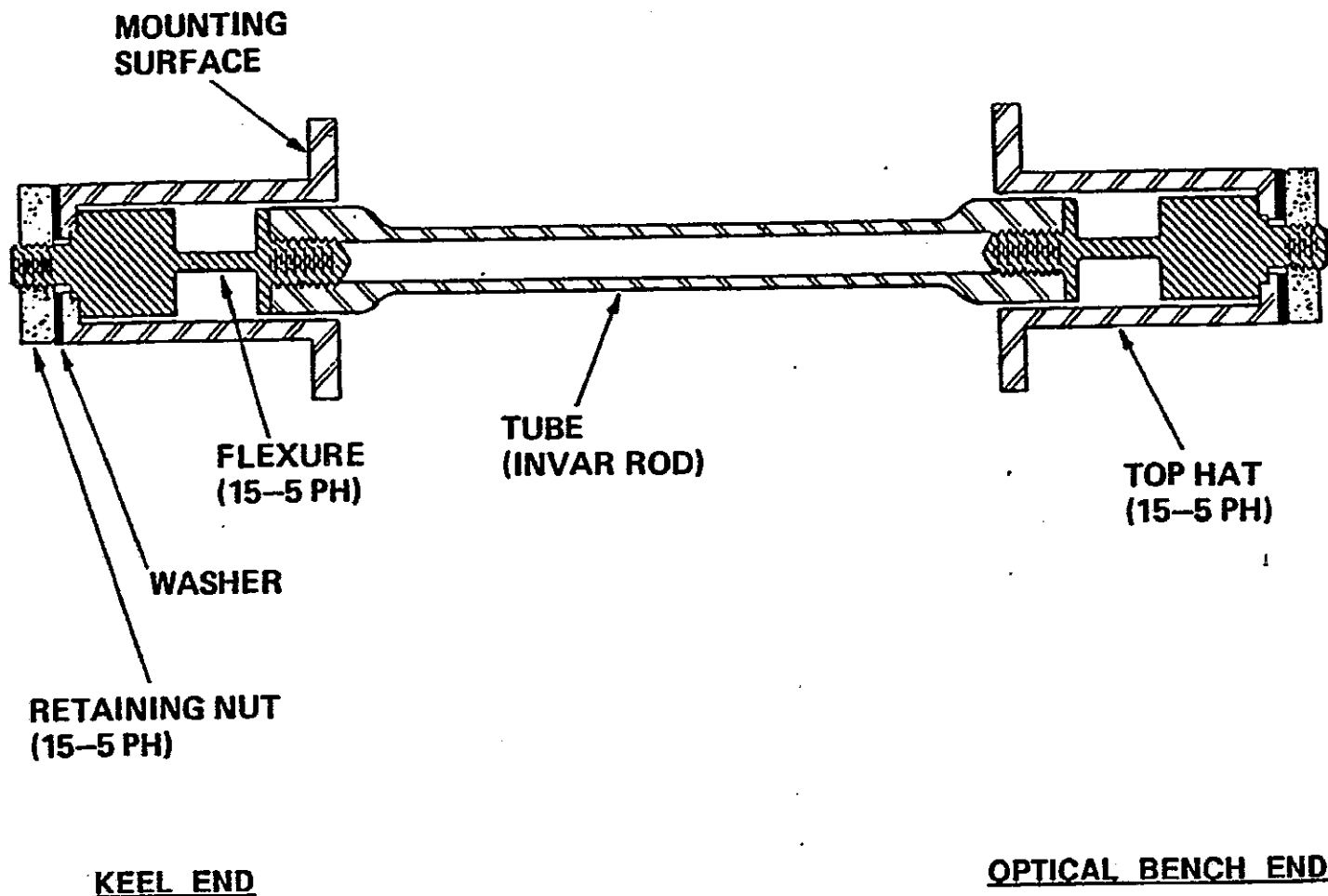


FIGURE 3a. SAMPLE DATA REQUIREMENT. DESCRIPTION OF KINEMATIC MOUNT (K-MOUNT, KM) LOCATIONS. KINEMATIC MOUNTS ARE ITEMS FOR WHICH FRACTURE CONTROL RESULTS ARE TO BE SHOWN.

KINEMATIC MOUNT SUBASSEMBLY



24b

FIGURE 3b. SAMPLE DATA REQUIREMENT. DESCRIPTION OF KINEMATIC MOUNT SUBASSEMBLY

ASSEMBLY OPTICAL TELESCOPE ASSEMBLY (OTA)
SUBASSEMBLY FINE GUIDANCE SENSOR KINEMATIC MOUNTS

(KINEMATIC MOUNT #1)

PART NAME	PART NUMBER	PART SIZE (IN)*	MATERIAL	FLAW			TYPE NDE DONE	LIFE- TIME	STRESS (KSI)	S.F. KEY
				DEPTH (IN)	LENGTH (IN)	TYPE				
TOP HAT (OPTICAL BENCH END)	679-3495	t = 0.0625 w = 2.259	15-5PH ST. ST. AMS 5659 H-1025	0.0625	0.34	TC	UT ET	4	18.0	8.6 A
TOP HAT (KEEL END)	679-7249	t = 0.0625 w = 2.259	15-5 PH ST.ST. AMS 5659 H-1025	0.0625	0.34	TC	UT ET	4	18.0	8.6 B
TOP HAT FASTENERS	NAS1351N3	d = 0.1497	A-286 ST.	0.041	0.4703	C	UT ET	4	30.9	5.2 C
TUBE	679-3497	t = 0.117 w = 0.836	INVAR 36	0.117	0.31	TC	UT ET	4	20.4	3.2 D
FLEXURE (THREADED END)	679-3496	d = 0.2591	15-5 PH ST.ST. AMS 5659 H-1025	0.031	0.814	C	UT ET	4	22.1	7.0 E
FLEXURE (PLATE END)	679-3496	t = 0.10 w = 0.5937	15-5 PH ST.ST. AMS 5659 H-1025	0.038	0.038	PTE	UT ET	4	19.7	7.9 F
NOTES: *SIZE USED IN FRACTURE MECHANICS MODEL, t x w, DIAMETER, ETC. TC = THROUGH CENTER C = CIRCUMFERENTIAL AT THREAD ROOT PTE = PART-THROUGH EDGE				UT = ULTRASONIC ET = EDDY CURRENT						

FIGURE 3c. SAMPLE DATA REQUIREMENT. DESCRIPTION OF ANALYTICAL AND NDE RESULTS.

TOP HAT (OPTICAL BENCH END) KM # 1

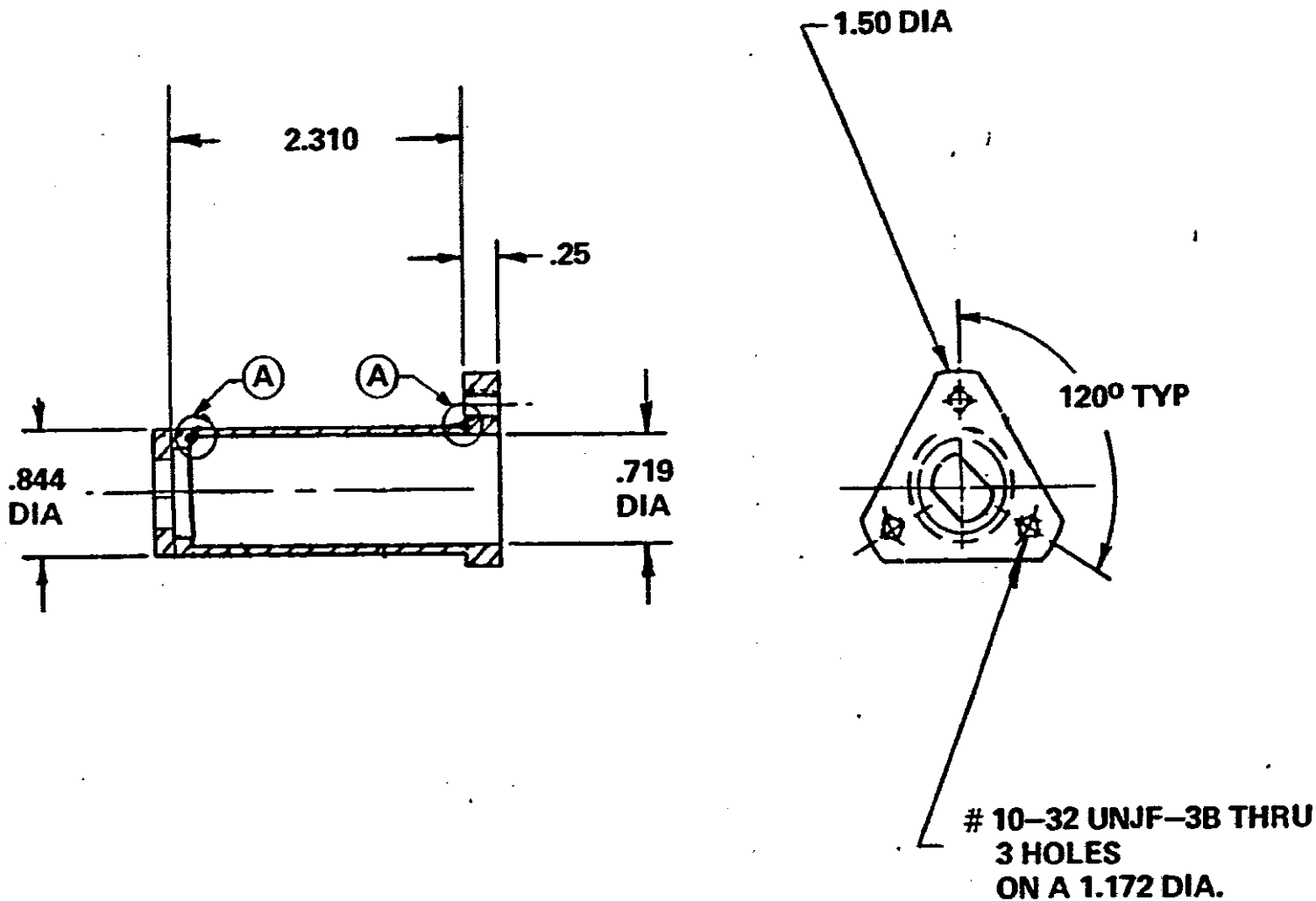


FIGURE 3d. SAMPLE DATA REQUIREMENT. FLAW AT LOCATION "A", KEYED TO FIGURE 3c.

**TOP HAT (KEEL END)
KM # 1**

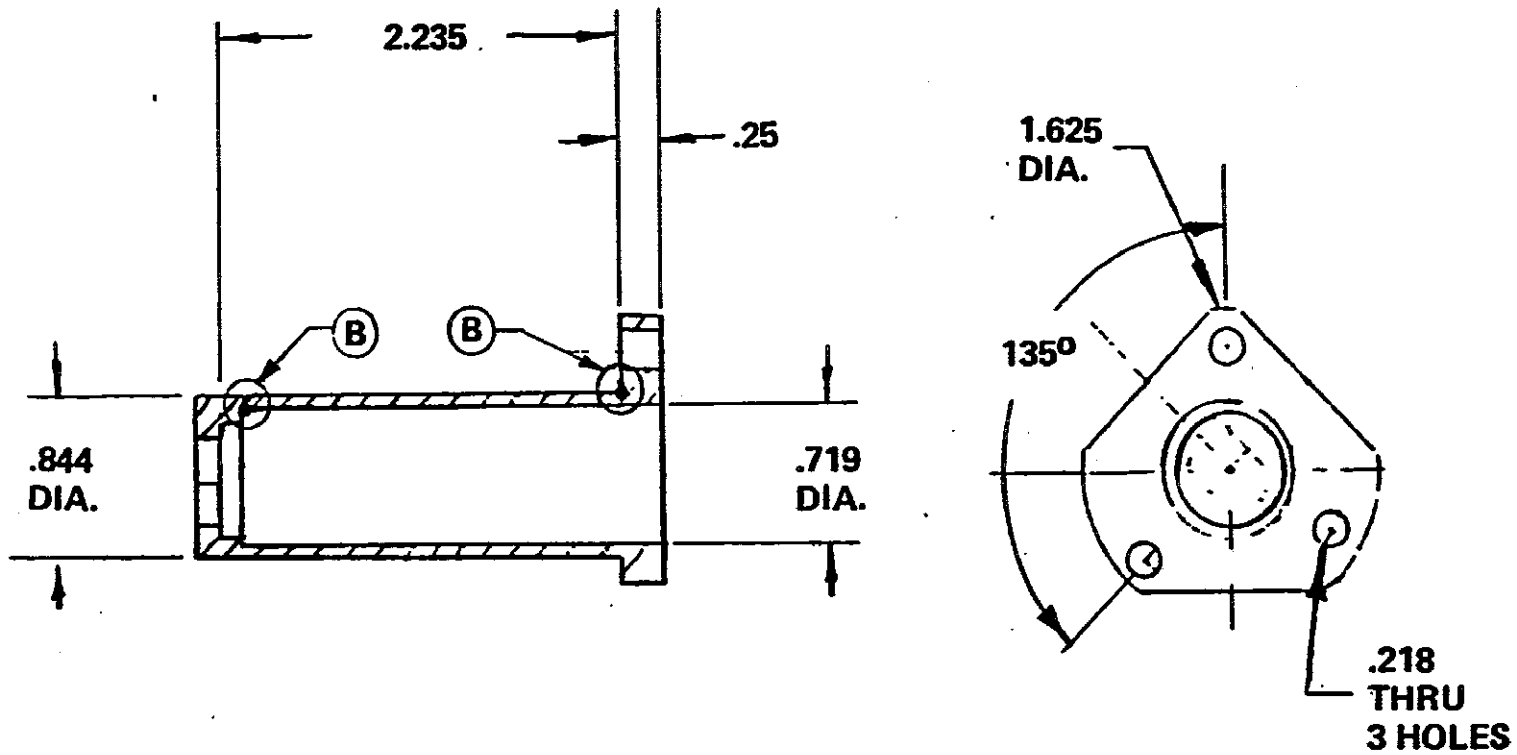
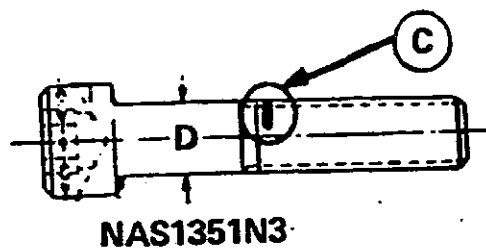


FIGURE 3e. SAMPLE DATA REQUIREMENT. FLAW AT LOCATION "B" KEYED TO FIGURE 3c.

TOP HAT FASTENER KM #1



24F

FIGURE 3f. SAMPLE DATA REQUIREMENT. FLAW AT LOCATION "C" KEYED TO FIGURE 3c.

TUBE KM #1

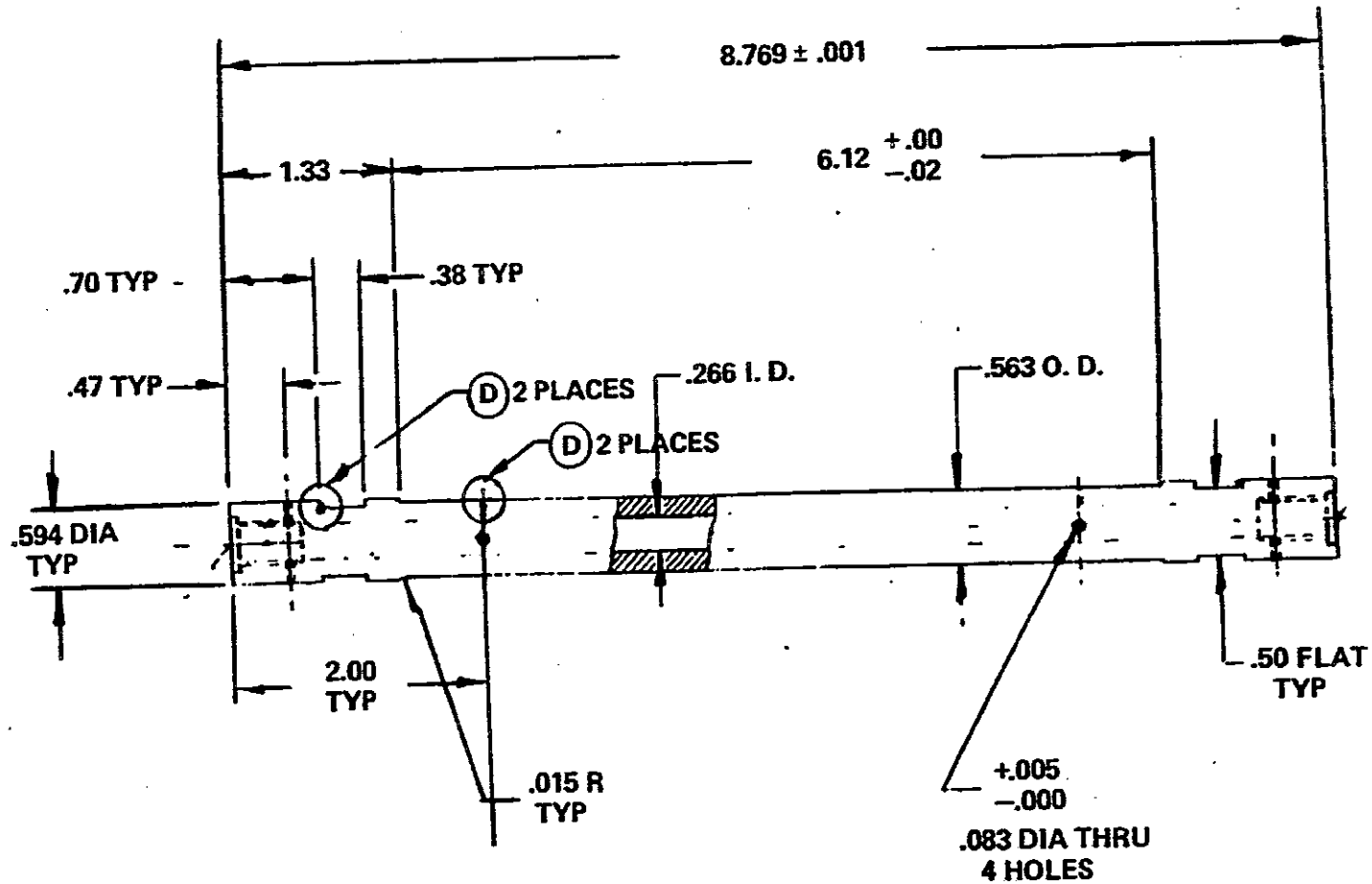


FIGURE 3g. SAMPLE DATA REQUIREMENT. FLAW AT LOCATION "D" KEYED TO FIGURE 3c.

FLEXURE KM #1

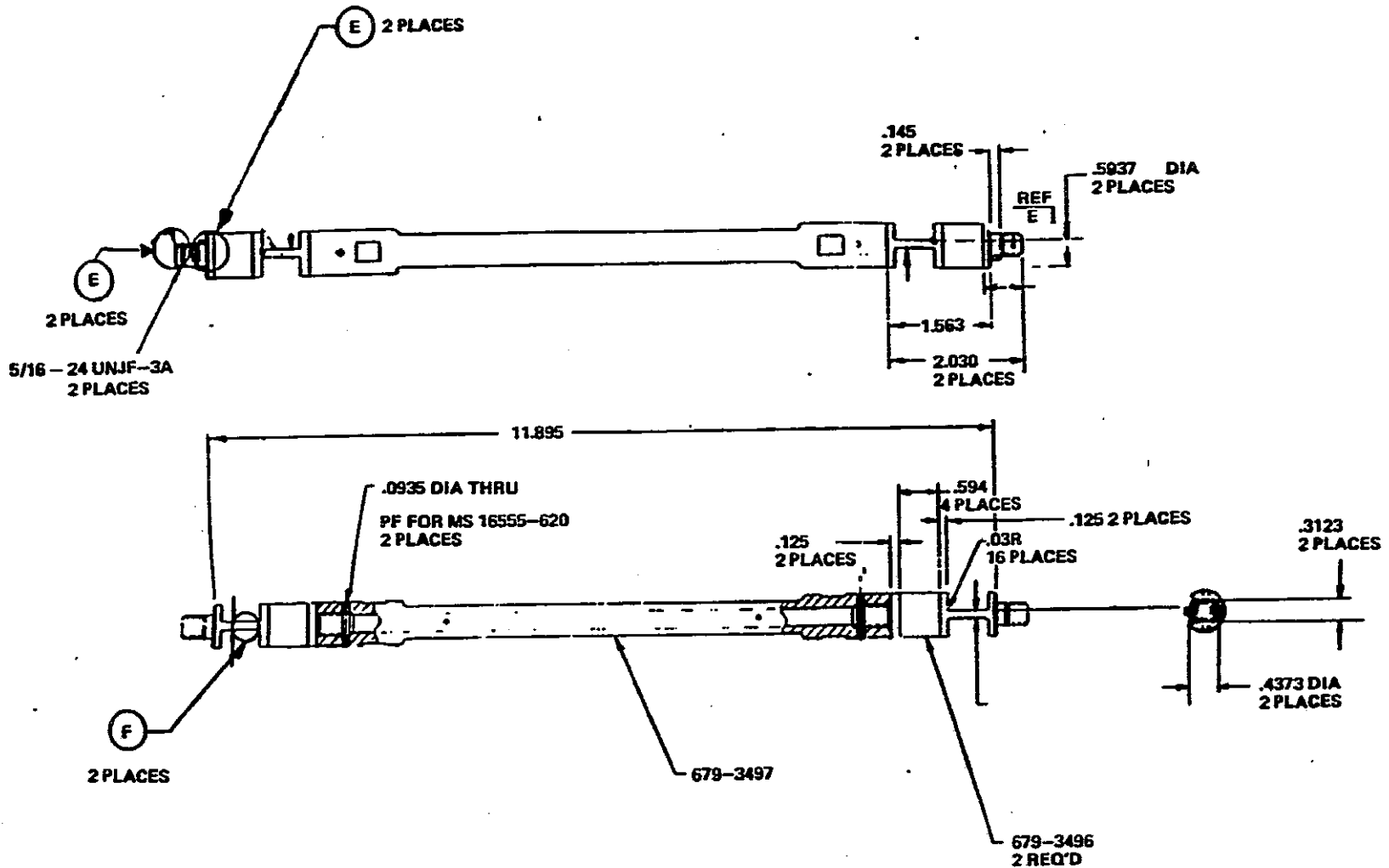


FIGURE 3h. SAMPLE DATA REQUIREMENT. FLAW AT LOCATIONS "E" AND "F" KEYED TO FIGURE 3c.

24h

FILE NO. MSFC-HDBK-1453

202 -

DR060PRO

PACKAGE NO. 10443R

DOCUMENTATION RELEASE LIST
GEORGE C. MARSHALL SPACE FLIGHT CENTERMSFC CODE IDENT 14981/339B2
ISSUE DATE FEB 22 2007

PAGE 1

C H	DOCUMENT NUMBER	DRL DRL DSH REV	TITLE	CCBD NO.	PCN	PC	EFFECTIVITY
*	MSFC-HDBK-1453	202 -	FRACTURE CONTROL PROGRAM REQUIREMENTS	000-00-0000	0000000	ZA	NONE
CHG NO.	CHG REV	CHG NOTICE	RESPONSIBLE ENGINEER	RESPONSIBLE ORGANIZATION	ACTION DATE	DESCRIPTION	
			G. FAILE	ED25	02/22/94	BASELINE RELEASE	
*	1	DCN000	EUGENA GOGGANS	EO03	02/22/07	DOCUMENT RELEASED THRU PDS. NO LONGER TRACKED IN ICMS.	

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PACKAGE NO: 10443R

PROGRAM/PROJECT: MULTI

LAST UPDATED: 02/22/07

NOMENCLATURE: MSFC-STD- GOING TO NONE EFFECTIVITY

ECR NO:	PCN:	CCBD NO:	DATE PREPARED:
EO03-0000	0000000	000-00-0000 SB3-00-0000	02/22/07

DWG SIZE	DRAWING NUMBER	DWG REV	EPL/DRL/DDS NUMBER	DWG REV	EPL DSH	EPL REV	EO DASH NUMBER	EO REV	PART NUMBER
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			MSFC-HDBK-1674		202	-			
			MSFC-HDBK-2221		203	-			
			MSFC-HDBK-505		202	-			
			MSFC-HDBK-670		202	-			
			MSFC-MNL-1951		209	-			
			MSFC-PROC-1301		202	-			
			MSFC-PROC-1721		202	-			
			MSFC-PROC-1831		202	-			
			MSFC-PROC-1832		202	-			
			MSFC-PROC-404		202	-			
			MSFC-PROC-547		202	-			
			MSFC-QPL-1918		204	-			
			MSFC-RQMT-1282		202	-			
			MSFC-SPEC-1198		202	-			
			MSFC-SPEC-1238		202	-			
			MSFC-SPEC-1443		202	-			
			MSFC-SPEC-164		202	-			
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			MSFC-SPEC-2491		203	-			
			MSFC-SPEC-2492		203	-			
			MSFC-SPEC-2497		211	-			
			MSFC-SPEC-250		202	-			
			MSFC-SPEC-445		202	-			
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			MSFC-SPEC-766		202	-			
			MSFC-STD-1249		202	-			
			MSFC-STD-1800		202	-			
			MSFC-STD-246		202	-			
			MSFC-STD-2594		203	-			

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02/22/07 DR120PR0 PAGE 2

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DWG SIZE	DRAWING NUMBER	DWG REV	EPL/DRL/DDS NUMBER	DWG REV	EPL DSH	EPL REV	EO DASH NUMBER	EO REV	PART NUMBER
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			MSFC-STD-2904		202	-			
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			MSFC-STD-2907		202	-			
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			MSFC-STD-383		202	-			
			MSFC-STD-486		202	-			
			MSFC-STD-506		203	-			
			MSFC-STD-531		202	-			
			MSFC-STD-557		202	-			
			MSFC-STD-561		203	-			
			MSFC-STD-781		202	-			

SUBMITTED BY ENGINEERING AREA:	BASIC	CHANGE	PARTIAL	COMPLETE	CLOSES	ACTION
EO03		X		X		EO03

PREPARED BY:
EUGENA GOGGANS
12/19/06

SUBMITTED BY:

CONCURRENCE:

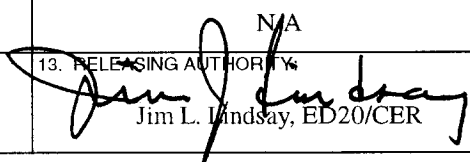
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TO MSFC DOC REP 02/22/07 00:00

REMARKS:

2007 FEB 22 AM 11:22

MSFC DOCUMENTATION REPOSITORY - DOCUMENT INPUT RECORD**I. GENERAL INFORMATION**

1. APPROVED PROJECT: Multiprogram	2. DOCUMENT/DRAWING NUMBER: MSFC-HDBK-1453	3. CONTROL NUMBER:	4. RELEASE DATE: 10/06/1987	5. SUBMITTAL DATE: 08/19/2003
6. DOCUMENT/DRAWING TITLE: Fracture Control Program Requirements			7. REPORT TYPE: Standard	
8. CONTRACT NUMBER / PERFORMING ACTIVITY: N/A	9. DRD NUMBER: N/A	10. DPD / DRL / IDRD NUMBER: N/A		
11. DISPOSITION AUTHORITY (Check One): <input checked="" type="checkbox"/> Official Record - NRRS 8/12/1A <input checked="" type="checkbox"/> Reference Copy - NRRS 8/5/A/3 (destroy when no longer needed)	12. SUBMITTAL AUTHORITY: Gregory R. Swanson	13. RELEASING AUTHORITY:  Jim L. Lindsay, ED20/CER		
14. SPECIAL INSTRUCTIONS: None.				
15. CONTRACTOR/SUBMITTING ORGANIZATION, ADDRESS AND PHONE NUMBER: Gregory R. Swanson ED22/Strength Analysis Group Building 4666 544-7191		16. ORIGINATING NASA CENTER: MSFC		
17. OFFICE OF PRIMARY RESPONSIBILITY: Engineering Directorate/ED22				
18. PROGRAMMATIC CODE (5 DIGITS):			19. NUMBER OF PAGES:	

II. ENGINEERING DRAWINGS

20. REVISION: N/A	21. ENGINEERING ORDER: N/A	22. PARTS LIST: N/A	23. CCBD: N/A
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III. REPORTS, SPECIFICATIONS, ETC.

24. REVISION:	25. CHANGE:	26. VOLUME:	27. BOOK:	28. PART:	29. SECTION:
30. ISSUE:	31. ANNEX:	32. SCN:	33. DCN:	34. AMENDMENT:	
35. APPENDIX:	36. ADDENDUM:	37. CCBD:	38. CODE ID:	39. IRN:	

IV. EXPORT AND DISTRIBUTION RESTRICTIONS


- Privacy Act (see MWI 1382.1)

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- Proprietary (see MPD 2210.1)

 Other ACI (see NPG 1620.1 and MPG 1600.1)
- Patent (see MPG 2220.1)

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V. ORIGINATING ORGANIZATION APPROVAL

40. ORG. CODE: ED22	41. PHONE NUMBER: (000) 544-7191	42. NAME: Gregory R. Swanson	43. SIGNATURE/DATE:  8/19/03
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VI. TO BE COMPLETED BY MSFC DOCUMENTATION REPOSITORY

44. RECEIVED BY: 	45. DATE RECEIVED: 10-15-03	46. WORK ORDER:
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