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SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

TWR-60352

EVALUATION OF RSRM CASE HARDWARE FRETTING CONCERNS

11 October 1990

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

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Thiokol CORPORATION
SPACE OPERATIONS

P.O. Box 707, Brigham City, UT 84302-0707 (801) 863-3511

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Prepared by:

Thomas R. Swauger

T. R. Swauger
Metal Component Design

Approved by:

K. M. Sperry, Supervisor
Metal Component Design

J. V. Daines, Manager
Metallic Component Design

J. M. Seiler, Project Engineer
Case Project Engineer

H. G. Kotter, Program Manager
Steel Case

Bruce Howard 10/25/90

B. Howard
SR&QA

T. K. Lai
Fracture Control Board

Released by:

Dolores Mills 10-24-90

Data Management
SS2432

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1.0 Introduction

Fretting corrosion was first noted on Shuttle flight STS-26. This flight was the first usage of the Redesigned Solid Rocket Motor (RSRM). The occurrence of fretting has since been observed on both the field and factory joints of the RSRM. As defined by G.A. Tomlinson (1939), fretting is a form of corrosion that occurs at the interface between contacting, highly loaded, metal surfaces when exposed to slight relative vibratory motions. The resulting effect is a loss of metal (pitting) and accumulation of metal and metal oxides on the interfacing surfaces. The magnitude of the defect is a function of the interface loads and the number of vibratory cycles to which the interacting surfaces are exposed.

This report has been prepared to summarize the engineering effort performed to evaluate the effect of fretting on the RSRM case hardware. Based on the results of this evaluation, several conclusions have been drawn concerning flight safety. Also, recommendations have been made concerning trending the effects of multiple generations of fretting damage, and further evaluation of case service life concerns.

The remainder of this introduction will briefly address the occurrence of fretting at both the field joint and factory joint regions, as well as give an overview of the engineering effort performed to evaluate the effect of fretting on the RSRM hardware.

1.1 Field Joint Fretting

The field joint fretting occurs at the capture feature/inner clevis leg interface, see Figure 1 below.

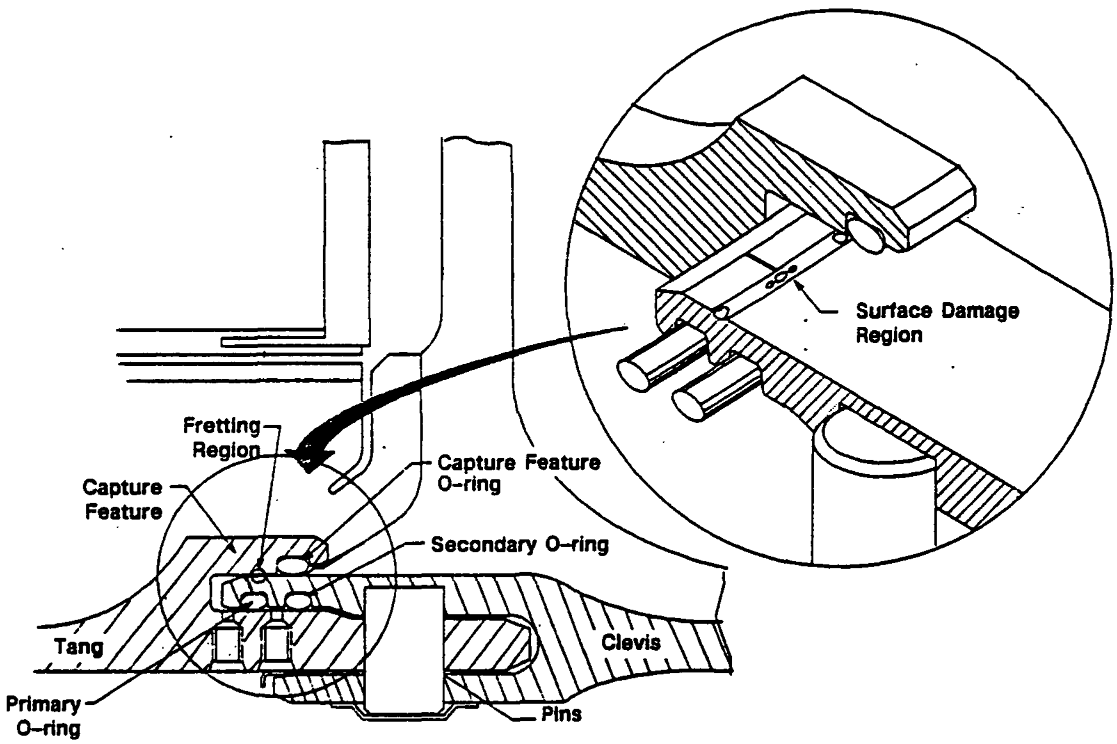

Figure 1: Field Joint Fretting Location

The capture feature interface did not exist prior to the Shuttle Rocket Motor redesign and was the primary element in the case hardware field joint change. The capture feature was added to the field joint configuration to control relative motion between the inner clevis leg and the tang sealing surfaces during motor pressurization. This motion was characteristic of the 51-L and earlier Space Shuttle missions and requires the joint O-rings to track the growing seal gap. This becomes an insurmountable task at colder temperatures when the O-ring has lost some of its resiliency. To provide the minimum possible relative motion between these surfaces the capture feature was designed with an interference fit over the inner clevis leg. Since the redesign, fretting has become a regular occurrence at the field joints with every motor since STS-26 exhibiting at least slight fretting on a few of the joints.

1.2 Factory Joint Fretting

Also, recently becoming evident is the advent of fretting at the factory joints. This occurrence had not been documented until QM-7 and was first detected after flight on STS-29. However, once brought to light the post flight data from STS-26 and STS-27 was reviewed and it was determined some light fretting did occur at the factory joint on these flights also.

The factory joint fretting occurs at the interface between the inner clevis leg and the tang surface at the area of the land between the primary and secondary O-ring grooves. See Figure 2, which illustrates this location. Factory joint fretting is much smaller in both magnitude and number than the fretting at the field joint. The presence and/or awareness of the factory joint fretting can be attributed to two factors:

1. The more severe fretting at the field joint brought us to a greater awareness of the occurrence of fretting.

2. The field joint shims (pin retainer clips) were modified during the SRM redesign to provide a "force" fit at the outer clevis leg/tang gap. This fit changes the relative positions of the surfaces exhibiting fretting.

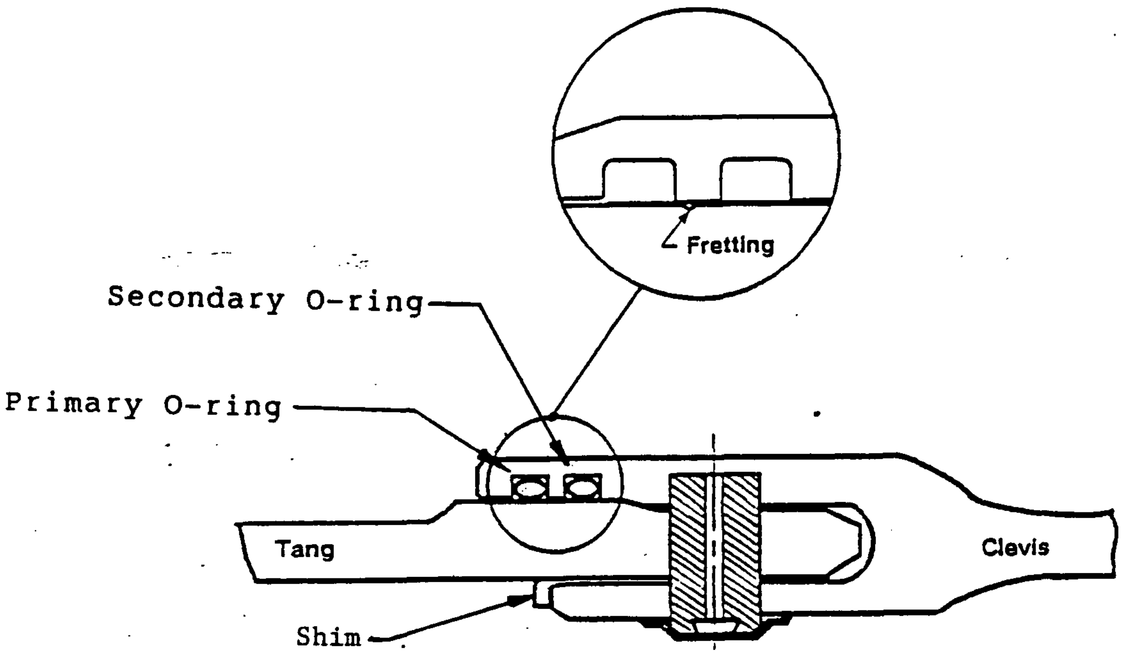

Figure 2: Factory Joint Fretting Location

It is not clear whether fretting at the factory joint was occurring prior to the redesign. The small indications could have easily been attributed to other causes (rust, scratches, etc..) and repaired per standard repair procedures without much attention drawn to the occurrence.. The design change to increase factory joint shim thicknesses to obtain a "custom" tighter fit may result in having a shim which is too thick selected. By forcing a shim which is too thick into the shim gap, the tang and clevis are forced to shift slightly, with respect to each other, upon insertion. The shift brings the surfaces known to exhibit fretting together, providing a greater opportunity for local interface contact, as well as increased interface pressures. This condition is thought to aggravate the fretting problem, resulting in a larger number and slightly more severe occurrences. Fretting at the factory joint is also now a regular occurrence, with fretting noted on each of the flight sets to date.

1.3 Overview of Effort

In an effort to provide an adequate understanding of the fretting problem, and to alleviate flight safety concerns over the occurrence of fretting, this report addresses the following topics:

1. Case Fretting in Detail
2. Possible Fretting Scenarios
3. Fretting Refurbishment Criteria
4. Metallurgical Concerns
5. Structural Concerns - Including Thermal Effects
6. Joint Seal Concerns

Recommendations as to the non-critical nature of the concerns are also made.

2.0 Conclusions and Recommendations

A thorough evaluation of fretting on the RSRM case hardware has been performed. While we do not have a clear picture of the exact scenario in which fretting occurs on the RSRM we can, based on these evaluations, make an assessment of the resulting damage and determine the effect on flight safety.

A metallurgical evaluation of an actual piece of fretted hardware was performed to determine the extent of the damage to the micro-structure of the material. This study revealed that at each fret indication there is a very shallow (.0015 in. deep or less) heat affected zone, as was expected. Also noted, was the presence of surface micro-cracks. The micro-cracks are less than .001 in depth, and run parallel to the contour of the pit along the interface between the heat affected zone and the parent case material.

Stresses in the region of the fretting pits were also evaluated for the flight load situation. The stresses all result in large positive margins of safety, including the required 1.4 factor of safety. To evaluate stress corrosion cracking concerns, stresses in the region were evaluated for the as-assembled load case, as well as residual stresses in the region of the frets. Assembly stresses are tensile, however, the magnitude is much less than that which would result in a concern. Residual stresses at the frets are compressive as indicated by X-ray diffraction examination of an actual fret indication. Compressive stresses do not support a stress corrosion environment. A fracture mechanics analysis was performed for all of the regions exhibiting fretting. The critical crack size was calculated for each region. The critical crack size for each region is larger than that which can be detected by Non-Destructive Examination (NDE) during refurbishment. Also, the number of pressure cycles required to propagate a crack from an undetectable size to the critical size, is far larger than the safe life requirement of four missions.

The case refurbishment specification requires that O-ring compression be evaluated at each seal surface fret repair location, thus insuring adequate O-ring squeeze is maintained. Repairs in the interference zone are limited to the removal of raised metal which maintains the integrity of the interference fit, causing no significant thermal flow paths through the interference fit.

All the required inspections to the case have been implemented during refurbishment which assures that any fretting defect which falls outside our experience base, will require

Material Review Board (MRB) action prior to usage. With all these factors considered, fretting does not represent a safe life concern. This eliminates the need to address this issue at the Flight Readiness Reviews and allows added devotion to other more pertinent items.

The issue of case attrition should not, however, be considered closed. While we can assure flight safety on a one-by-one basis thru refurbishment requirements, multiple generations of fretting may eventually cause the dimensional requirements (specifically those features which affect the interference fit) to begin falling out of specification. At this point in time we have very limited data concerning the effects of multiple damage, therefore, useful life predictions are impossible to make.

It is with this knowledge in mind that we make the following recommendations. We must continue to closely monitor multiple generations of fretting. This will provide engineering the required information to identify possible trends which would cause decreases in case life. It is also recommended that we develop an automated system which is capable of inspecting, in detail, local defect and repair zones. The data generated by this equipment could then be put into a working data base to support the trending effort.

We must concurrently pursue load characterization and testing to help evaluate the case service life concern. This would be best accomplished by taking steps to instrument during the various loading scenarios which are thought to be contributors in the occurrence of fretting. Then institute a comprehensive testing program, which more accurately simulates actual conditions. Information gathered in this testing could be used two fold:

1. Testing would give us insight into the case life concern.
2. Testing would help characterize the actual mechanism of fretting and may lead to a possible fix. Thus, totally avoiding the service life concern.

As a last recommendation, the Quality Organization must move quickly in completing their probability of detection study to substantiate the magnetic particle inspection sensitivity level. This would insure that inspection requirements are met.

3.0 Discussion

3.1 Case Hardware Fretting in Detail

Both the fretting which is occurring at the field joint and the factory joint have been identified as flight safety issues. To better understand the phenomena each have been described in detail in this report. Also, TWR-61070 "RSRM Joint Fretting Summary" (preliminary) provides a flight by flight history of the fretting damage which has been encountered.

3.1.1 Field Joint Fretting in Detail

The fretting which is occurring at the capture feature of the field joint has very defined characteristics. A typical fret on the clevis leg side of the interface is a small pit approximately .004 to .005 inch deep and approximately .020 to .060 inch wide. The most severe pit was .017 inch deep (STS-29) which is a great deal larger than any other occurrence. The capture feature side of the interface is characterized by very light pitting and the presence of slightly raised material. During disassembly of the field joint, the raised metal present on the capture feature leaves a small scratch trailing from the pit on the clevis. This scratch is typically .0015 inch or less deep, and less than .020 inch wide. Figure 3 below illustrates typical field joint fretting as described.

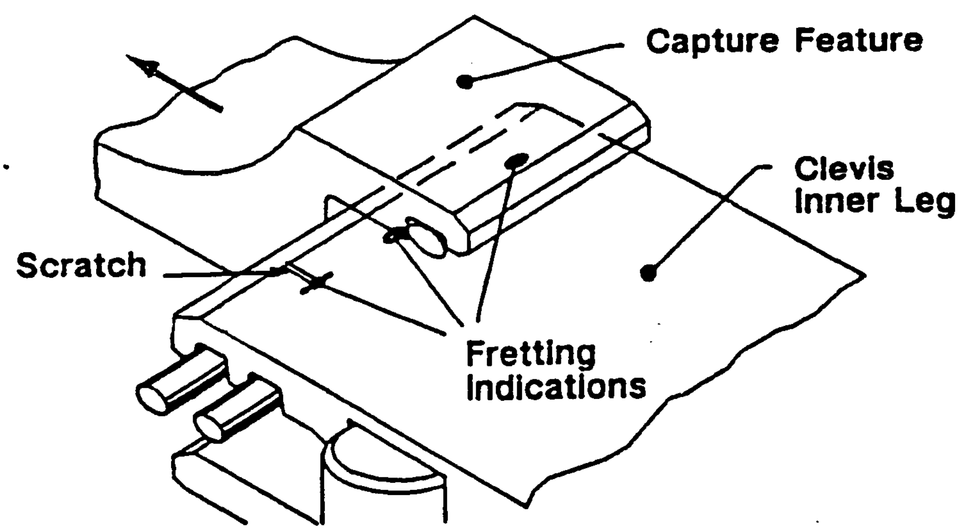

Figure 3: Field Joint Fret Indication with Associated Scratch

Figure A1 in Appendix A, shows an actual photograph of a typical clevis leg fret, note the scratch or "tail" trailing from the pit towards the end of the part.

3.1.2 Factory Joint Fretting in Detail

The fretting characteristic of the factory joint is a very shallow pit usually only .001-.002 inch deep and approximately .030 inch wide. The worst case instance is documented at .004 inch deep. Occasionally very slight raised metal is associated with these pits but is hardly detectable. Factory joint fretting has been much less severe than that noted on field joints. The number of indications is also much less than fretting on the field joint.

3.2 Possible Fretting Scenarios

The exact scenario for the occurrence of fretting on the RSRM is not clearly understood. A number of possible scenarios have been defined, however, it is not known which is the culprit, and in fact it may be the combined effect of all, or an isolated few of them. What is clear, however, is that no matter what the scenario, two basic elements are required: contact pressure and vibration. It is not the intent here to discuss each of these possible scenarios in detail in this report. It does however, seem prudent to outline them with a few brief conclusions.

For those scenarios which occur without motor pressure the capture feature interface pressures would be a direct result of the assembly loads induced due to the interference fit. However, in those scenarios which assume the fretting is occurring during motor pressure, the resulting interface load would be the combined effect of assembly loads and much higher loads induced due to internal motor pressure. Even the lower assembly loads can generate locally high interface pressures, since the load is reacted out along a line of contact with very little contact area. If you add to this effect the local asperities on each of the contact surfaces, and possible case out of roundness, very localized high pressure points are definitely a possibility, even for the assembly load fretting scenarios. Given the varied vibration environments and the possibility of high local interface loads for both the pressurized and non-pressurized cases it has proven very difficult to determine the exact scenario for the occurrence of fretting. Table B1 in Appendix B lists each possible scenario with a brief statement where appropriate.

3.3 Case Refurbishment (Re-use) Requirements - Fretting

The major concern generated by fretting is the reuse of fretted hardware. The case hardware has a reuse goal of 19 flights. The cost effectiveness of the entire RSRM program is a direct result of the ability to reuse this critical case hardware. In order that we understand the concerns of flying fretted case segments we must first have a thorough understanding of how fretted indications are repaired and inspected during refurbishment operations. The following data is compiled from the RSRM Case Segment Refurbishment Specification (STW7-2744).

3.3.1 Refurbishment of Field Joint Fretting

The field joint fretting occurs at the capture feature interface. Due to the interference, the inner clevis leg is forced to bend slightly. This bending action forces hard contact, and thus the major occurrence of fretting to be at the extreme end of the interface. This area is extremely close to the capture feature O-ring seal surface. In fact, given assembly tolerances what may be the interference zone for one particular joint mate, may actually stray into the capture feature seal zone for another mate. The refurbishment specification must and does account for the worst case tolerance seal zone, resulting in some fretting pits occurring in the defined seal zone of the clevis leg. Fretting which occurs in the seal zone is blended using an abrasive Dremel tool and a final hand polish. As part of the repair procedure, O-ring squeeze requirements are verified for the reworked region to insure minimum squeeze requirements have not been violated. Also, the surface finish in the rework zone is reverified to assure that original surface finish requirements are maintained.

Fretting pits which occur in the seal zone but so near the interference zone that the projected blend zone would cross into the interference zone are feathered out in the axial direction at the seal/interference zone boundary. By not allowing the blend to extend into the interference zone the interference fit is not compromised. Those pits which are entirely in the interference zone are repaired by only breaking sharp edges and removing raised metal. The entire capture feature tang fretting region falls into this category of surface. Figures 4 thru 6 identify the seal and non-seal zones as well as illustrate the required rework for the various situations we have described above.

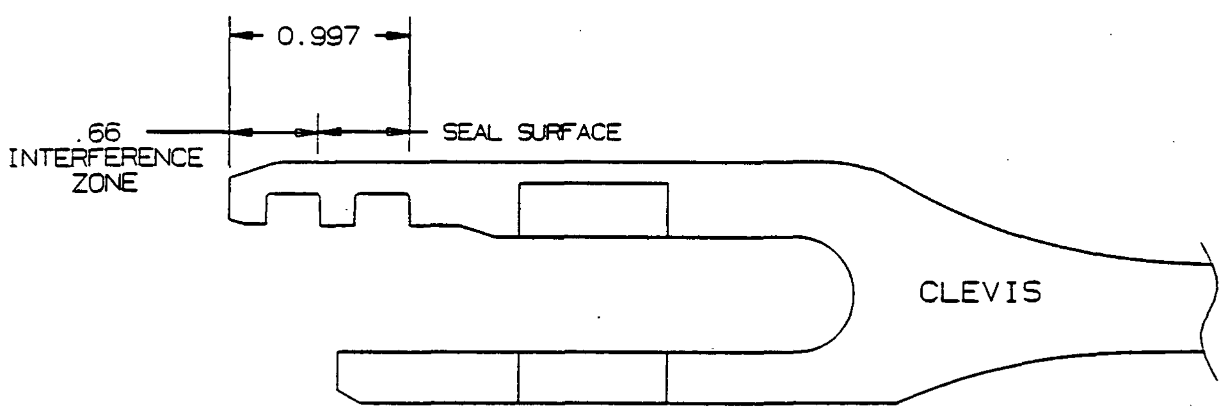

Figure 4: Inner Clevis Leg I.D. Seal Zone

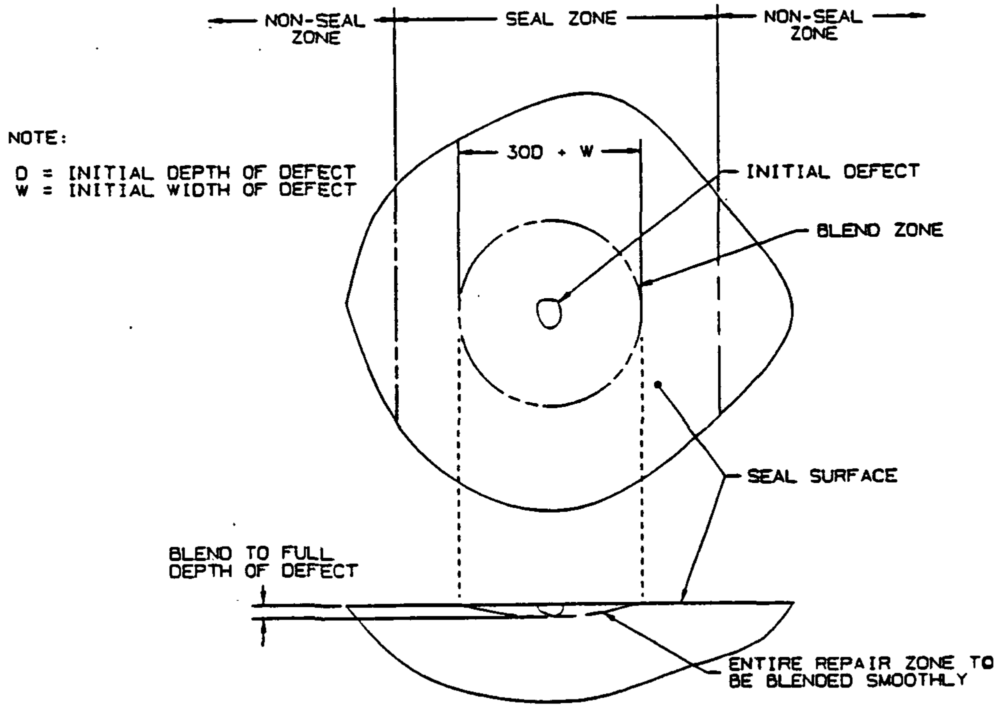

Figure 5: Fret Repair Entirely in Seal Zone

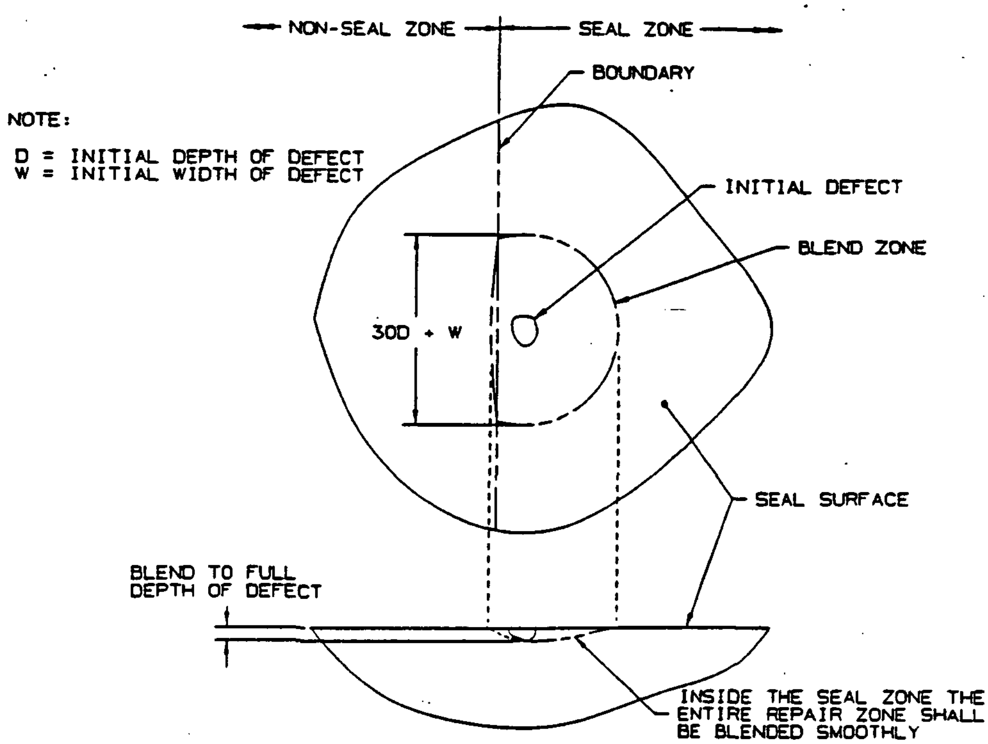

Figure 6: Fret Repair, Blend Zone Projected Into Interference Zone

It should also be noted that no pitting in excess of .010 inch deep is permitted by the specification. Any pit which exceeds this limitation must be evaluated through formal Material Review Board (MRB) action.

The segment is proof tested at 1.12 times the maximum expected operating pressure prior to each usage. After the proof test a magnetic particle inspection is performed to detect surface cracks. The Refurb Specification requires that no cracks greater than .100 long are acceptable.

3.3.2 Refurbishment of Factory Joint Fretting

As indicated earlier, fretting at the factory joint occurs at the land between the primary and secondary O-ring grooves. The tang surface at this interface is considered to be a seal surface and the fretting pits are blended just as those for frets on the field joint surface. Non-seal surfaces of the clevis have only the raised metal and sharp edges removed. The extent of the fretting damage at the factory joint is much less severe than the field joint fretting and results in very small blends. As in field joint fretting the case component is magnetic particle inspected and proof tested prior to it's next usage.

3.4 Metallurgical Evaluation of Fretted Region

In an effort to understand the micro-structure of the fret, an actual piece of fretted flight hardware from mission STS-27 was sectioned to perform a metallurgical study (Reference TWR-19666). The cross section of the fretting pit was examined using high magnification and x-ray diffraction. It was determined that a residue of metal oxides was present on the surface at the region of the fret. This presence of oxides is evidence that fretting is really a form of corrosion. The pits also showed a thin (.001 inch or less) discontinuous layer of white martensite at the surface of the pits. The total depth of the heat affected zone, excluding the white martensite, was approximately .0015 inch deep. The heat affected zone is caused by the very localized hot spots generated by the fretting action. Also observed, was the presence of small micro-cracks at the surface of the pitted region. These micro-cracks were shown to be .001 inch or less deep and did not extend into the parent material. The cracks are approximately .003 inch long and run parallel to the contour of the pit at the approximate boundary between the martensite and the heat affected regions. A typical cross section of a fret pit is shown in Figure 7 which illustrates some of the details described above. Figure A2 in Appendix A shows a 500X photo of one of the sectioned frets.

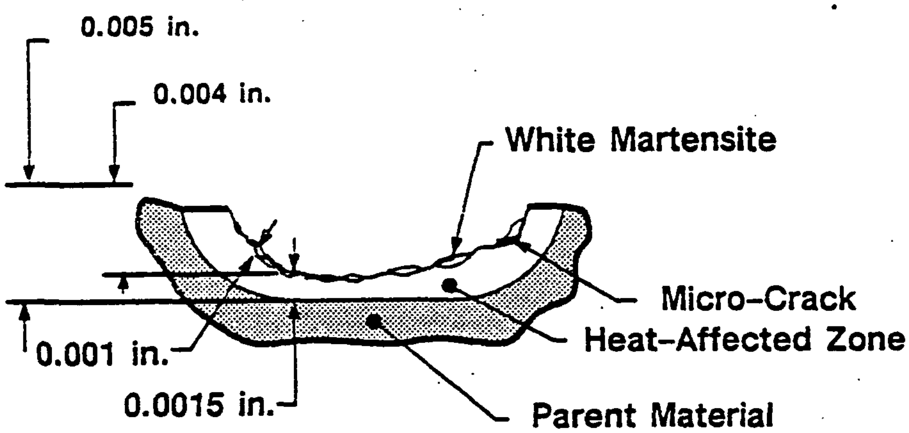

Figure 7: Fret Cross Section

3.5 Flight Safety Concerns

The flight safety concerns caused by fretting can be broken down into five major categories:

1. Stress- Due to Flight Loading
2. Thermal Effects to the Case Structure
3. Stress Corrosion Crack Growth
4. Fatigue Crack Growth
5. Joint Seal Effects

Each of these concerns must be evaluated to establish the flight safety of the fretted hardware.

3.5.1 Flight Safety Concerns - Stress

The regions on the case segments which are affected by fretting are areas of low to moderate stress. The stresses are summarized below in Table I with the associated margins of safety (MS) for each region affected by fretting:

Table I: Stress Under Flight Loads

Field Joint

* Inner Clevis Leg Maximum Stress: 113 ksi, MS = 0.26
* Capture Feature Maximum Stress: 75 ksi, MS = .90

Factory Joint

* Inner Clevis Leg Maximum Stress: 75 ksi, MS = .90
* Tang Maximum Stress: 107 ksi, MS = .33

Reference: "RSRM Structural Analysis Field Joint"
TWR-17118 Supplement. B

Note: Margins of safety are based on a factor of safety of 1.4

As shown in the table, stresses are not so severe that the slight local stress risers associated with pitting in this region would be a concern. It should be recalled that any pit exceeding .010 inch deep would require MRB action. Fretting and fretting repairs will not result in a stress problem with adequate margins of safety being maintained.

3.5.2 Thermal Effects on Structural Integrity

The only defects associated with fretting which would effect the thermal analysis of the baseline field joint design, are those which a.) compromise the capture feature O-ring's ability to seal, and b.) allow an unrestricted gas path across the entire axial length of the interference fit. As we will establish in section 3.5.5.1, fretting will not compromise the capture feature O-ring's ability to seal. Assuming that the proper rework is performed on the fret indications, the only portion of the fret defect which crosses the entire interference fit, is the disassembly scratch which was depicted in Figure 3. A thermal analysis was performed to evaluate the effect of this condition (Reference Memo L213:FY89:M162, "Flow Thermal and Erosion Analysis for RSRM Interference Fit Fretting"). Temperatures generated in this analysis were much less severe than those used to evaluate the field joint fail-safe thermal loads. Therefore, the structural ramifications of the thermal analysis performed to evaluate the fretting scratch are not significant. This subject is treated in more detail in TWR-18585, "Structural Analysis of the RSRM Nozzle to Case and Field Joint Designs for Fail-Safe Thermal Loads". Reference also TWR-60353, "Map of Flow/Thermal Limits for RSRM Field Joint Non-Interference Gaps", which documents a parametric study of thermal effects of various non-interference conditions.

There is no effect to the other redundant features of the field joint design. Therefore, thermal effects due to the presence of fretting do not result in a specific structural concern.

3.5.3 Flight Safety Concerns- Stress Corrosion Cracking

In order for stress corrosion cracking to occur several factors must be present:

1. Surface Tensile Stress- applied or residual
2. Susceptible Material Structure
3. Corrosive Environment

With the right combination of the above, this phenomenon can take an environment which would otherwise result in only superficial corrosion damage and induce sometimes rapid crack propagation.

3.5.3.1 Surface Stresses

Assembly stresses at the fretted region are low at approximately 11 ksi (tensile) as indicated in the report TWR-17118 Supplement B, "RSRM Case Structural Analysis Field Joint". The metallurgical evaluation using x-ray diffraction on an .008 inch deep pit from STS-27 showed that there were very high residual compressive stresses at the very surface of the fret area. While these compressive stresses diminished with depth, compressive stresses were found to extend to a depth of .010 inch. Below the .010 level stresses were found to be near zero with only very low tensile stresses (Reference: TWR-19666, "Measurement of Residual Stresses on Fretted Area of RSRM Case Segment 1U50717 S/N 053", Preliminary).

3.5.3.2 Material Structure

For the case material (D6AC Steel) stress corrosion cracking will not occur at tensile stresses of less than 38 ksi versus the 11 ksi maximum assembly stress. This stress limit was based on a lower bound (-3σ) threshold stress intensity (Kiscc) of 11 ksi $\sqrt{in.}$ for D6AC steel and a .10 inch long semi-circular surface flaw (Reference: TWR-16873, "Fracture Control Plan for Space Shuttle RSRM Case"). Compressive stresses do not contribute to stress corrosion crack growth. Therefore, stress corrosion cracking of the fret pits is not a concern.

3.5.3.3 Environment

The last requirement for stress corrosion crack propagation is an environment which supports corrosion. The fretted regions are both stored and assembled with an application of HD-2 calcium grease, a very reliable corrosion preventative. This grease provides an excellent barrier against moisture. Given these conclusions, conditions do not support stress corrosion crack propagation and it is not a flight safety concern.

3.5.4 Flight Safety Concerns - Fatigue Crack Growth

Fatigue crack growth is the propagation of cracks due to cyclic loading. A fracture mechanics analysis was performed for each of the specific areas exhibiting fretting (Reference TWR-16873). The stresses used for each region in this evaluation are those which were previously documented in Table I. The critical crack size for each region is documented in Table II.

TABLE II: Critical Crack Size, Fretted Regions

Location	Critical Crack Size
Field Joint:	
* Inner Clevis Leg	0.3 in. Lg. x .15 Dp.
* Capture Feature	0.3 in. Lg. x .15 Dp.
Factory Joint:	
* Inner Clevis Leg	.72 in. Lg. x thru
* Tang	.52 in. Lg. x thru

Reference: TWR-16873, "Fracture Control Plan for RSRM Case"

As is shown the critical crack size for each of these areas is well above the actual fret size and extremely larger than the micro-crack length of .003 inch. It can be concluded that fatigue growth of a fret indication is not a concern, since the analysis also indicates that the number of cycles required to propagate the crack from an undetectable size (less than .10 inch) to the critical crack size is much larger than the safe life requirement of four missions.

3.5.5 Flight Safety Concerns - Sealing

The effect of fretting on the joint sealing function also deserves evaluation. The three O-ring seals at the field joint are the capture feature O-ring, the primary O-ring and the secondary O-ring, as shown earlier in Figure 1. The factory joint has only the primary and secondary O-rings (Reference Figure 2). At each of these joints the insulation configuration also provides a major sealing function. For the factory joint the insulation is considered to be the primary seal. The insulation is unaffected by fretting. The effects of fretting on sealing are evaluated in the following sections.

3.5.5.1 Field Joint Seals - Capture Feature

As shown in Figure 1 the capture feature O-ring gland is located just aft of the interference area. Case hardware tolerances in this area are such that case to case variances allow the interference surface for one case joint mate to stray slightly into the capture feature seal zone in another joint mate. The concern is that the seal surface fretting damage could be left unchecked leaving a defect which could impair the sealing function during the next case usage. This requires that the refurb specification take worst case tolerances into account when specifying the proper repair of fretted regions. As shown earlier in the Section 3.3 defects which fall into the capture feature O-ring footprint area are blended to assure a smooth contour is maintained. The case refurbishment specification (STW7-2744) defines the requirements for this repair. The blend zone is always verified to assure the surface finish meets original requirements, and O-ring squeeze calculations must be performed to determine the acceptability of the repair.

3.5.5.2 Field Joint Seals - Primary and Secondary

The effect to the primary and secondary seal function is somewhat of a secondary effect. The concern would be that the fretting damage would be so severe as to eliminate the interference fit, thus affecting the dynamics of the joint during motor pressurization. The interference fit of the capture feature is required to insure that the O-rings can meet a 2X tracking factor during motor pressurization. The fretting defects have not been so severe that this would be a concern in and of itself. The inner clevis leg has more than adequate bending stiffness to bridge the very localized fretting pits with no effect to seal performance. The concern arises over insuring that the proper rework gets performed in the interference zone. Large blends in this region would be detrimental to the life expectancy of the hardware. Numerous large reworks would eventually affect the overall case diameter thus reducing the interference fit. The case refurbishment specification again establishes the rework requirements insuring that the frets in the interference zone only have raised metal removed and sharp edges broken. It is also worth mentioning that prior to making all field joint assignments the interference fit is determined for each mate based on refurbishment measurements. The interference value must meet the requirements of STW9-3668 (.002 inch radial interference) before it is considered an acceptable mate. Therefore, there is no safety concern over the loss of interference. However, the accumulative effect of multiple generations of fretting must be monitored and evaluated before assessing the effect to case life.

3.5.5.3 Factory Joint - Primary and Secondary O-rings

As we have indicated earlier factory joint fretting has been very light in comparison to field joint fretting. The location of this fretting has been illustrated in Figure 2. The only concern is fretting damage to the seal surfaces. As with field joint fretting the frets which fall within a factory joint seal zone are blended per the requirements of the case refurbishment specification (Reference Section 3.3). O-ring squeeze calculations are performed and surface finish requirements are reverified after the rework is complete to determine the acceptability of the repair. Those fret indications which fall outside of the seal zone have raised metal removed and sharp edges broken.

During refurbishment of fretted segments, all necessary repairs are made. The refurbishment specification has been updated to clarify the criteria for allowable repairs of fret indications. Defects will have no affect on seal tracking. The insulation on both joints are unaffected by fretting. Therefore, fretting does not represent a seal flight safety concern.

3.5.6 Other Concerns

In an effort to present a complete picture of the evaluation performed concerning the fretting investigation, memo L640-FY90-M005 has been attached in Appendix C. This memo documents Thiokol's response to several other concerns (not addressed otherwise in this report) raised by Dr. Hoeppner, Thiokol's consultant for the fretting investigation.

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APPENDICES

APPENDIX A

Figures

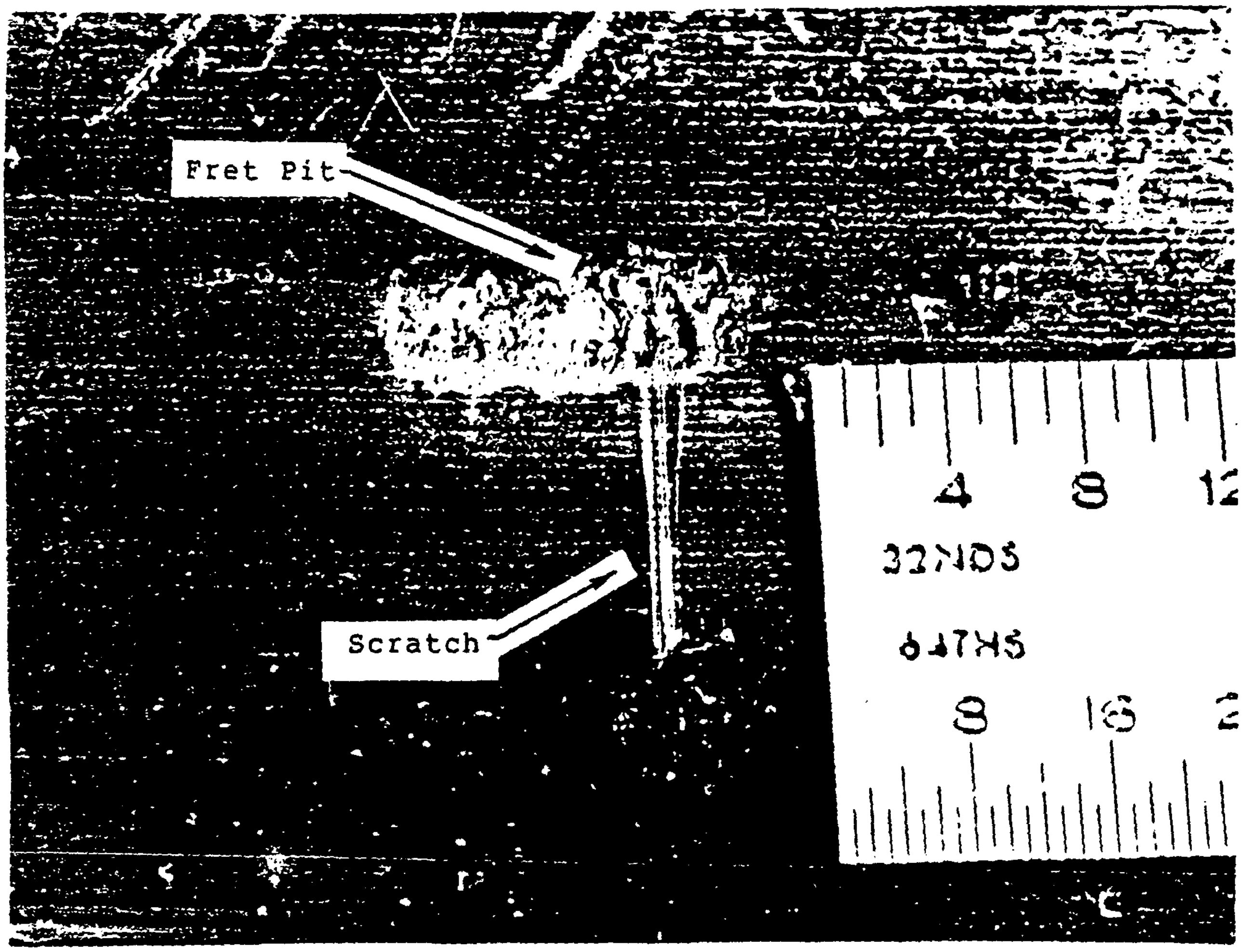

Figure A1: Photo of Field Joint Clevis Leg Fret

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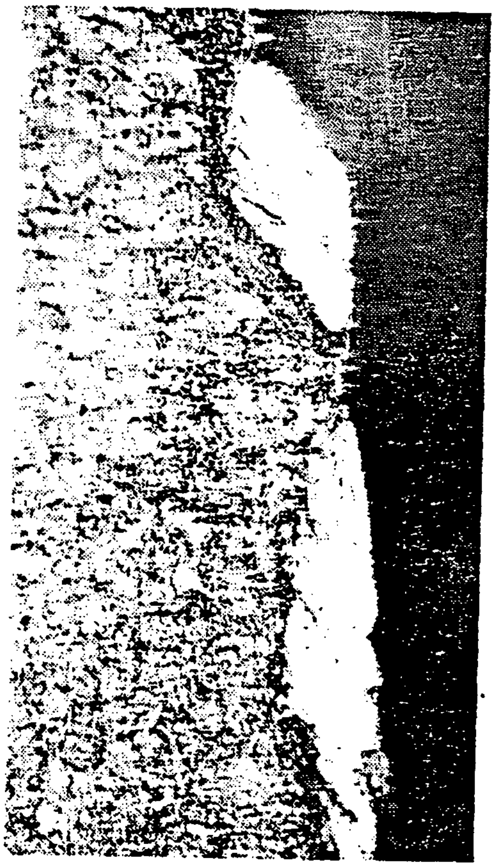
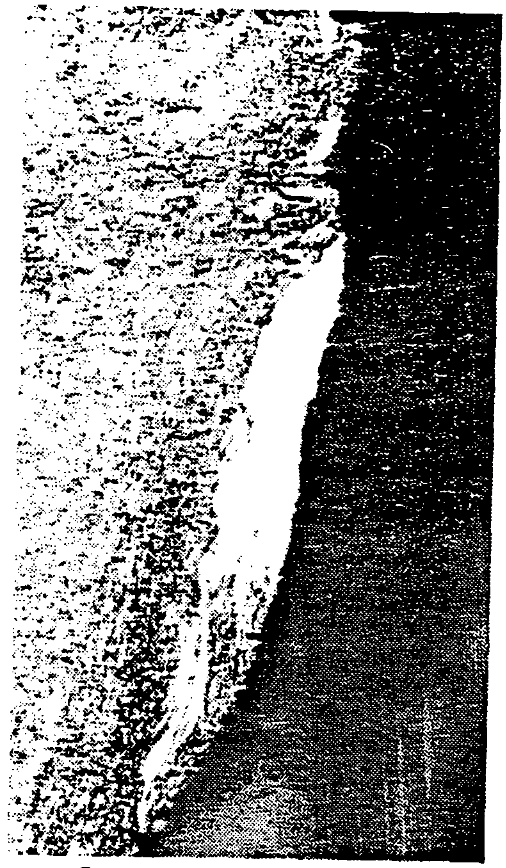
APPENDIX A: Continued



Original magnification 500X



Original magnification 500X

Figure A2: Magnified Cross Section of Actual Pit

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Appendix B
Tables

Table B1: Possible Fretting Scenarios

- **Conclusion—Exact scenario for fretting occurrence is unknown**

Scenarios	Comments
■ Rollout • Prelaunch • Flight readiness firing (FRF) • Lift-off	• Relative joint motions analyzed using RSRM global structural model, Rockwell International (RI) load cases, and 61-G rollout data • Results indicate lift-off has higher amplitude but a low number of cycles. Rollout and prelaunch has lower amplitude and a high number of cycles • FRF dismissed after fretting observed on STS-27
• Flight • Staging ■ Reentry • Recovery System Deployment • Water Entry • Floatation	• Dynamic environment not currently defined except for early flight • Some flight RI load cases are available. Global models being modified for various burn times • STS-26, STS-27, and STS-29 development flight instrumentation (DFI) data being processed • DFI revealed that Max-Q reentry is a significant event rivaling lift-off and splashdown in severity
■ Towback	• Dynamic environment not currently defined • Feasibility of barge retrieval, towback testing, towback analysis, and/or towback monitoring being studied

■ More probable causes

APPENDIX C

Memo L640-FY90-M008

Thiokol CORPORATION

SPACE OPERATIONS

18 August 1989
L640-FY90-M008

TO: S. Goleniewski
Project Engineering, Case

FROM: Ting Lai
Analytical Methods

CC: J. Daines, R. Webster, D. Mason, K. Sperry,
J. Kapp

SUBJECT: Fretting Damage Influence on Flight Safety

REFERENCE: Dr. Hoeppner's letter to Don Mason (7/10/89)

SUMMARY

Dr. Hoeppner, Thiokol's consultant for fretting investigation, met Thiokol Engineering Design personnel (J. Daines, R. Webster, D. Mason, K. Sperry and T. Lai) on 10 August, 1989 to discuss the concerns in his letter, referenced above. Later, Dr. Hoeppner attended the Fretting Team Meeting held by telecon with Thiokol team members and MSFC personnel.

Since Dr. Hoeppner wrote the referenced letter, additional information has been obtained from metallurgical evaluation of sectioned case segment S/N 53. This information is very encouraging; it removes most of the concerns about fretting damage effects on flight safety.

This memo is to address Dr. Hoeppner's concerns and summarize the results of our discussion with him. Some open issues remain and should be addressed in an orderly process.

At present, however, the information available suggests that even though all of the contributing factors are not known, the phenomenon of fretting has not produced enough damage to the material to pose a flight safety risk.

DISCUSSION

Each issue raised in the referenced letter is discussed below.

1. Metallurgical evaluation of fretted case, S/N 53

   Dr. Hoeppner found that the following results of the metallurgical evaluation are very encouraging. They support the conclusion that the fretting-related disruption of the material is very localized and does not represent a major fracture mechanics problem.

   a. Depth of pits - actual depth of pits measured by microscope were only about two mils deeper than those measured by micrometer.

   b. Cracks within the pits - microcracks observed on the surface of fretted pits are contained in the white martensite layer or extend parallel to the interface between the white martensite and the softer material underneath. None of the observed cracks penetrate into the parent material.

   c. Microstructural changes in the fretted pits - Hard white martensite was formed at the surface on fretted pits; underneath is a layer of softer material. The total thickness of white martensite and the softer layer measured only about 2 mils.

2. Load spectra

   Dr. Hoeppner stated that the exact loading conditions for the case segment life cycle is required to simulate and identify when fretting occurred, and to evaluate the service life of the case segments. However, exact loading conditions during rollout and towback are still unknown. Only very limited information is available. It was obtained during rollout of 61G. He also expressed concerns about the lack of detail in our flight load models.

Dr. Hoeppner recommended that load and motor response be monitored to acquire accurate information during rollout and towback. This is a reasonable recommendation and should be pursued. It should be noted, however, that our flight schedule will require that hardware with fretting damage will need to be used before those measurements can be obtained.

3. Fatigue crack initiation and propagation

Dr. Hoeppner has questioned whether the crack growth data of D6AC steel, using compact tension specimens tested with long cracks, is applicable for growth of short cracks resulting from fretting.

Dr. Newman of NASA, LaRC was asked on July 17, 1989 if he has any short crack test data of D6AC steel. He stated that LaRC has tested short crack (single edge notch surface crack) for AISI 4340 steel, which is very similar to D6AC steel. The results indicated the crack growth data based on compact tension specimen tests is applicable for long cracks as well as short cracks. Dr. Newman has since sent Dr. Hoeppner and Dr. Lai copies of the test report.

Dr. Hoeppner expressed concerns over the effect of R ratio and the dwell time at maximum load on fatigue crack propagation of D6AC steel. However, Thiokol has crack growth test data for R = 0.1 and marker band crack growth data for R = 0.8, at maximum load of proof test and flight condition. That data has strong evidence that dwell time does not have significant influences on crack growth rate for flight condition. In addition, the test data also indicates that the modified Forman equation of NASA/FLAGRO, which incorporates the R ratio effect on fatigue crack growth rate, is applicable for D6AC steel.

Based on the fracture toughness test data, crack growth rate of D6AC steel, and Thiokol NDE inspection capability, the safe-life analysis indicates that the current fretted condition of case segments will not cause fracture during the next flight after passing the proof test and NDE inspection.

However, to predict the residual life of a fretted segment and evaluate the reusability of case segments, Dr. Hoeppner recommended that fatigue testing of fretted sections of S/N 53 with various pit depths should be performed.

4. Temperature effect on the fracture toughness of D6AC steel

   Dr. Hoeppner expressed his concern that the temperature effect on the fracture toughness and crack growth of D6AC steel may have significant implication for the Space Shuttle launched at low temperature. Indeed, the data from fracture toughness tests conducted at NASA LaRC and Westinghouse at various temperatures show that the the fracture toughness of D6AC may be substantially reduced at lower temperatures. Fracture mechanics analysis based on this characterization data was used to establish a minimum case temperature of 35 degrees Fahrenheit as a launch constraint for RSRM. There is no intent to remove that constraint.

Of the concerns expressed by Dr. Hoeppner, two of them are not fully addressed by constraints currently imposed, related information available, or planned efforts. The two open issues are the load spectrum definition and the fatigue life of the fretted segments. There are plans being formulated to make measurements of loads and responses during rollout and towback. When this information is available, it can be factored into the fretting evaluations.

The experimental investigation of the effects of the fretting damage on the fatigue life of D6AC will require a large number of specimens. The test specimens can be cut from the damaged case, S/N 53 and tested with various combinations of damage depth, mean load, and cyclic load. Some further analytical sensitivity studies are needed before recommendations regarding this test program to be made.

Ting Lai

Ting Lai