#875653

10917

DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

⑭ Aero Materials Department

Report No. NADC-MA-7061 ⑪ 2 Oct[redacted]70 ⑫ 23 p.

⑥

EXAMINATION OF AN F8 AIRCRAFT MLG SHOCK STRUT P/N 548100-521 FAILURE.

ANALYTICAL REWORK PROGRAM, WORK REQUEST 1-3060

A comprehensive fractographic examination of an F8 AFCT MLG shock strut piston showed that improperly applied shot peening contributed to the failure which was initiated by fatigue.

~~Reported by:~~ William A Sipes
⑩ William A. SIPES
~~Physical Met~~allurgy Branch

Approved by: W. J. Fedyna
W. J. FEDYNA, Head
Physical Metallurgy Branch

F. S. Williams
F. S. WILLIAMS, Superintendent
Metallurgical Division

(402998 [redacted]

1473

SUMMARY

INTRODUCTION

One end of a fractured F8 AFCT MLG shock strut piston, P/N 548100-521, was forwarded to the NAVAIRDEVCEN (Naval Air Development Center) by the NAVAIREWORKFAC, NAS, NORVA (Naval Air Rework Facility, Naval Air Station, Norfolk), for a comprehensive fractographic examination. The purpose of the investigation was (a) to determine the origin of the failure, and (b) to verify the possibility that shot peening may have contributed to the premature failure.

CONCLUSIONS

1. Fractographic analysis shows that failure was by a fatigue mode initiated at many points at the base of the peripheral machined groove in the narrowest cross-section of the failed part.

2. Improperly applied and uncontrolled shot peening contributed to initiation of the failure. However, it cannot be stated that shot and/or roll peening properly applied would not have improved service life for this part.

RECOMMENDATIONS

Expedite specification of the shot peening process control parameters to be used for reworking of the older model piston pending replacement by the new design configuration.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

One end of a fractured F8 AFCT MLG shock strut piston (P/N 548100-521) was forwarded to the NAVAIRDEVCEN by the NAVAIREWORKFAC, NAS, NORVA, reference (a), arriving 7 May 1970. Their metallurgical examination, reference (b), noted that the total peripheral failure was remarkable in that the uniform fatigue pattern had no discernible point of origin. Since the area had been shot peened during some previous rework, they suspected that failure may have originated in the outer layer or adjacent matrix of the piston cross-section thus affected.

Therefore, in addition to the request for a comprehensive fractographic examination of the fracture so as to establish an origin for the failure, the NAVAIRDEVCEN was asked to "verify the possibility that for this appl. (sic) shot peening may have contributed to premature failure," reference (b).

INVESTIGATIVE APPROACH

First, visually and optically assisted examinations were made on the fracture face of the failed part. Beginning with the beach marks at the outer periphery, the fracture face was very uniform around the entire circumference of its outer edge, see Figure 1. Some brinelling (pressure burnishing), was most apparent in the areas next to the shear-lip along the inner circumference. The width of the shear lip, as seen in Figure 1, indicated that the fracture process ended at this general location. The NAVAIREWORKFAC investigation was well advised to take the section shown at 2 o'clock, Figure 1 (and rear right, Figure 2), for its metallographic examination. Figure 2 shows that the failure occurred in the 0.060" radius of the peripheral groove adjacent to the filleted land in the chrome plate run-out area. The land seems to have been the main target for the rework shot-peening. A closer investigation of the outer edge of the fracture face revealed that in addition to the brinelled facets, certain indentations existed in fracture lip, see Figure 3. For want of a better designation, these have been called "cleavage steps" for the purposes of this report. They can be distinguished from the brinelling because, although they showed the same beach mark pattern, the plane of failure was below the main fracture surface, which they joined by means of the "cleavage step." Hairline cracks, very difficult to observe or even to photograph, were found scattered in the shot peened surface of the groove containing the fracture plane. Figure 4 illustrates the condition of the fracture surface in the vicinity of the widest part of the shear lip at the inner diameter. Figures 3 and 4 are from fracture surfaces 90°, designated as areas A and B, respectively. Note the remarkable continuity of the beach marks.

Although several areas of the fracture surface were replicated and examined with the electron microscope, only those most representative of the fracture topology in areas A and B are given in Figures 5-8 (Area A) and Figures 9-12 (Area B). Figure 5, for instance, shows the obscuring effect of corrosion which may have masked fatigue indications, more clearly shown in Figure 6, found in the fracture lip edge of Area A. Similarly, Figure 9 shows the fatigue mode of failure at the fracture lip edge in Area B. Figures 7 and 10 show a mixture of dimpling and intergranular modes characteristic of shear failures in 7075-T6 aluminum alloys. They are representative of the fracture topology found in the central part of the fracture surface seen in both the A and B areas viewed macroscopically in Figures 3 and 4. Figure 11 is an additional fractograph showing an intergranular mode of failure in the central fracture topology found in Area B. Figures 8 and 12, fractographs of the inner wall surfaces adjacent the inner fracture lip of Areas and B, respectively, show patches of intergranular penetration in the mechanically deformed inner wall of the failed piston.

The metallographic examination of wall sections taken to include the fracture surface indicated that the failure proceeded from the outside to the inside by a transgranular mode in the short transverse direction. The grain structure showed the effects of recrystallization during homogenization but was normal for a 7075-T6 aluminum alloy heat treated to the T6 condition (R_B hardness for the failed part was 80). Shot peening effects on the groove radius and land surfaces, as seen in Figures 13 and 14, were minimal but with some surface roughening. The results of this effect can be seen in Figure 15 which shows an unetched view of the land surface in profile. This also gives a view of a penetrating surface crack, showing how it bifurcates when meeting the compressive stress field produced by shot peening.

ANALYSIS OF RESULTS

Beach marks can be useful for locating the origin of a fatigue fracture but in the piston failure examined here, their visual uniformity, both radial and peripheral, was such that the site of the crack origin could not be unambiguously determined. Why this should be so can be understood as follows: First, by considering the residual stresses produced by shot peening; and second, by considering the effect of cyclic loading on these residual stresses.

In shot peening, when individual particles of shot contact the metal surface, small rounded depressions are produced. The multiplicative effect of concentrated shot at a high velocity causes a plastic flow in the metal surface which can extend from 5-10 thousandths of an inch below the surface. (Note this effect in the worked layer at the surface in the profile views given in Figures 14 and 15.) Since the

the metal below this deformed layer is not plastically deformed, this surface layer is placed in residual compression after the shot peening process is completed. A schematic representation of the residual stress situation in the part at this stage is presented in Figure 16 (a). Of course, the actual residual stress conditions produced in any particular part will depend on a variety of factors. These include part design and material as well as the controllable parameters of the shot peening process itself: the shot material, its size and hardness, "exposure time" and "exposure velocity," These should be specified and controlled for the particular application. No facts have been developed that indicated, that for the failed piston, any control of the shot peening process was in effect during its rework.

To explain the observed fatigue failure mode in the failed part, the effects of a cyclic tensile load superimposed on the residual stresses also should be considered. Referring to Figure 16 (a), for conditions prior to loading, the shot peened part would have a surface residual compressive stress, designated σ_s. As shown, it is less in absolute value than the maximum residual compressive stress, σ_{max}, lying to a depth delta (Δ) below the surface. In a real situation, especially if an improper selection of shot peening control parameters had been made, residual stress conditions could have been induced in the part so as to leave the surface, and for a small distance below, in tension while allowing a maximum compressive stress near but not at the surface. A similar situation could be caused also by the superposition of a tensile load effect on the conditions represented by the sketch. That is, if a tensile load were superimposed, the neutral axis (the boundary between the tensile and compressive residual stress fields as depicted in Figure 16 (a)) would be displaced. Unloading would return it to its original position. Cyclic loading would thus mean that for every cycle the surface of the part would be in tension for a finite time. Since a tensile stress is one requirement for the initiation of stress corrosion, corrosion-fatigue, and fatigue modes of failure, it can be readily understood how, despite shot peening, failure can originate. Therefore, it cannot be inferred that shot peening would keep a surface from encountering tensile stress conditions in service. Shot peening only reduces the vulnerability of a part to fatigue and corrosion effects but does not eliminate their possibility. It does, however, maintain surface tensile stresses at a lower level than otherwise would be the case. As to whether or not "shot peening may have contributed to premature failure," reference (b), the answer requires better information than that so far available concerning the details of the shot peening process used and the service history available for the part.

A crack having been initiated in a shot peened surface would tend to penetrate the part in a direction perpendicular to the applied tensile load, see Figure 16 (b). On encountering a compressive stress field, the crack tip would be blunted or would branch, tending to extend laterally. A crack growing in such a manner would exhibit in cross-section a profile similar to that shown in the sketch, Figure 16 (b), and illustrated by Figure 15 in the failed part.

The remarkable uniformity of the fracture surface exhibited by the failed piston derives from the fact that, except for trivial dimensional variations, the component had a perfect radial symmetry. Also, internal pressure loads due to service conditions would, because of the radial symmetry, tend to produce a uniform distribution of wall stresses. Both effects would lead one to expect that crack propagation during failure would occur uniformly in a horizontal plane across the entire cross-section. The machined groove, despite its radius (0.06"), would act as a stress concentrating peripheral notch, further insuring one main fracture plane. Since the groove was shot peened during rework, the incipient cracking/tearing in the roughened groove surface would make the groove base the most likely site for crack initiation. In fact, even without shot peening, the notch effect of the peripheral groove could have caused the regularity noticed in the fracture surface.

Cumulative cyclic stress damage would extend initial cracks in the groove base until they were linked in a common plane of failure perpendicular to the acting tensile stresses. At the visual level, continued cyclic loading would produce the beach marks found in both the main fracture surface and in the base of the "cleavage steps" prior to the catastrophic final failure of the part. That this in fact is what occurred can be seen in the photomacrographs of Figures 1, 2, 3, and 4 as well as in the photomicrographs showing the fracture profile as shown in Figures 13, 14, and 15.

REFERENCES

(a) NAVAIRSYSCOMREPLANT R142028Z Apr 70

(b) NAVAIREWORKFAC NAS NORVA R081945Z Apr 70

ACKNOWLEDGEMENT

The author wishes to acknowledge Mr. John Danovich, Chemical Engineering Division, Naval Air Development Center, for providing the electron fractography for this report.

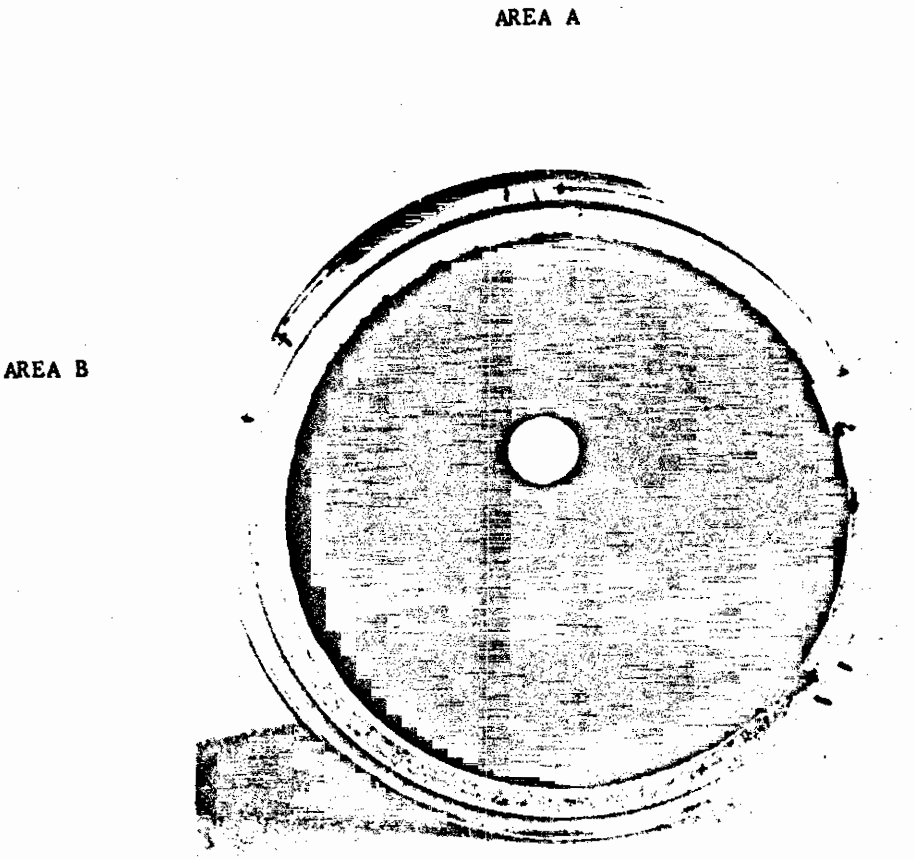


Fig. 1 - Plan View of As-Received Failed Piston

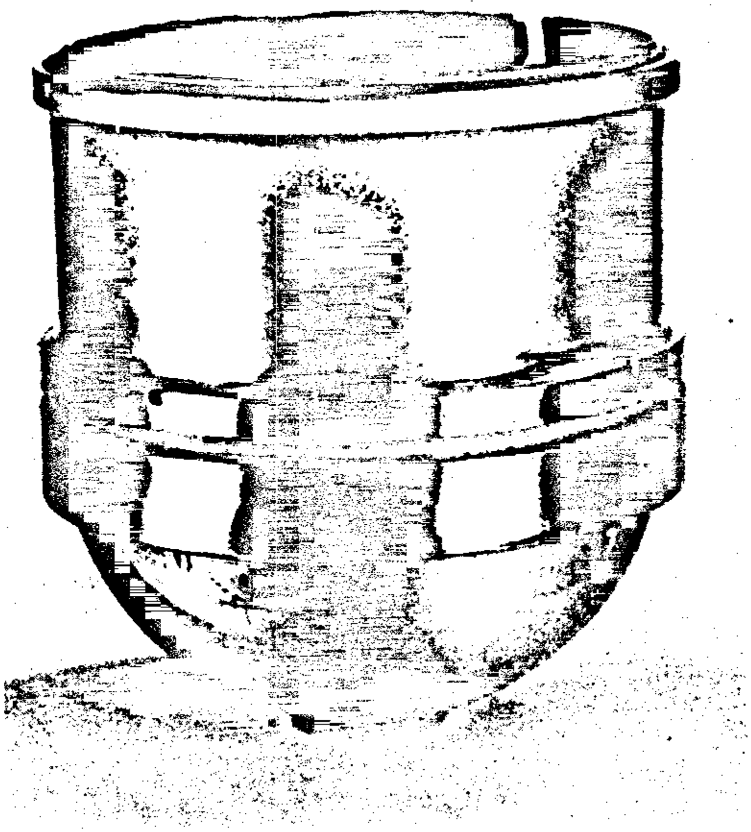


Fig. 2 - Elevation View of As-Received Failed Piston

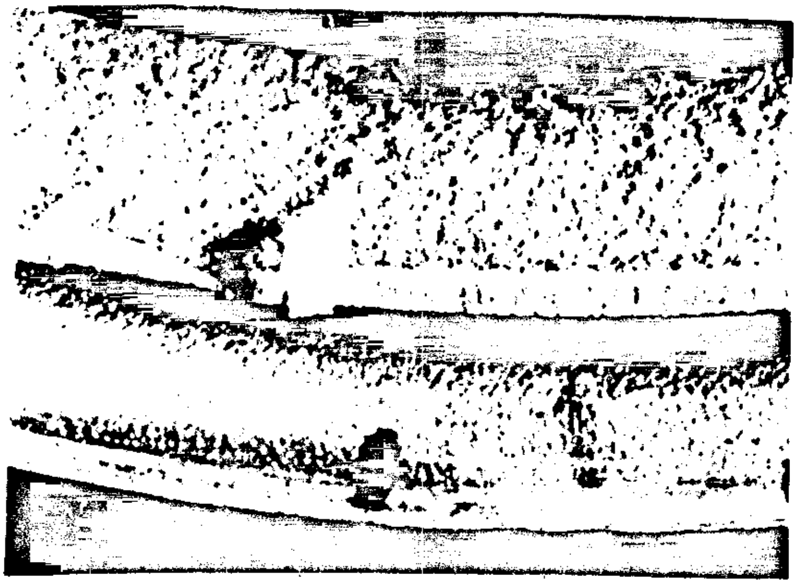


Fig. 3 - Photomacrograph of Fracture Surface, Area A

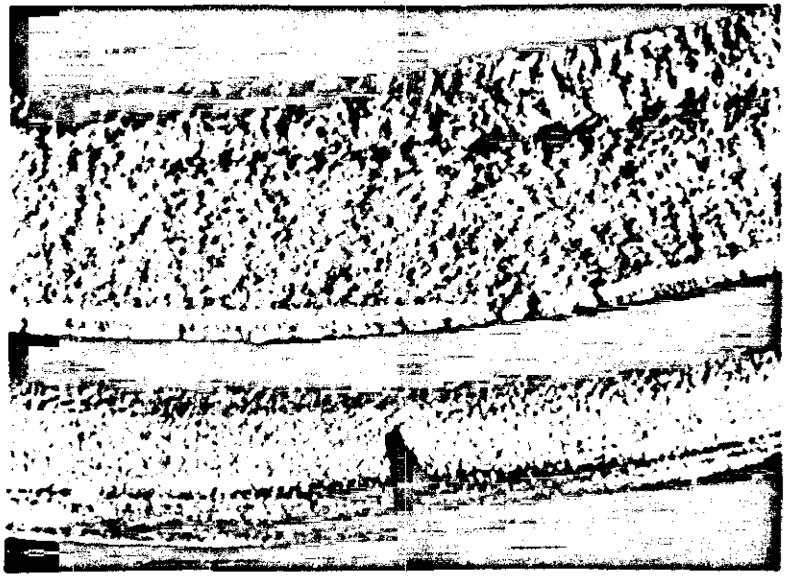


Fig. 4 - Photomacrograph of Fracture Surface, Area B

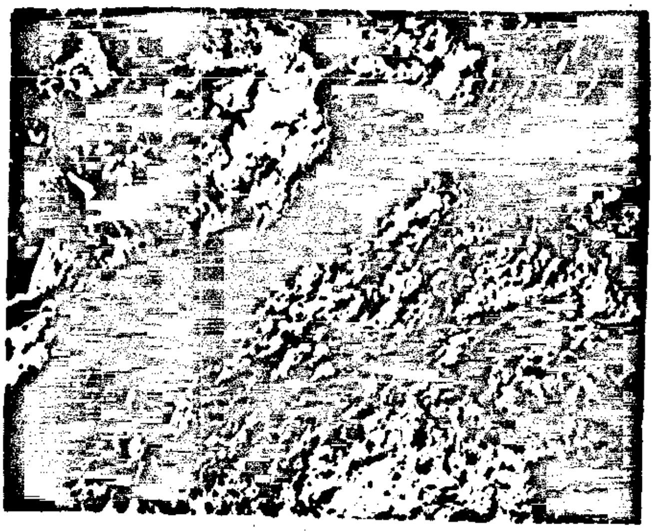


Fig. 5 - Electron Fractograph - Outside lip edge, corrosion masking fatigue, Area A.

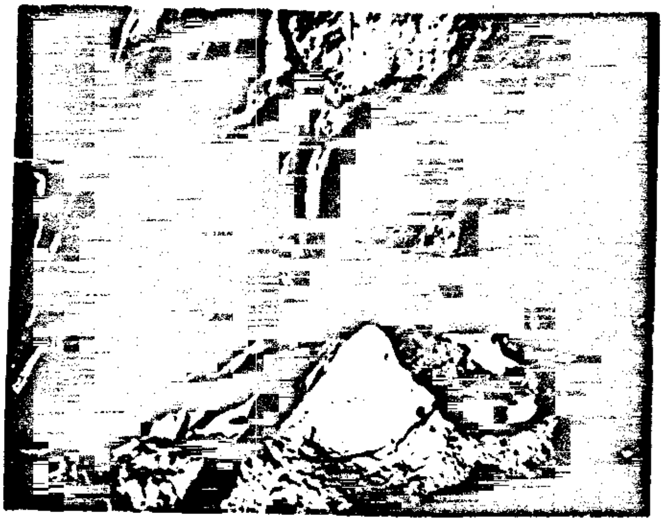


Fig. 6 - Electron Fractograph - Outside edge, fatigue mode, Area A.

Fig. 7 - Electron Fractograph - Middle cross-section, Area A

Fig. 8 - Electron Fractograph - Inside surface, Area A

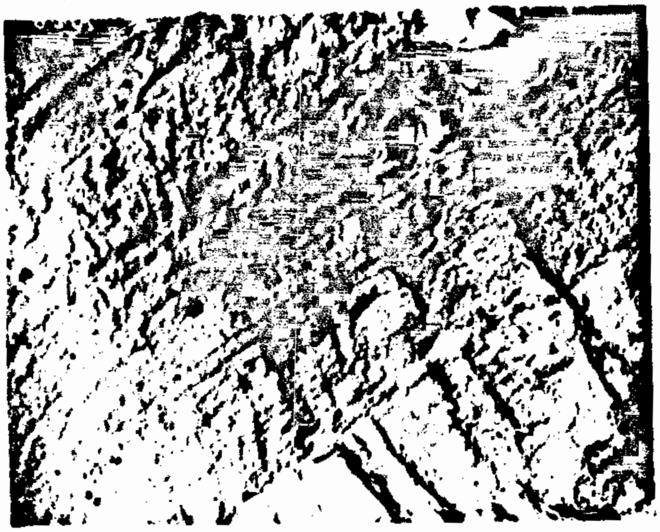


Fig. 9 - Electron Fractograph - Outside lip, Area B

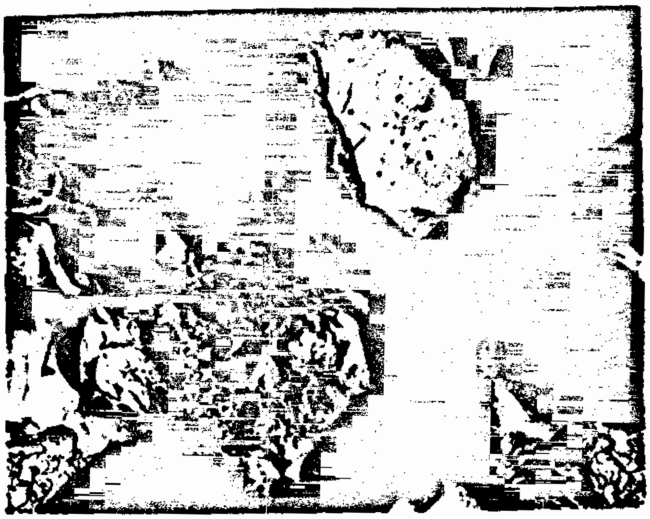


Fig. 10 - Electron Fractograph - Middle cross-section, Area B

Fig. 11 - Electron Fractograph - Inside edge, Area B

Fig. 12 - Electron Fractograph - Inside surface, Area B

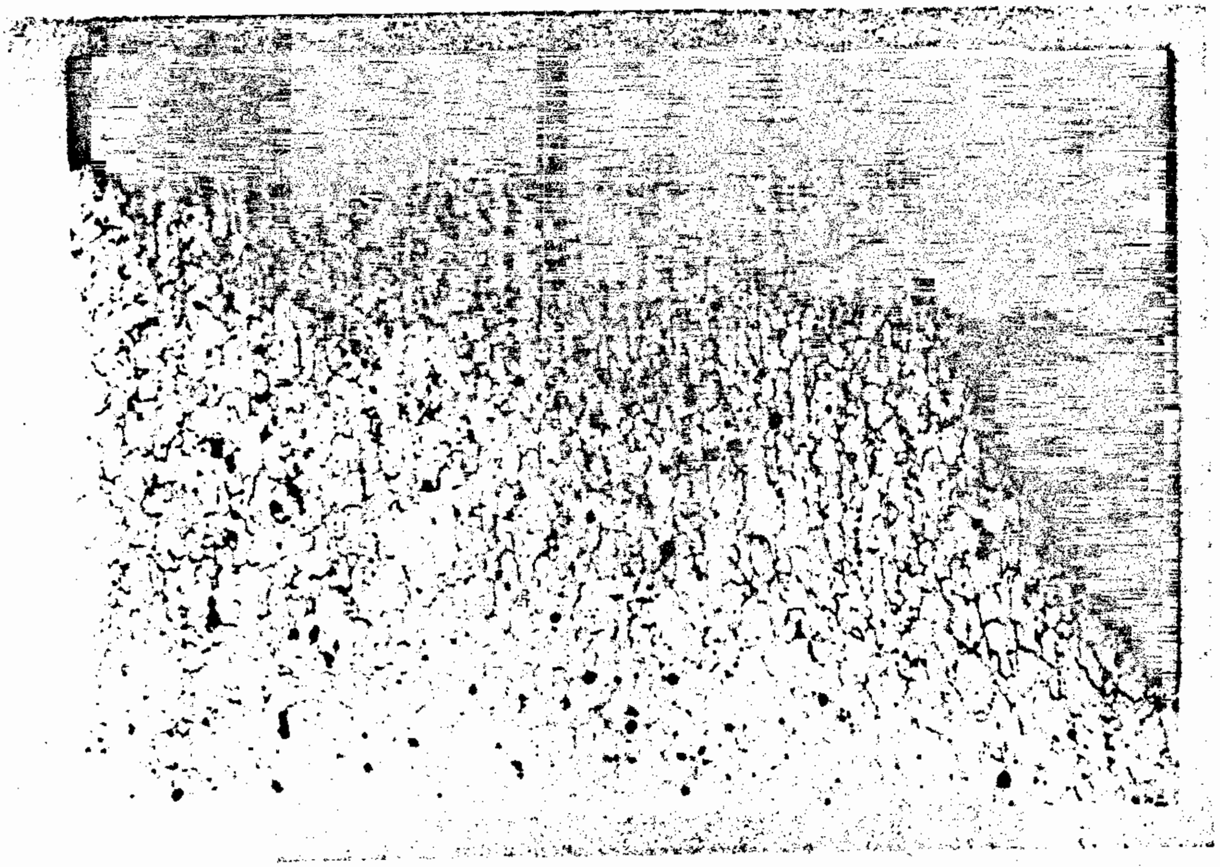


Fig. 13 - Photomicrograph (100X), etched
Fracture profile; shot peened groove.

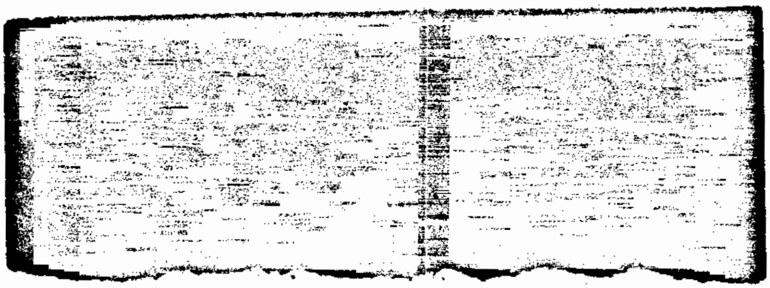


Fig. 14 - Photomicrograph (~250X), etched
Shot peened land surface profile.

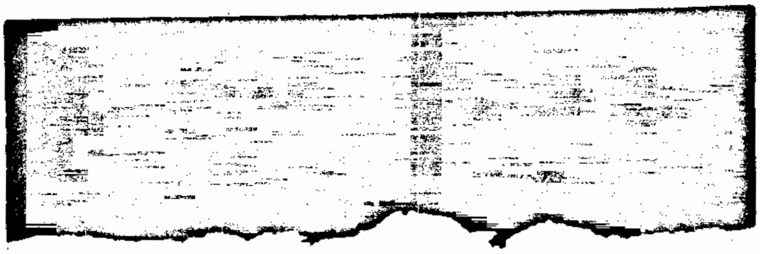
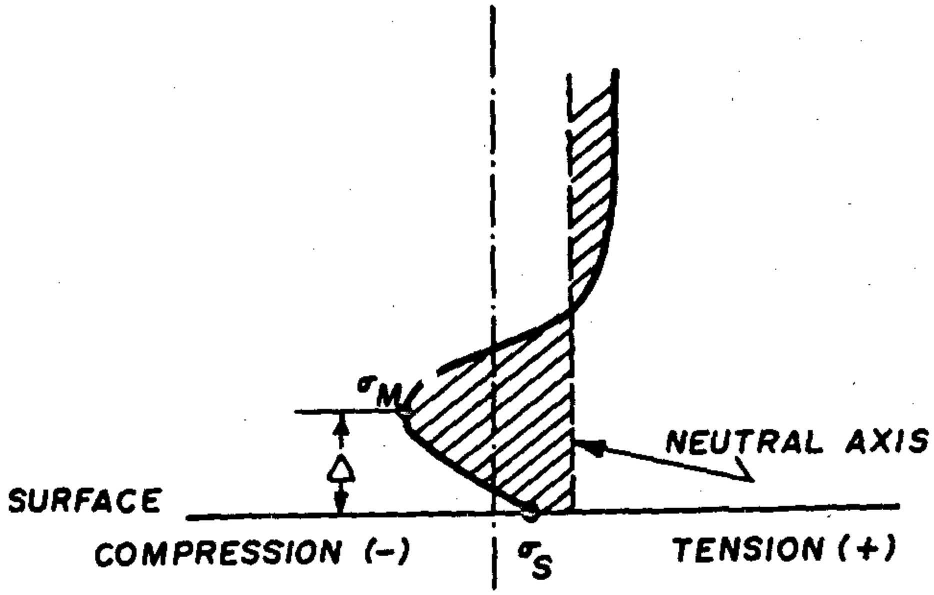
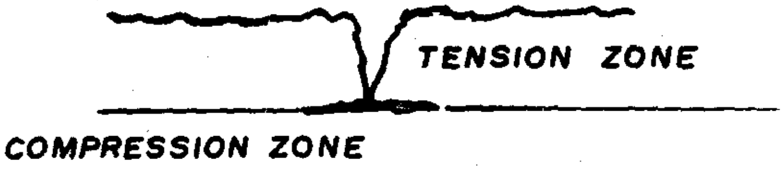


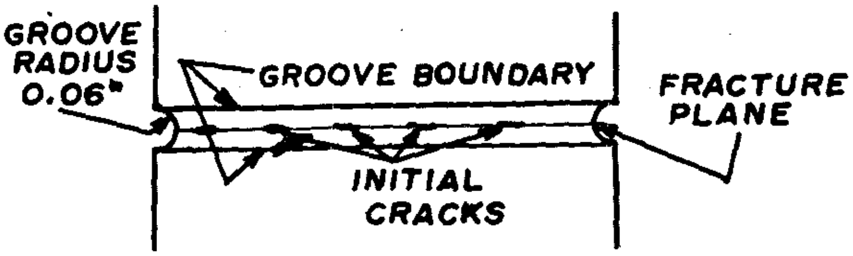
Fig. 15 - Photomicrograph (~250X), unetched
Shot peened land surface profile.



(a) RESIDUAL STRESSES AFTER SHOT-PEENING.



(b) CRACK INITIATION IN SHOT-PEENED SURFACE.



(c)

FIGURE 16 - SKETCHES OF SHOT-PEENED PART.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) AERO MATERIALS DEPARTMENT NAVAL AIR DEVELOPMENT CENTER WARMINSTER, PENNSYLVANIA 18974	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP None

3. REPORT TITLE
AIRCRAFT
EXAMINATION OF AN F8 / MLG SHOCK STRUT P/N 548100-521 FAILURE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
WILLIAM A. SIPES

6. REPORT DATE 2 October 1970	7a. TOTAL NO. OF PAGES 15	7b. NO. OF REFS 2

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. Analytical Rework Program, Work Request 1-5060 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NADC-MA-7061 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None

10. DISTRIBUTION STATEMENT Each transmittal of this document outside the Department of Defense must have prior approval of Commander, Naval Air Development Center or Commander, Naval Air Systems Command, Washington, D. C. 20360

11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY NAVAL AIR SYSTEMS COMMAND DEPARTMENT OF THE NAVY WASHINGTON, D. C. 20360

13. ABSTRACT
↓

A comprehensive fractographic examination of an F8 A/C MLG Shock Strut Piston showed that improperly applied shot peening contributed to the failure which was initiated by fatigue.

↑

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Failure analysis						
MLG strut piston						
Fractography						
Fatigue						
Corrosion						
Shot peening						
Residual stress						