NBSIR 79-1597

Examination of Components from a Mahler-Weber PJ-260 Aircraft

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Fracture and Deformation Division
Center for Materials Science
National Measurement Laboratory
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Failure Analysis Report

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

FIGURES (continued)

SUMMARY

The National Transportation Safety Board requested that the National Bureau of Standards characterize the fractures and determine the hardness of a number of components from a Mahler-Weber PJ-260 aircraft that had crashed and burned. Of the fractures examined, one exhibited evidence of a fatigue fracture mechanism. All of the other fractures appeared to have occurred via ductile overload. One of the components exhibited significant secondary cracking that had likely occurred before the time of the aircraft failure. That same component exhibited many large longitudinal stringer type inclusions.

Examination of Components From a Mahler-Weber PJ-260 Aircraft

1. INTRODUCTION

1.1 Reference

National Transportation Safety Board, Washington, D.C. 20594. This examination was conducted at the request of Mr. James F. Wildey II in a letter dated November 15, 1977.

1.2 Parts Submitted

A number of steel components from the aft fuselage/tail section of a Mahler-Weber PJ-260 aircraft, N4030B, were submitted to the National Bureau of Standards for examination. The parts, which were labeled 1 through 17, were submitted with the following descriptions:

Part No.	Part Description
1	Aft vertical fin spar/fuselage rudder post. This part mates with part no. 2.
2	Rear tail landing gear spring support and flying wire attachment.
3	Forward tail landing gear spring attachment tube. Parts nos. 3, 4, and 5 should mate.
4	Left fuselage diagonal tube.
5	Left lower fuselage longeron.
6	Left forward horizontal stabilizer. Parts nos. 6 and 7 mate.
7	Left forward inboard horizontal stabilizer spar.
8	Left rear inboard horizontal stabilizer spar. Parts nos. 8 and 9 should mate.
9	Left rear inboard horizontal stabilizer spar.
10, 11	Left horizontal stabilizer flying wire attachment bolt.
12	Right fuselage lower (inboard) horizontal strut attach fitting and bolt.
13	Lower end of right horizontal strut.

Part No.	Part Description
14, 15	Rear fuselage tubes. These tube sections may have been between part nos. 2 and 3.
16	Left inboard horizontal stabilizer rib.
17	Right horizontal upper (outboard) horizontal strut attach bolt.

The parts are shown as received at NBS in figure 1.

1.3 Background Information

The information in this section was furnished by the Federal Aviation Administration through the National Transportation Safety Board.

The aircraft lost the right horizontal stabilizer strut during aerobatic flight due to the failure of the right fuselage lower (inboard) horizontal strut attach fitting and bolt and the right horizontal upper (outboard) strut attach bolt. The aircraft landed without further incident. The left horizontal stabilizer strut was removed prior to the next flight. The aircraft was then flown to approximately 1500 feet (AGL) without the left and right struts and performed aerobatic maneuvers. After what appeared to be a normal descent, and during a normal turn at approximately 400 feet (AGL), the aircraft appeared to encounter empennage flutter. The left horizontal tail (horizontal stabilizer and elevator) separated from the aircraft in flight and the aircraft crashed and burned. One of the rear fuselage tubes (part no. 14) and the left horizontal tail were found along the flight path. The other unburned parts were thrown clear of the crash fire.

2. PURPOSE

The Federal Aviation Administration, through the National Transportation Safety Board, requested that the following tasks be performed:

1. Characterize the fracture between parts nos. 1 and 2.

2. Characterize the fracture separating parts nos. 3, 4 and 5 and determine the hardness of the material in these parts.

3. Characterize the fracture between parts nos. 6 and 7 and determine the hardness of the material.

4. Characterize the fracture between parts nos. 8 and 9 and determine the hardness of the material.

5. Characterize the fracture between parts nos. 10 and 11.

6. Characterize the fracture in part no. 12.

7. Characterize the fracture in part no. 17 and determine whether part no. 12 or part no. 17 failed first.

3. RESULTS OF EXAMINATIONS AND TESTS

3.1 Fractographic Examination

The fractures were examined macroscopically and with the scanning electron microscope (SEM). In those cases where both mating fracture surfaces were available, only the one appearing to be in the best condition was examined with the SEM.

For the fracture between parts nos. 1 and 2, the fracture had passed through part no. 1 adjacent to the point where the two parts had been welded together. Both fracture surfaces had suffered considerable mechanical damage as can be seen in figure 2 where both fracture surfaces are shown. In addition to the mechanical damage, there was a black deposit on the fracture surfaces and on the surrounding areas. The fracture surface remaining with part no. 2 was selected for examination with the SEM. It was cleaned ultrasonically with paint remover to remove the black deposit, and then with petroleum ether. There appeared to be some corrosion product on the fracture surface, so some further cleaning was undertaken with ammonium citrate to remove the rust. An SEM fractograph from this part is shown in figure 3. The fracture mode is unclear.

Among parts nos. 3, 4 and 5, the fracture surface of part no. 5 appeared to be in the best condition, even though the material was rather severely deformed adjacent to the fracture, and the fracture itself had suffered considerable mechanical damage. The fracture surface of part no. 5 was the only one of this group that was examined with the SEM. It is shown in figure 4 as it was received at NBS. In the region of the fracture that had not been damaged, dimpled rupture was the fracture mode. A representative fractograph is shown in figure 5.

For the fracture between parts nos. 6 and 7, the fracture passed through part no. 7 close to the point where part nos. 6 and 7 were welded together. The fracture surface of the major portion of part no. 7 was examined with the SEM. As can be seen in figure 6, this fracture exhibited much less mechanical damage than the previous two fractures that were discussed. Dimpled rupture was the fracture mode exhibited. A representative fractograph is shown in figure 7.

For the fracture between parts nos. 8 and 9, the fracture surface of the major portion of part no. 9 was examined with the SEM. This fracture is shown in figure 8 as it was received at NBS. As can be seen in the figure, the fracture exhibited rather severe mechanical damage. In a region where there was very little mechanical damage, there was evidence

of apparent fatigue striations. This region is indicated by the arrow in figure 8. Two fractographs showing examples of the striations appear in figures 9 and 10. The remaining part of the fracture that was examined with the SEM exhibited dimpled rupture as the fracture mode. A representative fractograph is shown in figure 11.

For the fracture between parts nos. 10 and 11, part 10 was selected for examination with the SEM. The fracture surface of part no. 10 is shown as received at NBS in figure 12. There was considereable deformation adjacent to the fracture of this part, and there was some necking. The fracture mode exhibited by the fracture was dimpled rupture. A representative fractograph is shown in figure 13.

The fracture surface of part no. 12 is shown in figure 14 as it was received at NBS. This fracture had been rather severely damaged mechanically and many of the fracture features had been obliterated. Nevertheless, dimpled rupture could be seen as the fracture mode. A representative fractograph is shown in figure 15.

The fracture surface of part no. 17 is shown in figure 16 as it was received at NBS. This part did not exhibit the degree of macroscopic deformation and necking that can be seen in part no. 10. The fracture mode exhibited by part no. 17 was dimpled rupture. A representative fractograph is shown in figure 17.

3.2 Metallographic Examination

Longitudinal sections intersecting the fractures were taken through the parts whose fractures were examined with the SEM in order to examine the fracture profiles and to facilitate taking hardness measurements.

A longitudinal section through the fracture surface of part no. 1 that was attached to part no. 2 showing the fracture profile appears in figure 18. At this location, the fracture passed through the heat affected zone in part no. 1 adjacent to the weld connecting part nos. 1 and 2. A considerable amount of deformation is exhibited adjacent to the fracture near the outside surface of part no. 1 (left side of the fracture profile in figure 18), but very little deformation is evident adjacent to the rest of the fracture profile. The fracture profile is relatively smooth. A higher magnification examination revealed no significant secondary cracking.

Part of the fracture profile of part no. 5 is shown in figure 19. There was a significant amount of deformation at the fracture adjacent to both the inside and the outside surfaces of the tubing. The fracture profile is relatively smooth and there is no significant secondary cracking.

The fracture profiles in two longitudinal sections through part no. 7 are shown in figures 20 and 21. The outside of the tubing wall is at the right in figure 20 and at the left in figure 21. In both locations, the

fracture profile is about 45° to the longitudinal axis of the tubing. In figure 21, the fracture appears to pass through the heat affected zone of the weld connecting part nos. 6 and 7 together, whereas in figure 20, the fracture passes through material that appears to have no visual effects from the welding operation -- hence, the difference in the microstructure between the two figures. Some macroscopic deformation was evident near the fracture in both sections. There was no significant secondary cracking.

Two longitudinal sections through part no. 9 showing the fracture profile appear in figures 22 and 23. The section shown in figure 22 was taken through the region of the fracture where apparent fatigue striations were detected. There was some deformation evident in the section shown in figure 23, but very little in the section shown in figure 22. The fracture profile in figure 22 is much smoother than that of figure 23. The reason for the difference in microstructure between the two sections is analogous to that given above for part no. 7 -- namely, in figure 23, the fracture passed through the heat affected zone of the weld connecting part nos. 8 and 9, whereas in figure 22, the fracture passed through material apparently unaffected by the welding operation. There was no significant secondary cracking.

A longitudinal section through part no. 10 showing a portion of the fracture profile appears in figure 24. There was a considerable amount of deformation and necking in the vicinity of the fracture. There was no significant secondary cracking.

As can be seen in figure 14, part no. 12 consisted of two layers of steel at the fracture. At the location where the part was sectioned, there was some deformation adjacent to the fracture, but very little necking. The fracture profiles of the two layers are shown in figures 25a and 25b. There was no significant secondary cracking in the section shown in figure 25a. There was a small amount of secondary cracking adjacent to the fracture in the layer shown in figure 25b, but away from the fracture, there was significant secondary cracking. Some of this cracking can be seen in figure 26 at a magnification of 100X. At higher magnifications, e.g., 500X, it appeared that the grains in the microstructure terminate at the cracks, which would imply that the cracks were present before the material was heat treated. In addition to the cracking, there are a number of longitudinal stringer type inclusions that parallel the one indicated by the arrow in figure 26. In some places, the secondary cracking follows the inclusions.

A longitudinal section through part no. 17 intersecting the fracture is shown in figure 27. There was some deformation adjacent to the fracture. There was no significant secondary cracking.

3.3 Hardness Measurements

Rockwell A (HRA) hardness measurements were made on several of the components. Four measurements were made in each case. The average HRA value and the HRA range for each component are given in the following table.

The approximately equivalent HRB or HRC average values are given for convenience.

	HRA			
Component	Average	Range	HRB Equiv.	HRC Equiv.
3	61	60-61	99	
4	66	65-66		31
5	62	62		23
6	64	63-65		27
7	58	56-59	95	
8	64	63-65		27
9	62	61-63		23

4. DISCUSSION

Most of the components had been mechanically damaged before being submitted for examination. In addition, some of the components were covered with a black deposit, possibly as a result of the fire that occurred when the aircraft crashed. Because of the mechanical damage, some of the fracture features had been obliterated. Nevertheless, it appeared that all of the fractures except for the one between part nos. 8 and 9 occurred due to ductile overload with dimpled rupture as the predominant fracture mode. Dimpled rupture is the expected fracture mode when the fracture mechanism is ductile overload. Several of the fractures occurred near welds connecting two components.

There was evidence of fatigue striations on the fracture surface of component no. 9 indicating that a crack had initiated and propagated some distance via fatigue before the time of the accident. The fatigue portion of the fracture passed through material that was close to the weld that connected part nos. 8 and 9.

In part no. 12, the fact that the grains in the microstructure terminate at the secondary cracks suggests that the cracking was probably present before the material was heat treated. The very long longitudinal inclusions in this part are considered detrimental, but they do not appear to have contributed to the fracture.

The NTSB had requested that NBS determine whether part no. 12 or part no. 17 failed first. It was not ascertained from the results of the NBS examination which of these parts failed first. However, part no. 12 did have a defect that was apparently present before the time of the failure of the aircraft.

In each of the components for which the hardness was determined, the hardness was rather consistent. There was, however, a significant variation in hardness among the various components.

5. CONCLUSIONS

1. The fracture surface of part no. 9 exhibited apparent fatigue striations indicating that fracture probably initiated via a fatigue crack.

2. The fracture surfaces of all the other components that were examined exhibited dimpled rupture indicating ductile overload as the fracture mechanism.

3. Part no. 12 exhibited significant secondary cracking. This cracking was likely present before the failure of the aircraft.

4. Part no. 12 exhibited a significant number of large, detrimental longitudinal inclusions.

5. Several of the fractures occurred in the vicinity of welds connecting two components.

6. ACKNOWLEDGEMENT

Metallographic specimen preparation and hardness measurements were performed by Leonard C. Smith of the NBS Fracture and Deformation Division. The photographic work was performed by Mr. Smith, and by Todd Eudy and Marcia Cline, both formerly of the NBS Fracture and Deformation Division.

Figure 1. Parts of the Mahler-Weber PJ-260 aircraft as received. X 1/5

Figure 2. Fracture surfaces of part no. 1 (top) and part no. 2 (bottom) as received at NBS. X 1/2

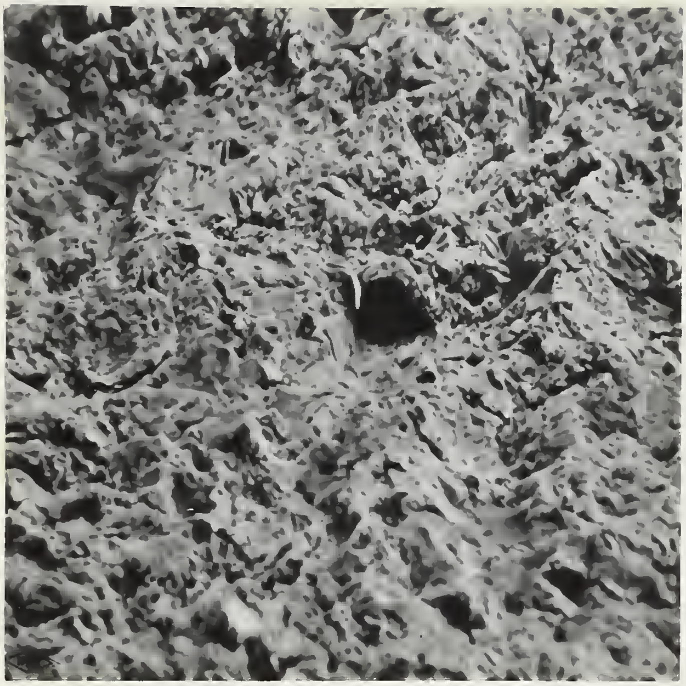

Figure 3. Representative SEM fractograph from part no. 2. X 900

Figure 4. Fracture surface of part no. 5 as received at NBS. X 2

Figure 5. Representative SEM fractograph from part no. 5. Dimpled rupture is the primary fracture mode. X 950

Figure 6. Fracture surface of part no. 7 as received at NBS. X 2

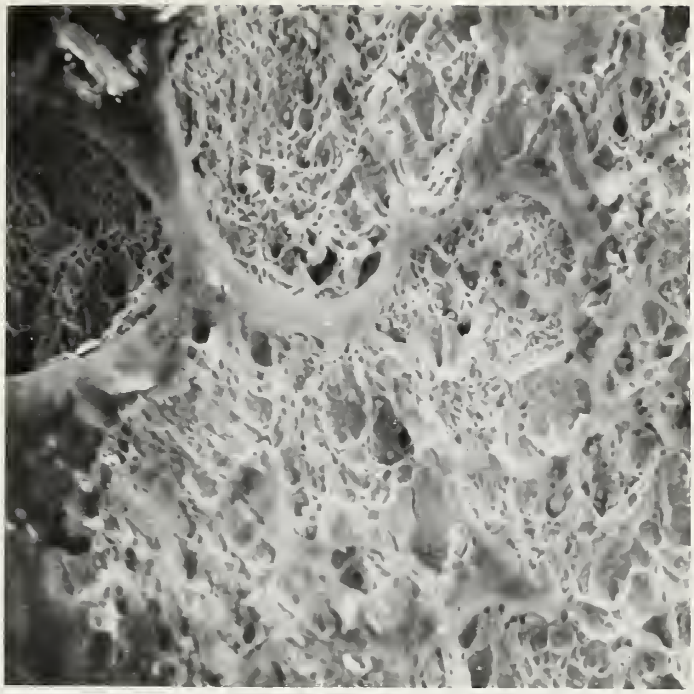

Figure 7. Representative SEM fractograph from part no. 7. Dimpled rupture is the primary fracture mode. X 550

Figure 8. Fracture surface of part no. 9 as received at NBS. Arrow indicates region of apparent fatigue striations as shown in figures 9 and 10. X 2

790057

X1210

Pat #9

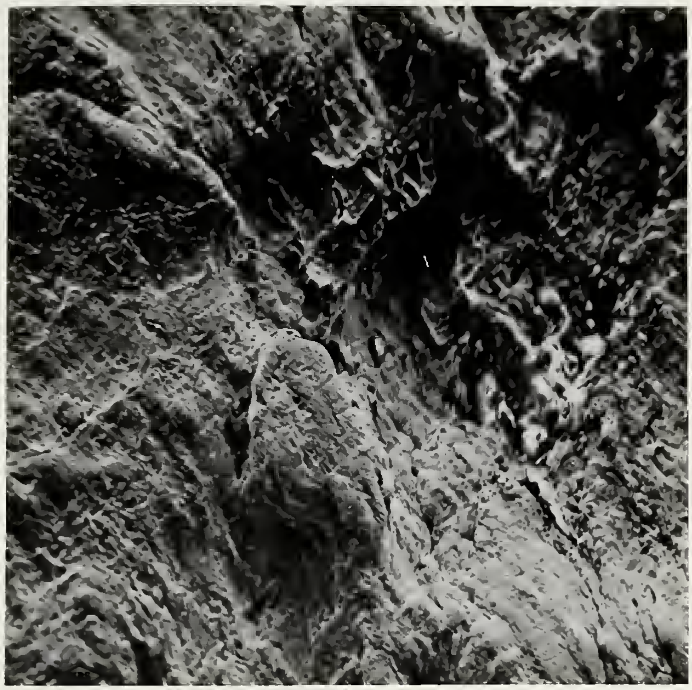

Figure 9. SEM fractograph from the region of the fracture of part no. 9 indicated by the arrow in figure 8. Apparent fatigue striations are evident. X 610

Figure 10. SEM fractograph from another area of the region indicated by the arrow in figure 8. Apparent fatigue striations are evident. X 1210

Figure 11. Representative SEM fractograph from an area away from that indicated by the arrow in figure 8. The primary fracture mode is dimpled rupture. X 1300

Figure 12. Fracture surface of part no. 10 as received at NBS. X 5

Figure 13. Representative SEM fractograph from part no. 10. The primary fracture mode is dimpled rupture. X 1100

Figure 14. Fracture surface of part no. 12 as received at NBS. X 5

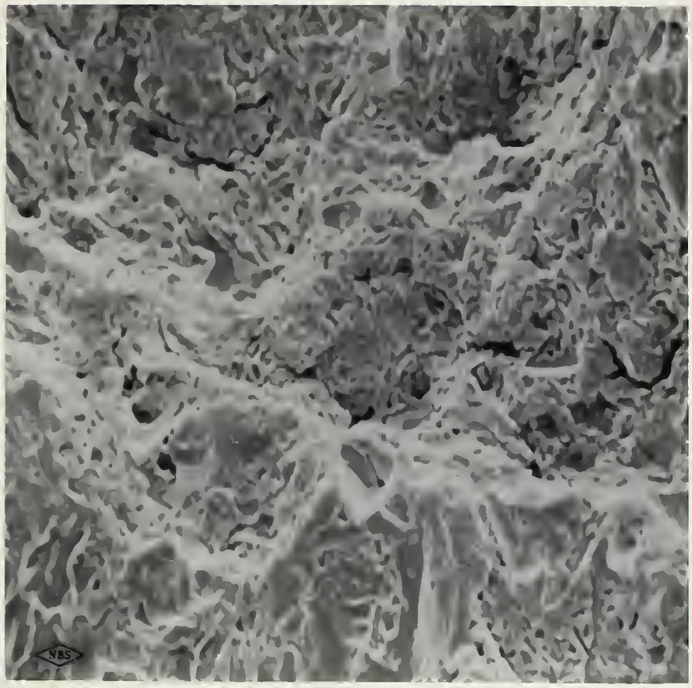

Figure 15. Representative SEM fractograph from part no. 12. The primary fracture mode exhibited here is dimpled rupture. X 925

Figure 16. Fracture surface of part no. 17 as received at NBS. X 5

Figure 17. Representative SEM fractograph from part no. 17. The primary fracture mode exhibited is dimpled rupture. X 1000

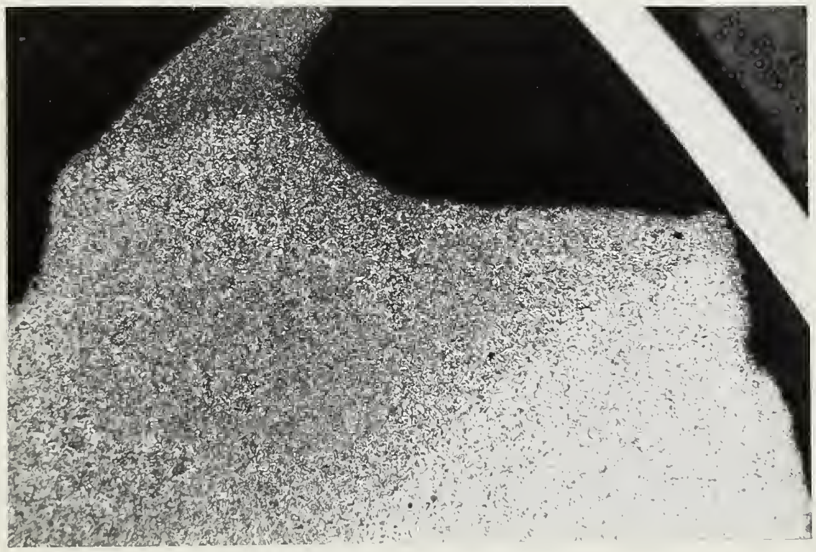

Figure 18. Longitudinal section intersecting the fracture attached to part no. 2. The fracture profile is at the top in the figure. Deformation is present at the left at the fracture. The fracture passes through the heat affected zone of the weld connecting part nos. 1 and 2.
Etchant: 4% picral X 80

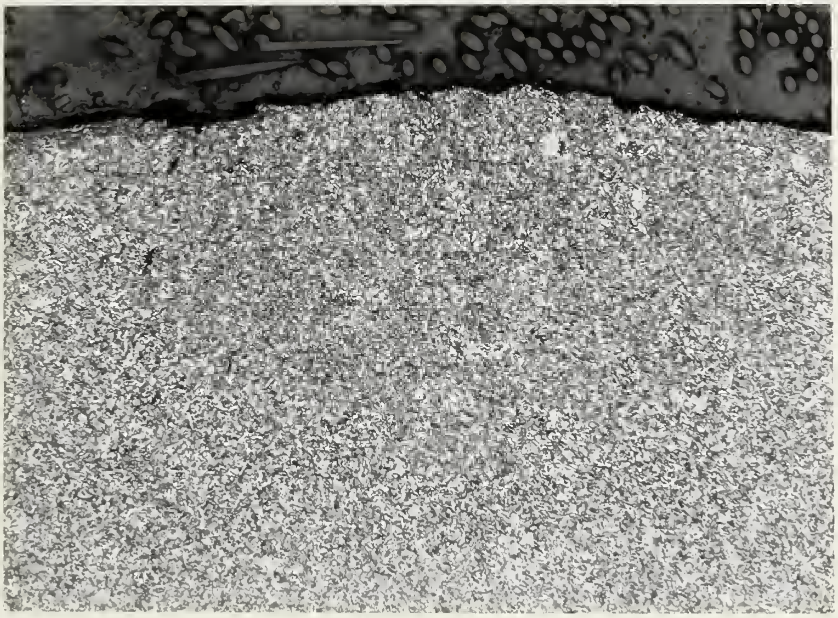

Figure 19. Section through part no. 5 showing the fracture profile (horizontal at the top).
Etchant: 4% picral X 200

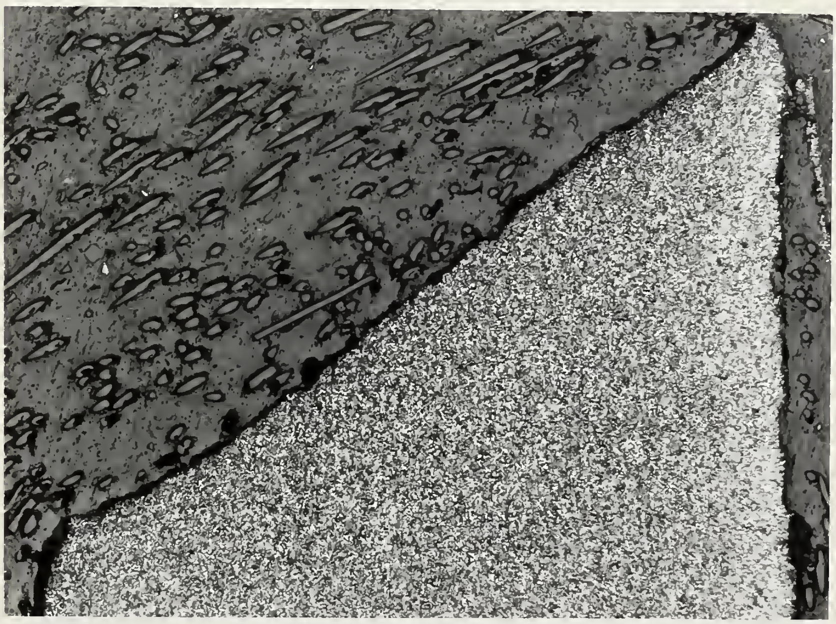

Figure 20. Longitudinal section through part no. 7 showing the fracture profile at the top. In this location, the fracture passed through material that shows no visual effects from welding.
Etchant: 4% picral X 100

Figure 21. Longitudinal section through part no. 7 showing the fracture profile at the top. In this location, the fracture passed through what appeared to be the heat affected zone of the weld connecting part nos. 6 and 7.
Etchant: 4% picral X 100

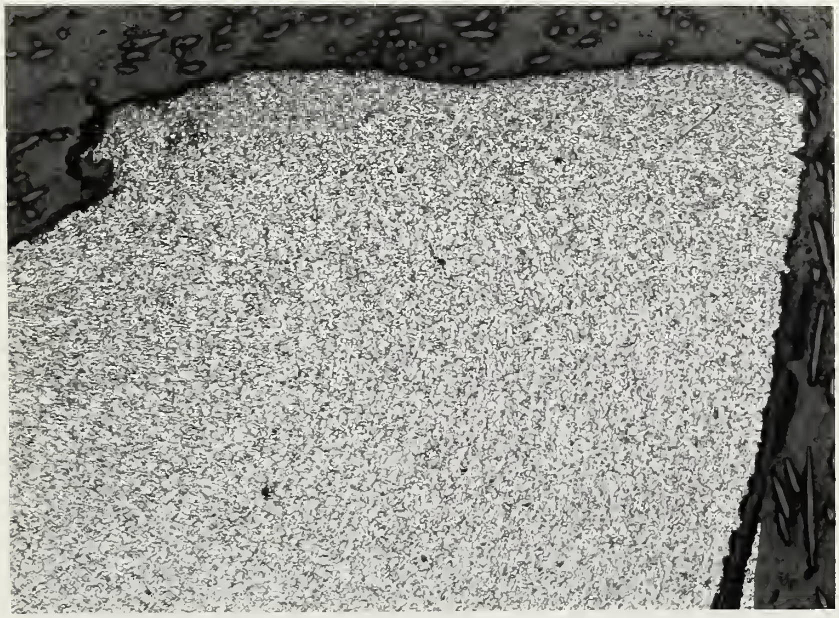

Figure 22. Longitudinal section through part no. 9 where apparent fatigue striations were detected. The fracture profile is at the top. At this location, the fracture passed through material that exhibited no visible effects from the welding operation.
Etchant: 4% picral X 100

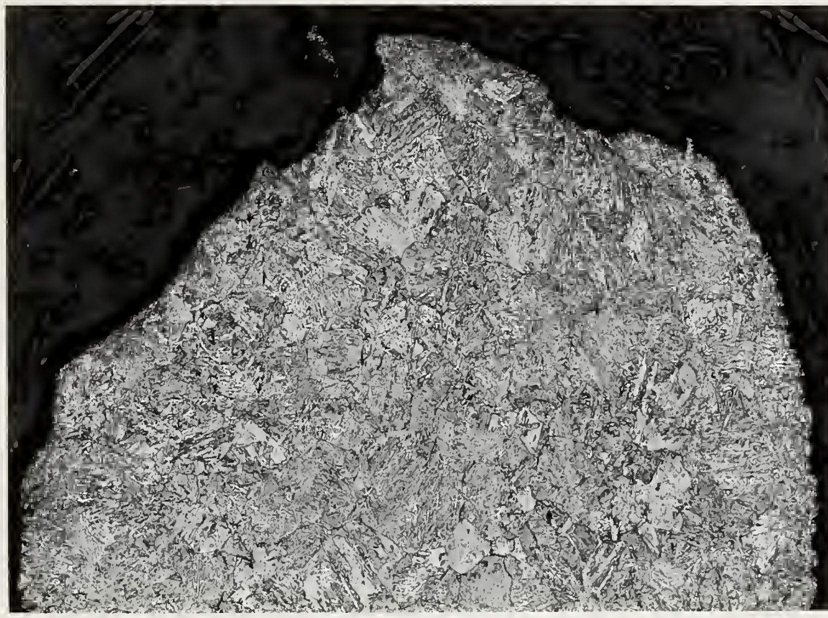

Figure 23. Longitudinal section through part no. 9 where the fracture mode was primarily dimpled rupture. At this location, the fracture passed through the heat affected zone of the weld connecting part nos. 8 and 9.
Etchant: 4% picral X 100

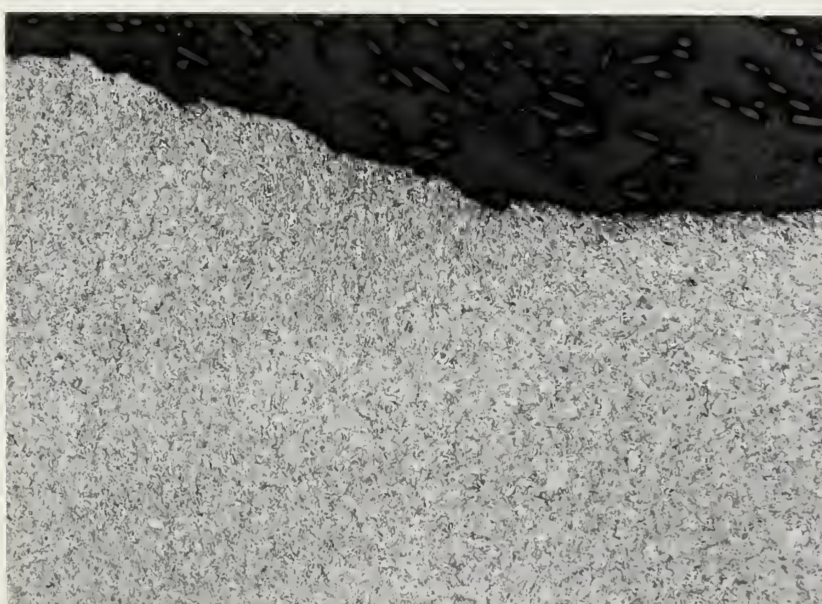

Figure 24. Longitudinal section through part no. 10 showing the fracture profile at the top.
Etchant: 4% picral X 100

a

b

Figure 25. Fracture profiles of the two layers of part no. 12. The fracture profiles are at the top in figures a and b. The layer shown in figure b exhibited secondary cracking away from the fracture as shown in figure 26.
Etchant: 4% picral X 80

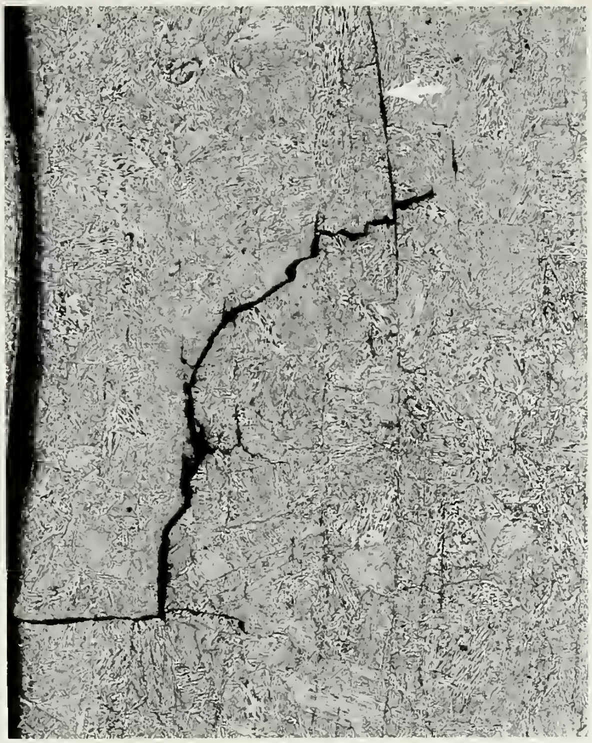

Figure 26. Longitudinal section through part no. 12 in a region away from the fracture showing significant secondary cracking. The field shown here is from the same section appearing in figure 25b. In addition to the secondary cracking, there are a number of long stringer type inclusions evident. These inclusions are parallel to the longitudinal axis if the part. The arrow indicates one of the inclusions.
Etchant: 4% picral X 100

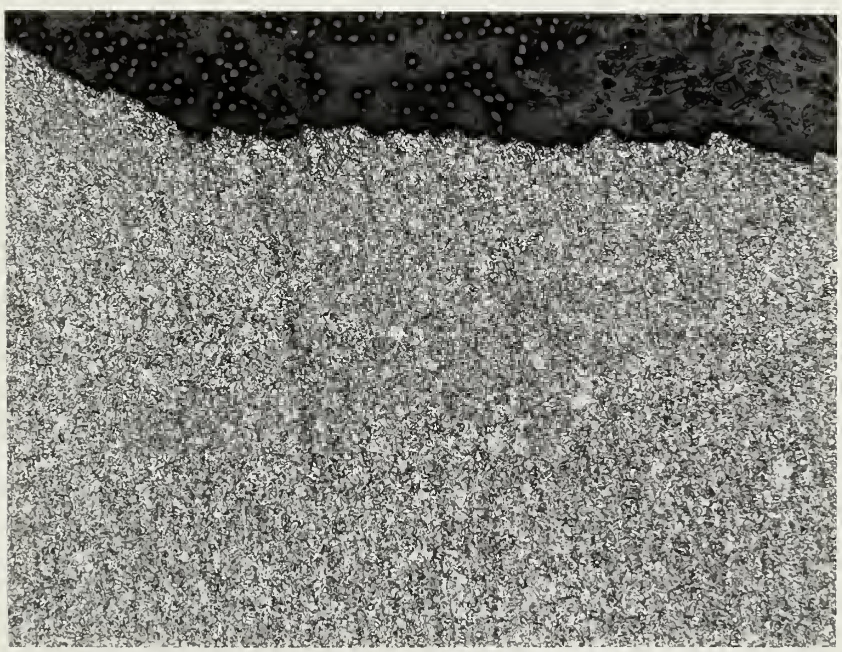

Figure 27. Longitudinal section through part no. 17 showing the fracture profile at the top.
Etchant: 4% picral X 100

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The National Transportation Safety Board requested that the National Bureau of Standards characterize the fractures and determine the hardness of a number of components from a Mahler-Weber PJ-260 aircraft that had crashed and burned. Of the fractures examined, one exhibited evidence of a fatigue fracture mechanism. All of the other fractures appeared to have occurred via ductile overload. One of the components exhibited significant secondary cracking that had likely occurred before the time of the aircraft failure. That same component exhibited many large longitudinal stringer type inclusions.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Aircraft failure; dimpled rupture; ductile failure; fatigue; fatigue striations.

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