NBSIR 74-468

Examination of Failed Aircraft Rudder Torque Tube Assembly

T. Robert Shives

Mechanical Properties Section
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National Bureau of Standards
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Failure Analysis Report

Prepared for

Bureau of Aviation Safety
National Transportation Safety Board
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Prepared for

Bureau of Aviation Safety
National Transportation Safety Board
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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FIGURES

FIGURES (Continued)

SUMMARY

The left rudder torque tube assembly from a Nieuport 28 Replica had failed when fracture occurred through the heat affected zone on the torque tube side of the welded joint between the torque tube and the pedal connecting tube. The fracture appeared to have been caused by tensile overload in bending, probably due to a force applied to the left pedal.

The primary feature exhibited by the fracture surface was dimpled rupture indicating ductile fracture. There were some areas of the fracture surface having an intergranular appearance. These were probably regions of gas porosity through which the fracture passed.

There was one small area of the fracture well removed from the fracture origin that exhibited a mixture of dimpled rupture and quasi-cleavage, indicating a somewhat brittle fracture in this area. This may indicate an unusually hard place in the heat affected zone. The heat affected zones adjacent to the welds in both the right and left assemblies were harder than desirable relative to the hardness of the parent tube material and the weld metal.

The prior austenite grain size in the heat affected zones adjacent to the welds of both assemblies was larger than desirable. Otherwise, the microstructures of the various regions appeared to be satisfactory. The weld metal and the parent tube material were relatively free of inclusions except for a few areas in the parent tube material in the right assembly which contained stringers.

There were several undesirable conditions associated with the welded joints, particularly that of the right assembly, such as apparent undercutting, a sharp angle between the two tubes, and gas porosity, a slag inclusion, and cracking in the heat affected zone. These conditions were much less severe in the welded joint of the left assembly, even though the left assembly was the one that failed.

Examination of Failed Aircraft Rudder Torque Tube Assembly

1. GENERAL INFORMATION

1.1 Reference

Bureau of Aviation Safety, National Transportation Safety Board, Department of Transportation, Washington, D.C. Request by Mr. Jerry A. Houck dated February 11, 1974.

1.2 Accident Identification

Nieuport 28 Replica, registration number N2SR. The accident occurred on January 21, 1974 at Indian Dunes, California.

1.3 Part Identification

Left and right rudder torque tube assemblies were submitted for examination. The left assembly had failed when the tube connecting the left pedal to the torque tube had separated from the torque tube. The parts are shown as received in figure 1.

2. PURPOSE

The Bureau of Aviation Safety requested a failure analysis of the failed part.

3. RESULTS OF EXAMINATIONS, ANALYSES, AND MEASUREMENTS

3.1 Visual Examination

The tube connecting the left pedal to the left torque tube (referred to as the left pedal connecting tube in this report) had separated from the torque tube where the two tubes had been welded together. Fracture occurred adjacent to and on the torque tube side of the weld. Assuming the pedal connecting tube to be vertical (or nearly so) in service, the fracture apparently started at the back of the welded joint and propagated across both sides toward the front, with respect to the fore and aft directions of the aircraft. The region of fracture initiation is indicated by the arrows in the left part of figure 1. The front of the welded joint appeared to be the last part to fail.

The fracture surface on the left pedal connecting tube side of the failure is shown in the lower part of figure 2. A curved disk, part of the torque tube, can be seen attached to the pedal connecting tube at the welded joint. The location of this disk is indicated by the letter A in figure 2. The presence and location of this portion of the torque tube relative to the fracture indicates that the wall of the torque tube had been melted through when the welded joint was made. In addition, the presence and location of what appears to be weld metal around the circumference of the joint also indicates that the weld had penetrated the wall of the torque tube.

There was considerable deformation in the torque tube in the vicinity of the fracture, as can be seen in figure 2. Near the front of the fracture, the torque tube had been "pushed" inward. This was apparently caused by the application of a bending load on the welded joint between the pedal connecting tube and the torque tube after it had been partially fractured. The bending load was likely caused by a force exerted on the pedal. There was some "necking" or thinning of the torque tube wall in the vicinity of the fracture origin.

Both the left and right pedal connecting tubes were sectioned longitudinally, through the welded joint for the right tube and intersecting the fracture for the left tube. While the inner wall surface of the failed left pedal connecting tube was relatively clean, there was a considerable amount of corrosion product found inside the intact right pedal connecting tube. Some of this corrosion product can be seen in figure 3.

3.2 Fractographic Examination

Both of the opposing fracture faces were examined macroscopically, and the fracture surface on the pedal connecting tube side of the failure was examined with the scanning electron microscope (SEM). There was a significant amount of mechanical damage on the fracture surface at both the back and front. The fracture surfaces appeared to have been smeared as though the pedal connecting tube fracture surface had rubbed across the torque tube fracture surface. The appearance of the fracture surfaces indicated that the fracture had been completed by bending the pedal connecting tube forward relative to the torque tube (assuming the pedal connecting tube to be in a nearly vertical position in service). This is consistent with the deformation observed in the torque tube.

The primary feature found in essentially all areas of the fracture surface examined with the SEM was dimpled rupture, indicating a ductile failure. Typical examples of this are shown in figures 4 and 5. In one area, however, there was evidence of quasi-cleavage (figure 6) which indicates brittle fracture. The quasi-cleavage was found near one side of the fracture surface and does not appear to be related to the apparent origin of the fracture.

In several isolated areas of the fracture surface, there were small regions having an intergranular appearance. Two examples of this are shown in figures 7 and 8. Dimpled rupture is exhibited along the sides of many of the grains shown in these figures. As indicated by an examination of the microstructure, which will be discussed later, the fracture passed through an area of the heat affected zone adjacent to the weld where the microstructure is martensitic. The sizes and shapes of the grains shown in figures 7 and 8 indicate that the fracture surface is probably following prior austenite grain boundaries in these regions. Some secondary cracking and porosity are evident in figures 6, 7, and 8. Mechanical damage is evident in figure 7.

3.3 Thickness and Diameter Measurements

After chemically removing the paint on the surface of the tubes, wall thickness measurements were made on the left pedal connecting tube about 1/4 inch from the fracture and near one end of each of the torque tubes. Ten measurements were made in each of these three areas at approximately equal circumferential intervals. The results are as follows:

Component	Thickness (in.)	
	Average	Range
Fractured left pedal connecting tube	0.0356	0.034 - 0.037
Left torque tube	0.0348	0.034 - 0.036
Right torque tube	0.0356	0.035 - 0.036

Minimum and maximum outside diameter measurements were made on the same three tubes in the same areas that the wall thickness measurements were made with the following results:

Component	Outside Diameter (in.)		
	Minimum	Maximum	Average
Fractured left pedal connecting tube	0.731	0.769	0.750
Left torque tube	0.751	0.753	0.752
Right torque tube	0.748	0.752	0.750

The left pedal connecting tube was somewhat out of round, but the nominal diameter of all three tubes was essentially the same.

3.4 Chemical Analyses

In order to classify the steels from which the tubes had been fabricated, semi-quantitative chemical analyses by emission spectroscopy were performed by the NBS Analytical Chemistry Division on samples from the left torque tube and the left pedal connecting tube. Similar amounts of those elements detected were found in the material from both tubes. The results are as follows:

Element	Per Cent (weight)
Nickel	0.1 - 1.0
Molybdenum	0.03 - 0.3
Chromium	0.1 - 1.0
Manganese	0.1 - 1.0
Silicon	0.03 - 0.3
Copper	0.03 - 0.3
Vanadium	< 0.01

Samples from these same two tubes were analyzed by combustion techniques for carbon with the following results:

Component	Per Cent Carbon (weight)
Left pedal connecting tube	0.27
Left torque tube	0.31

No analyses for phosphorus or sulfur were made. Based on the analyses performed, the material from both tubes appears to be essentially the same low alloy, medium carbon steel, probably AISI 8627-8630[1].

A qualitative chemical analysis by electron microprobe techniques was performed by the NBS Analytical Chemistry Division on the weld material. In addition to iron, chromium and manganese were found in amounts of less than two percent. No major differences were found between the weld metal and the tube material. The system did not allow the detection of nickel, and the samples were not analyzed for elements with atomic numbers lower than that of sodium.

3.5 Metallographic Examination

3.5.1 As polished cross sections

3.5.1.1 Left assembly

Two longitudinal cross sections were taken through the left pedal connecting tube intersecting the fracture at the weld between the left torque tube and the pedal connecting tube. One cross section, shown in figure 9a, was in a plane perpendicular to the longitudinal axis of the torque tube. The other, shown in figure 9b, was in a plane parallel to the longitudinal axis of the torque tube.

The tube material in both cross sections was relatively free of inclusions, and no areas containing large inclusions were found. Figure 10 shows a field with a typical inclusion content. No areas of gas porosity or welding slag were found in the material, although the SEM fractographs indicated that the fracture had passed through regions of gas porosity.

The angle between the tubes at the arrow in figure 9a is rather severe with essentially no fillet, although this is on the inside of the welded joint. There is what appears to be a large deposit of welding flux or slag at this same location, which is shown at higher magnification in figure 11. There is little or no evidence of undercutting in these two cross sections.

3.5.1.2 Right assembly

Two longitudinal cross sections were taken through the right pedal connecting tube in locations similar to those taken through the left torque tube assembly. A photomacrograph of one, in a plane perpendicular to the longitudinal axis of the torque tube, is shown in figure 12a. The other cross section, in a plane parallel to the longitudinal axis of the torque tube, is shown in figure 12b.

An accumulation of corrosion product on the inside of the right pedal connecting tube was shown in figure 3. As can be seen in figure 12, the interior wall surface of the pedal connecting tube and the outside wall surface of the torque tube enclosed by the connecting tube at the weld have suffered corrosive attack. Arrows A, figure 12, indicate examples of corroded areas. The results of corrosive attack were much more severe on the interior wall surface of the right pedal connecting tube than in the left pedal connecting tube, which is consistent with the visual appearance of the inside wall surfaces of the tubes.

A small crack starting at the inner wall surface of the right pedal connecting tube was found in an area of the heat affected zone and is indicated by arrow B in figure 12b. This is shown at higher magnification in figure 13.

Two areas of large, stringer type inclusions in the torque tube material are indicated by arrows C in figure 12b. One of these is shown at higher magnification (arrow C) in figure 14. Except for a few isolated areas, the overall inclusion content was essentially the same as that found in the tube material in the left assembly.

There are some undesirable conditions associated with the welded joint in the right assembly which can be seen in figure 12. Arrows D, figure 12b, indicate an area in the heat affected zone which appears to be a combination of gas porosity and a slag inclusion. A crack (arrow E, figure 12b) appears to have propagated between the porosity-slag region and the surface. There is corrosion product in the crack as can be seen in figure 15.

There are areas (indicated by arrows F in figure 12) of what appear to be undercutting[2]. Arrow G, figure 12a, indicates a condition which, if on the outside of the joint, would appear to be an overlap[2]. The angle between the two tubes at this point is rather severe and there is essentially no fillet.

3.5.2 Etched cross sections

3.5.2.1 Left assembly

Photomacrographs of the two cross sections shown as polished in figure 9 are shown in the etched condition in figure 16. The microstructure of the parent tube material away from the heat affected zones (in areas indicated by arrows A, figure 16) is similar for both tubes. It consists primarily of pearlite and ferrite with some spheroidized cementite[3]. A typical field is shown in figure 17. There is some decarburization adjacent to the outside surface of the tube material as can be seen in figure 18. The microstructure of the weld metal (areas indicated by arrows B, figure 16) appears to consist of coarse tempered martensite[3]. A typical field in the weld is shown in figure 19.

There are two distinctly different microstructures in different areas of the heat affected zones. Adjacent to the weld (locations indicated by arrows C, figure 16), the microstructure consists of coarse grained martensite outlined by the grain boundaries of prior austenite grains. An example of this microstructure is shown in figure 20. Close to the parent tube material (areas indicated by arrows D, figure 16), the microstructure appears to consist of martensite and some ferrite. An example of this is shown in figure 21.

The fracture profiles of the cross sections shown in figures 9a and 9b are shown in figures 22 and 23, respectively. It can be seen that the fracture passed through the heat affected zone. There is some secondary cracking evident in figure 22, and these cracks appear to be following the grain boundaries of the prior austenite. The fracture path appears to be transgranular for the most part.

3.5.2.2 Right assembly

The microstructures of the parent tube material, the weld metal, and the material in the heat affected zones in the cross sections from the right assembly shown in figure 12 are essentially the same as in corresponding regions of the cross sections through the left torque tube assembly as discussed in section 3.5.2.1.

The area containing the gas porosity and the slag inclusion (arrow D, figure 12b) and the crack connecting them to the surface of the tube (arrow E, figure 12b) is shown in the etched condition in figure 24. It can be seen that these defects are in the heat affected zone.

3.6 Hardness Measurements

Knoop microhardness measurements at a load of 500 grams were made on the same cross sections used for the metallographic examination. The range of Knoop hardness numbers (KHN) for the various regions of the cross sections, and the approximate Rockwell C equivalent hardness numbers, are given below:

Region	KHN_{500}	R_C
Left pedal connecting tube	265-291	23-27
Left torque tube	264	23
Left assembly heat affected zones		
Adjacent to the weld	441-551	43-51
Adjacent to the parent tube	359-420	36-42
Right pedal connecting tube	267-300	23-28
Right torque tube	240-279	20-24
Right assembly heat affected zones		
Adjacent to the weld	420-574	42-52
Adjacent to the parent tube	394-444	39-43

The hardness of the tube material and the weld metal in both assemblies was very similar, but some areas of the heat affected zones, particularly adjacent to the welds, were considerably harder.

4. DISCUSSION

The fracture in the left rudder torque tube assembly occurred in the heat affected zone adjacent to the weld joining the left pedal connecting tube to the left torque tube. The fracture was on the torque tube side of the weld. The primary feature found on the fracture surface was dimpled rupture (ductile fracture), indicating that the fracture was probably due to tensile overload. The appearance of the fracture surface and the deformation in the torque tube indicates that the overload was caused by a bending stress, probably induced by a force applied to the left pedal. The pedal connecting tube acted as a bending moment arm which amplified the load received at the point of failure.

Assuming that the pedal connecting tube was in a vertical (or nearly so) position in service relative to the longitudinal axis of the aircraft, the appearance of the fracture and the deformation in the torque tube indicate that the fracture initiated at the back (relative to the back and front of the aircraft) and propagated toward the front. This is consistent with the bending load having been applied at the pedal.

The significance of the one small area of the fracture surface exhibiting a mixture of dimpled rupture and quasi-cleavage is unclear. The quasi-cleavage does not appear to be associated with the fracture origin, but the presence of this feature indicates a somewhat brittle fracture area. This may be an unusually hard region in the heat affected zone.

There were several small, isolated areas of the fracture surface that had an intergranular appearance. This probably indicates regions of gas porosity in the heat affected zone through which the fracture passed. The microstructure in this part of the heat affected zone consisted of martensite outlined by the grain boundaries of large prior austenite grains. The intergranular appearance indicates that the fracture probably followed these grain boundaries in these areas.

The parent tube material in both assemblies appeared to be clean, except for a few isolated areas in the right assembly, and the weld material appeared to be free of inclusions. The etched microstructures in both assemblies appeared to be satisfactory except possibly for that of the heat affected zones adjacent to the welds. As mentioned above, the martensite in these zones was outlined by grain boundaries of large prior austenite grains. A finer grained microstructure would be more desirable.

The hardness of the tube material, in areas away from the heat affected zones, was similar for both torque tubes and both pedal connecting tubes. Based on the hardness, the approximate ultimate tensile strength of the tube material would be about 110 to 130 ksi. The hardness of the weld metal was similar to that of the parent tube material.

The hardness of the material in the heat affected zones adjacent to the parent tube material was greater than that of the parent tube and the weld metal, and the hardness of the heat affected zones adjacent to the welds was significantly greater than that of any of the other areas where the hardness was determined. The fracture passed through this relatively hard zone. Even though this fracture was primarily ductile, a very hard heat affected zone could lead to a region of brittle material. It would be desirable for the hardness of all the regions in the welded joint to be similar. Large differences in hardness could result in unfavorable stress patterns at the boundaries between adjacent regions.

The most detrimental single condition, in addition to differences in hardness, found in either assembly was associated with the heat affected zone adjacent to the welded joint between the right torque tube and the right pedal connecting tube. There was a large gas porosity-slag inclusion combination which was connected to the surface by an apparent crack. Corrosion product in the crack indicates that the crack is not fresh. It may have formed when the joint was cooled after welding. The cross section of the material could be significantly reduced at the location of the gas porosity-slag inclusion-crack, which would in turn result in a reduced load carrying capacity. The areas of intergranular features on the left assembly fracture indicate that there probably was porosity in the heat affected zone of this weld also.

Other undesirable features associated with the weld areas such as undercutting and the results of corrosive attack appeared to be worse in the intact right assembly than in the failed left assembly. These features do not appear to have contributed to the failure.

Chemical analyses indicate that the material in the left torque tube assembly and the left pedal connecting tube was essentially the same medium carbon, low alloy nickel-chromium-molybdenum steel. The results of the analyses of the tube material and the weld material do not indicate incompatibility of materials at the welds.

The wall thicknesses and diameters of the tubes measured were all nominally the same, although the left pedal tube was considerably out of round at the place the diameter was measured.

The inside wall surface of the right pedal connecting tube exhibited corrosion product. The inside wall surface of the left pedal connecting tube showed little evidence of corrosive attack. Corrosion did not appear to be a significant contributing factor in the failure.

5. CONCLUSIONS

1. The left torque tube assembly failed due to a tensile overload caused by a bending load probably applied at the left pedal.

2. Fracture occurred through the heat affected zone on the torque tube side of the welded joint between the left pedal connecting tube and the left torque tube.

3. The primary feature exhibited by the fracture surface was dimpled rupture indicating a ductile fracture.

4. Small areas of the fracture surface exhibited an intergranular appearance indicating that the fracture passed through regions of possible gas porosity in the heat affected zone.

5. There were a number of undesirable conditions associated with the welded joint between the right torque tube and the right pedal connecting tube such as apparent undercutting, a sharp angle between the two tubes with essentially no fillet, and gas porosity, a slag inclusion, and cracking in the heat affected zone.

6. The undesirable conditions associated with the welded joint in the right assembly (conclusion 5, above) were much less severe in the welded joint in the failed left assembly, and none except possibly gas porosity appeared to have contributed to the failure.

7. The hardness of the heat affected zones adjacent to the welds was undesirably high relative to that of the other regions.

8. A small area of the fracture surface exhibited a mixture of dimpled rupture (ductile fracture) and quasi-cleavage (brittle fracture) which may indicate an unusually hard region of the heat affected zone.

9. The tube material was relatively free of inclusions except for a few isolated areas where there were large stringers. These were not involved in the fracture.

10. The weld metal appeared to be clean and free of inclusions.

11. The microstructures of the various regions appeared to be satisfactory except possibly for that of the heat affected zones and adjacent to the welds which consisted of martensite outlined by the grain boundaries of larger than desirable prior austenite grains.

12. The results of semi-quantitative chemical analyses indicate that the left torque tube and the left pedal connecting tube were both fabricated from essentially the same medium carbon, low alloy steel, probably AISI 8627 - 8630.

13. Based on limited semi-quantitative chemical analyses, the tube material and the weld metal appear to be compatible.

14. The nominal wall thicknesses and diameters of both torque tubes and both pedal connecting tubes were the same.

15. The inside wall surface of the right pedal connecting tube exhibited results of corrosive attack.

16. The inside wall surface of the left pedal connecting tube showed little evidence of corrosive attack, and corrosion does not appear to have contributed to the failure.

6. ACKNOWLEDGEMENT

Mr. L. C. Smith of the NBS Mechanical Properties Section prepared the metallographic specimens, performed the photographic work, and made the hardness and dimensional measurements.

REFERENCES

1. Heat Treatment and Properties of Iron and Steel, NBS Monograph 88, National Bureau of Standards, 1966.

2. Welding Handbook, 5th Edition, American Welding Society, 1962.

3. Metals Handbook, American Society for Metals, Volume 7, 8th Edition, 1972.

Figure 1. Failed left and intact right rudder torque tube assemblies as received. The apparent origin of the fracture of the left assembly is indicated by the arrows.

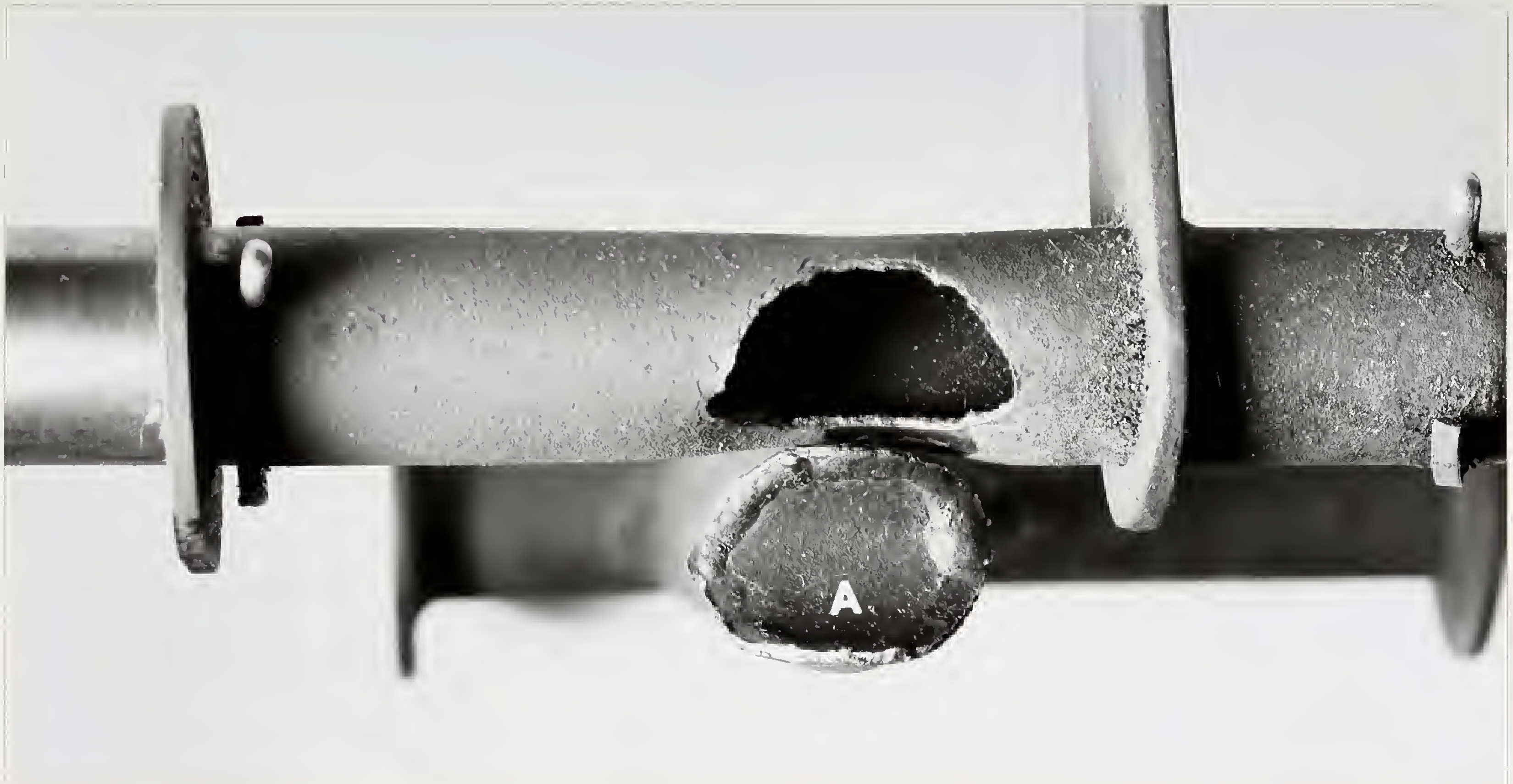


Figure 2. Opposing fracture surfaces of the left torque tube (top) and the left pedal connecting tube (bottom). A curved disk portion from the torque tube which remained joined to the pedal connecting tube is designated by the letter A. X 2

Figure 3. Corrosion product in the right pedal connecting tube adjacent to the welded joint between the connecting tube and the torque tube. X 2

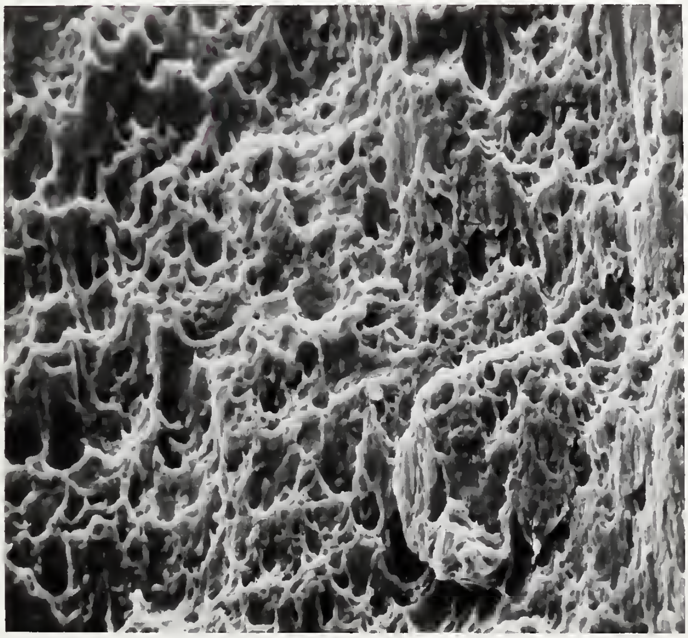


Figure 4. SEM fractograph from the back part of the fracture showing dimpled rupture. X 1190

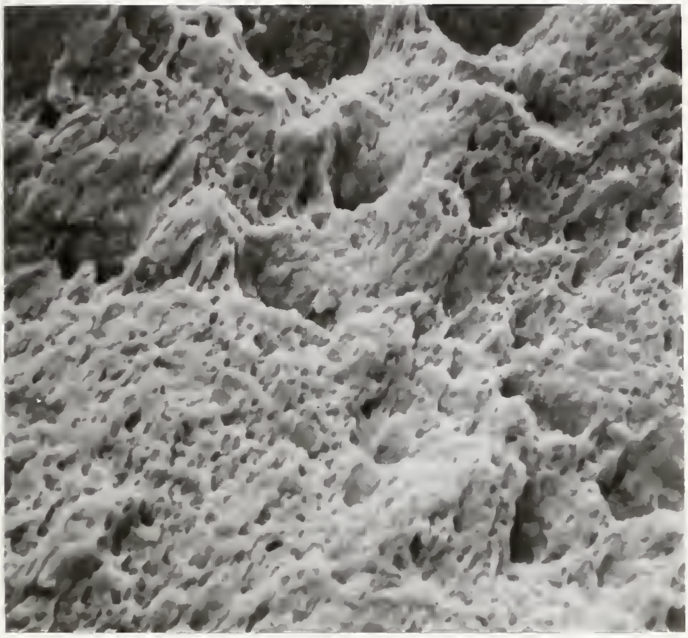


Figure 5. SEM fractograph from the front part of the fracture showing dimpled rupture. X 1150

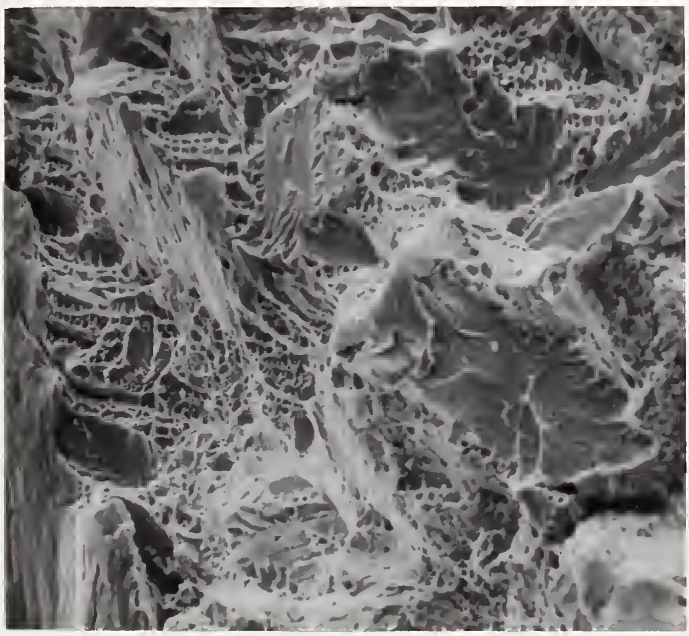


Figure 6. SEM fractograph from the side of the fracture surface showing a mixture of dimpled rupture and quasi-cleavage. Some porosity is evident. X 510

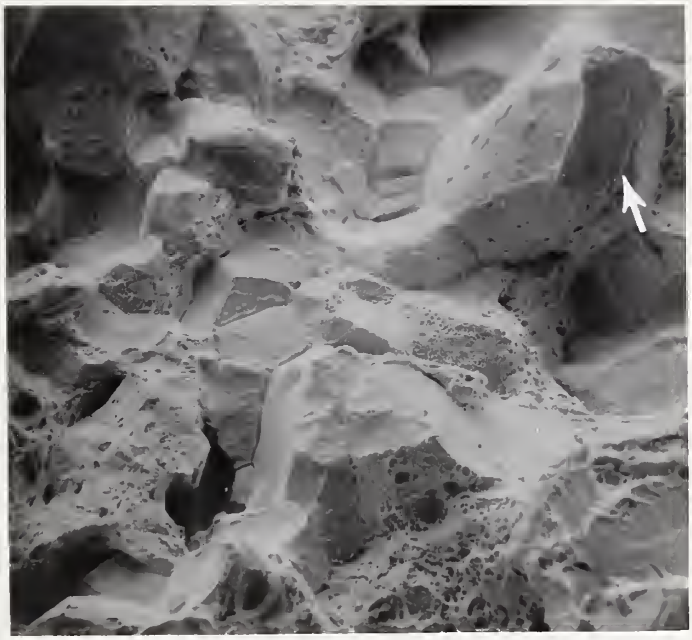
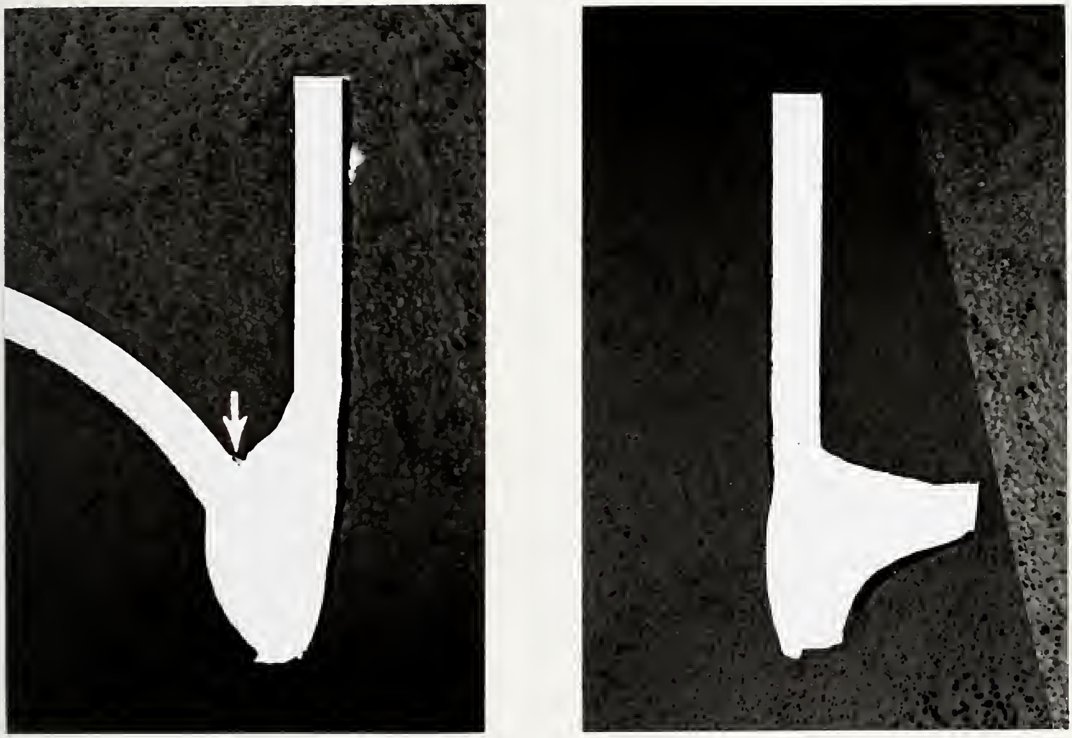


Figure 7. SEM fractograph from the back part of the fracture showing an intergranular appearance. Dimpled rupture can be seen on the sides of several of the grains. The arrow indicates an area of mechanical damage. Some porosity is evident. X 260

Figure 8. SEM fractograph from the front part of the fracture showing an intergranular appearance. Some dimpled rupture is evident and there is some porosity. X 650



a b

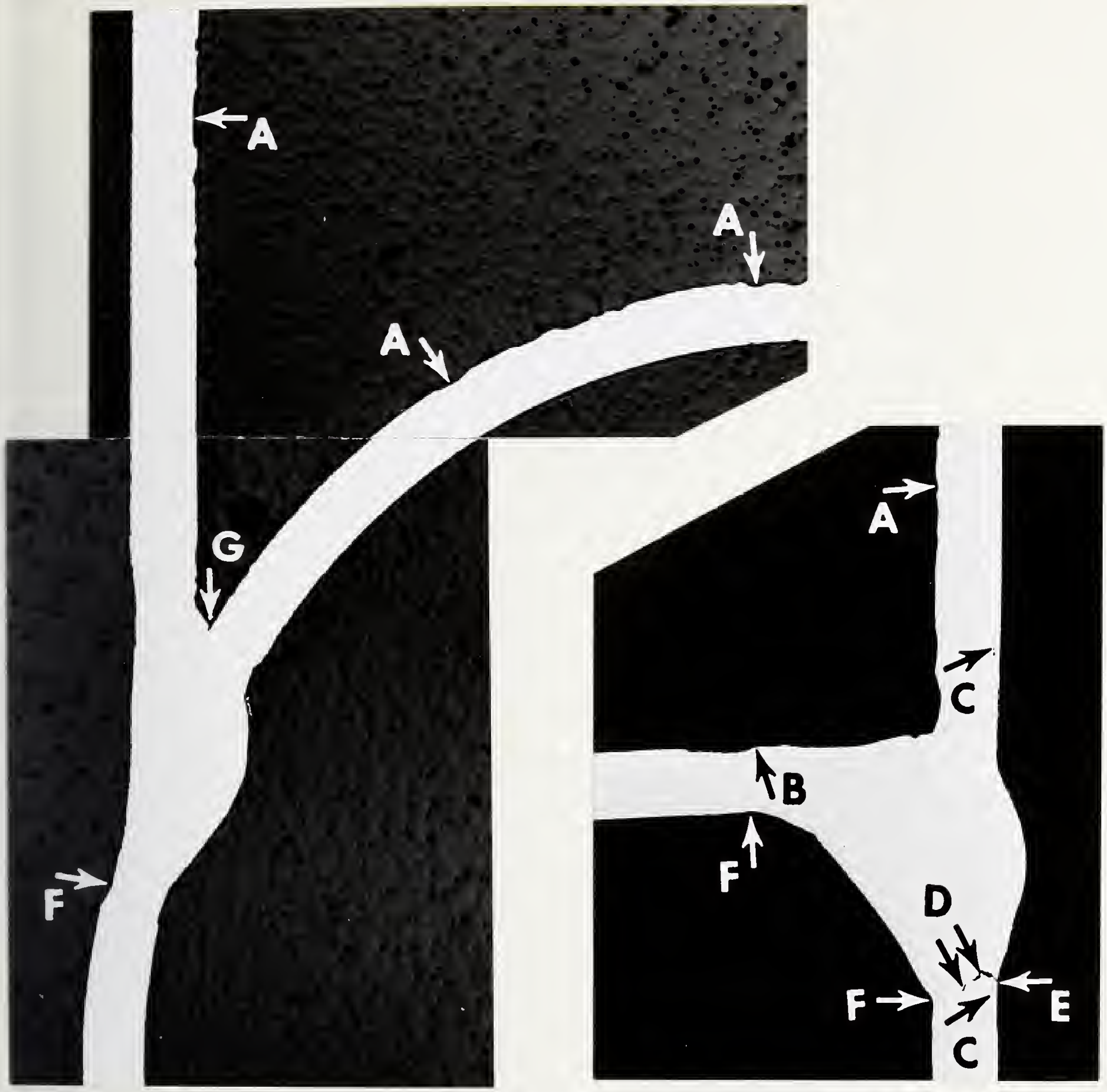
Figure 9. Longitudinal cross sections through left pedal connecting tube. As polished. X 7

a. Section perpendicular to longitudinal axis of torque tube.
b. Section parallel to longitudinal axis of torque tube.

Arrow indicates location of flux deposit and sharp angle between the tubes.

Figure 10. Longitudinal cross section through left torque tube assembly showing a field with a typical inclusion content. As polished. X 100

Figure 11. Area of longitudinal cross section through left torque tube assembly. Arrow indicates location of heavy deposit of welding flux or slag and sharp angle between the two tubes (arrow, figure 9a). As polished. X 40



a b

Figure 12. Longitudinal cross sections through right pedal connecting tube. As polished. X 10

a. Section perpendicular to longitudinal axis of torque tube.
b. Section parallel to longitudinal axis of torque tube.

Arrows A indicate examples of corroded areas.
Arrow B indicates location of crack in heat affected zone.
Arrows C indicate locations of large inclusions.
Arrows D indicate area of gas porosity-slag inclusion in heat affected zone.
Arrow E indicates apparent crack in heat affected zone.
Arrows F indicate examples of apparent undercutting.
Arrow G indicates sharp angle between the two tubes.

Figure 13. Longitudinal cross section through right torque tube assembly showing crack in heat affected zone at location of arrow B in figure 12b. As polished. X 500

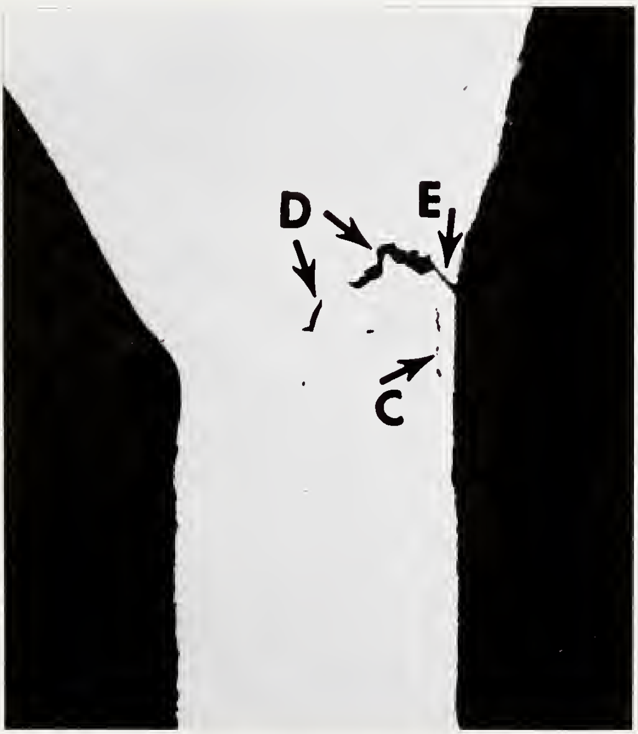


Figure 14. Longitudinal cross section through right torque tube assembly showing large stringer type inclusion at arrow C, area of gas porosity-slag inclusion in heat affected zone at arrows D, and apparent crack at arrow E. Same arrow designations indicate these features in figure 12b. As polished. X 40

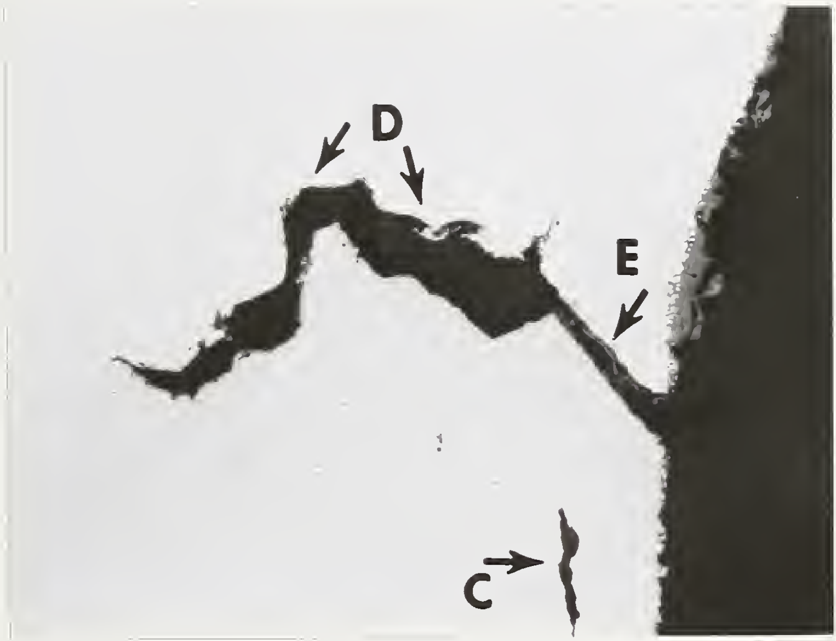
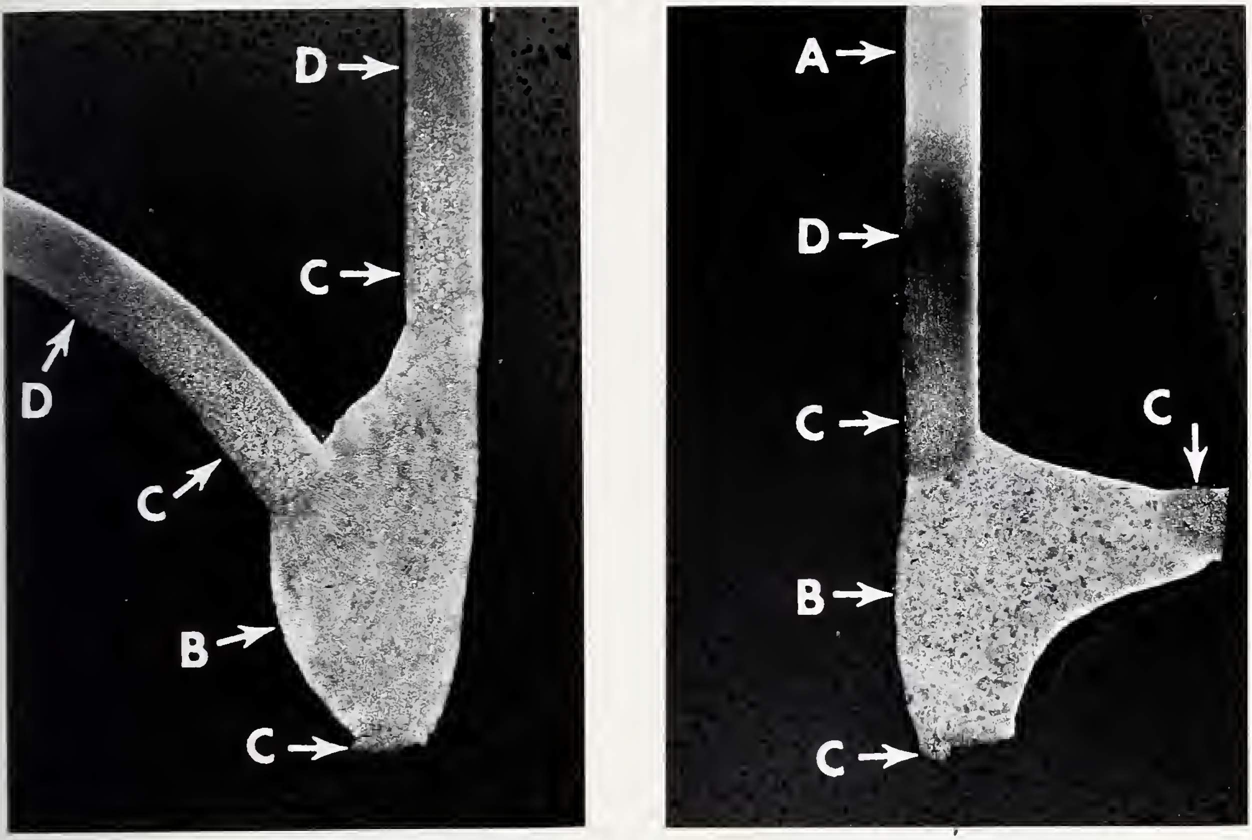


Figure 15. Longitudinal cross section through right torque tube assembly showing gas porosity-slag inclusion area (arrows D), apparent crack in heat affected zone between inclusion and surface (arrow E), and part of stringer inclusion in tube (arrow C) shown in figure 14. As polished. X 200



a b

Figure 16. Etched longitudinal cross sections through left pedal connecting tube. Etch: 1% nital. X 7

a. Section perpendicular to longitudinal axis of torque tube.
b. Section parallel to longitudinal axis of torque tube.

Arrow A indicates parent tube material.
Arrows B indicate weld metal.
Arrows C indicate heat affected zone adjacent to the weld.
Arrows D indicate heat affected zone adjacent to the parent tube material.

Figure 17. Etched longitudinal cross section showing microstructure of the tube material. Microstructure consists of pearlite (dark) and ferrite (light) and some spheroidized cementite. Etch: 1% nital. X 1000

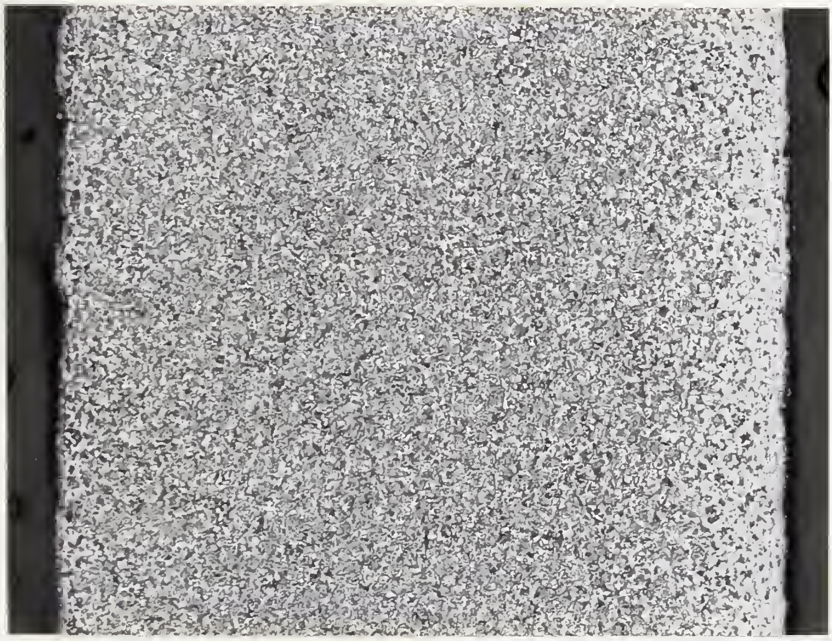


Figure 18. Etched longitudinal cross section showing decarburized layer adjacent to the outside surface of the tube. The entire thickness of the tube is shown. The decarburized layer is at the right. Etch: 1% nital. X 100

Figure 19. Etched longitudinal cross section showing microstructure of the weld metal which consists of coarse, tempered martensite. Etch: 1% nital. X 1000

Figure 20. Etched longitudinal cross section showing the microstructure of the heat affected zone adjacent to the weld. Microstructure consists of coarse grained martensite outlined by grain boundaries of prior austenite grains. Etch: 1% nital. X 1000

Figure 21. Etched longitudinal cross section showing the microstructure of the heat affected zone adjacent to the parent tube material. Microstructure consists primarily of martensite with some ferrite. Etch: 4% picral. X 1000

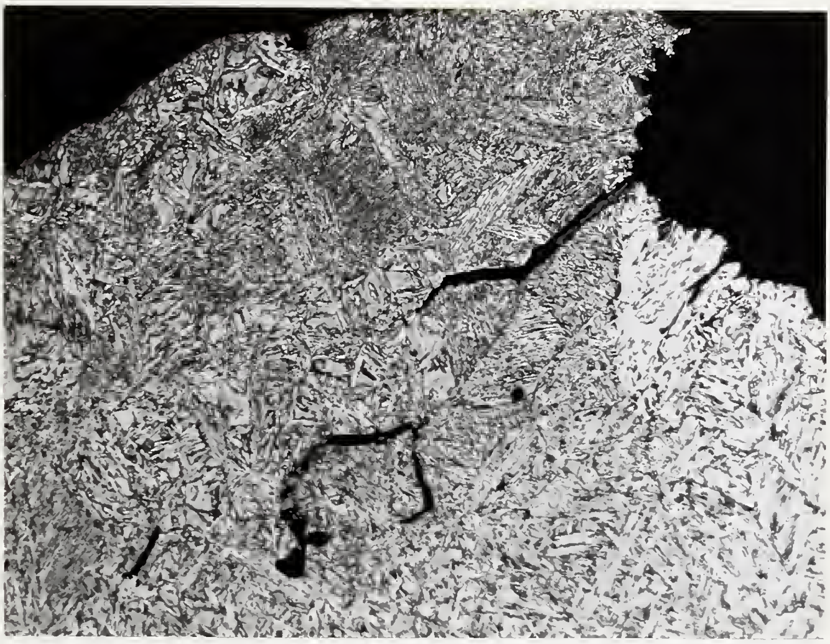


Figure 22. Etched longitudinal cross section through left torque tube assembly showing part of fracture profile (upper left) and some secondary cracking. Etch: 1% nital. X 200

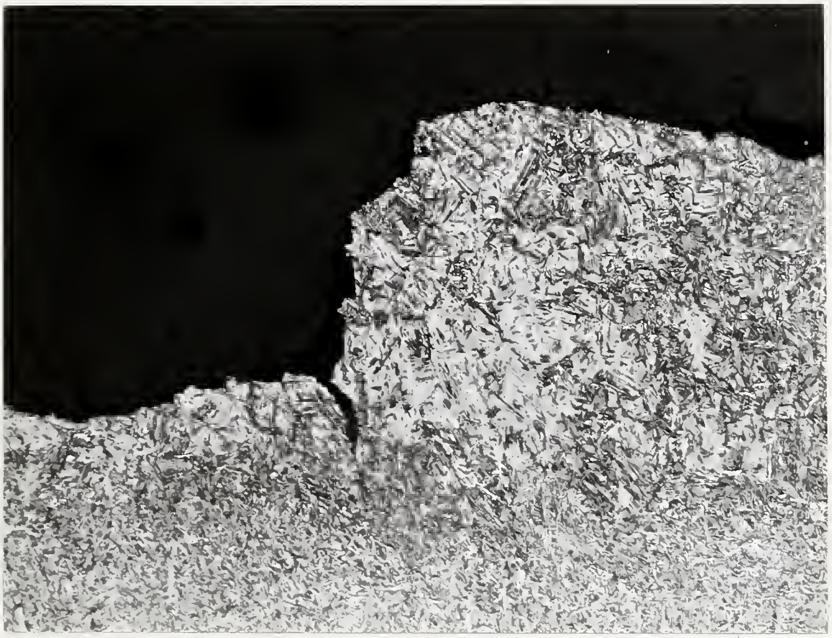


Figure 23. Etched longitudinal cross section through left torque tube assembly showing part of fracture profile. Etch: 1% nital. X 200

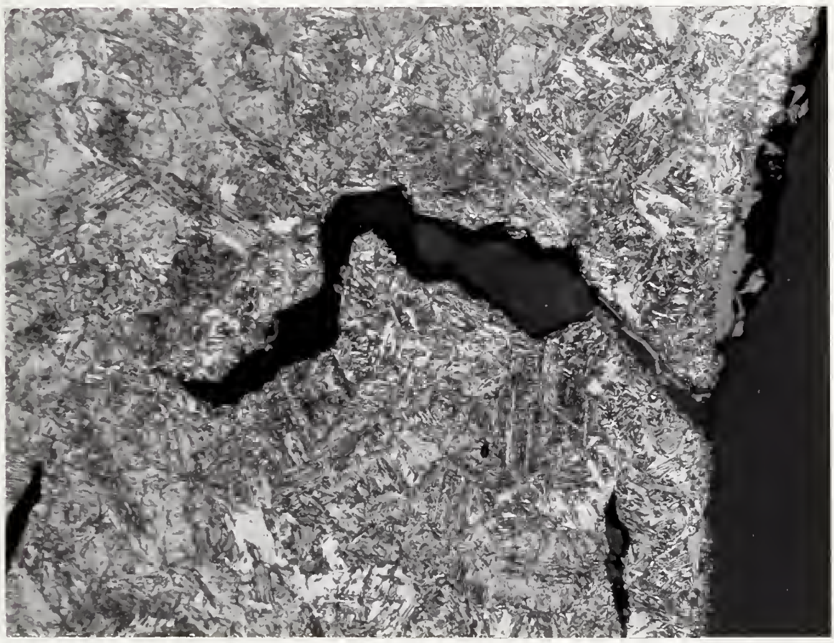


Figure 24. Etched longitudinal cross section through right torque tube assembly showing location of gas porosity, welding slag inclusion, and crack in the heat affected zone. Etch: 1% nital. X 200

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15. SUPPLEMENTARY NOTES

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.)*

A fractured rudder torque tube assembly from a Nieuport 28 Replica was submitted for examination. Fracture had occurred through the heat affected zone adjacent to a weld joining the left torque tube to the left pedal connecting tube. The primary feature exhibited by the fracture was dimpled rupture indicating that failure had probably occurred by ductile overload. Certain areas of the heat affected zones were quite hard relative to other regions of the assembly, and there were certain other undesirable features associated with the welds in both the right and left assemblies.

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; fractographic examination; overload failure; weld heat affected zone.

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