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Examination of Compressor Parts from Allison Engine from Fairchild Hiller Helicopter

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Mechanical Properties Section
Metallurgy Division
Institute for Materials Research
National Bureau of Standards
Washington, D. C. 20234

March 30, 1973

Failure Analysis Report

Prepared for
Bureau of Aviation Safety
National Transportation Safety Board
Department of Transportation
Washington, D. C. 20591

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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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SUMMARY

The compressor case and the fifth and sixth stage compressor wheel assembly from an Allison helicopter engine were submitted for examination. The compressor case lining had been wiped in areas opposite the first five stages of the compressor blades. The compressor case lining was severely damaged in the areas opposite the fifth and sixth compressor wheel stages and in the fifth and sixth stator blade stages. The lining was cracked in places; wiped, gouged, or galled in others; and in some areas, pieces of the lining were missing. The fifth and sixth stage compressor blades and stator blades were badly damaged. Two of the sixth stage and one of the fifth stage compressor blades had completely fractured. The fifth stage blade and one of the sixth stage blades had failed due to the propagation of fatigue cracks. The other fractured sixth stage compressor blade exhibited considerable deformation adjacent to the fracture surface and had apparently failed from tensile overload. The extensive damage to the case lining and to the blades in and around the fourth, fifth, and sixth stage of the case and the fifth and sixth stage of the wheel may have been caused by motion of one or more of the fractured blades or a foreign object in the operating compressor. The microstructure of the compressor blade material appeared to be normal, except perhaps for a high inclusion content. The hardness of the compressor blade material was close to, and in some areas possibly below, the specified minimum.

Examination of Compressor Parts from Allison Engine from Fairchild Hiller Helicopter

1. GENERAL INFORMATION

1.1 Reference

Bureau of Aviation Safety, National Transportation Safety Board, Department of Transportation, Washington, D. C. Request by Mr. William L. Holshouser, dated October 4, 1972.

1.2 Accident Identification

Fairchild Hiller FH1100, N590FH, helicopter, North Bend, Washington, July 19, 1972. NTSB accident no. SEA 73-A-S001.

1.3 Parts Identification

The following parts were submitted for examination:

1. Compressor case.
2. Fifth and sixth stage compressor wheel assembly.
3. Plastic envelope containing fragments of a stator blade and a compressor blade.

The parts are shown as received in figure 1.

1.4 Background Information

The information in this section was taken from documents furnished by the Bureau of Aviation Safety.

According to drawing no. 6873965 of the Allison Division of the General Motors Corporation, the fifth and sixth stage wheel assembly was to be cast from AMS 5355 CRES, which is a precipitation hardening alloy steel. The material is described in Aerospace Material Specification (AMS) 5355B, a copy of which was furnished to NBS by the Bureau of Aviation Safety.

The aircraft had suffered engine failure while being used in a timber survey. Upon examination after the failure, it was noted that the first stage compressor vanes could not be turned by hand. The compressor was disassembled, revealing extensive damage to the fifth and sixth stage wheel blades, and to the case lining and the stator blades. The engine had logged a total of 1206.5 hours, and had been in service 318 hours since a new fifth and sixth stage wheel assembly and a new case assembly had been installed.

2. PURPOSE

The submitting agency requested an analysis of the failure of the missing blades and documentation of the other damage to the compressor parts.

3. RESULTS OF EXAMINATIONS

3.1 Visual Examination

There was no apparent damage to the outside of the compressor case. The case had been painted and the paint appeared to be in good condition. Part of the outside of the case can be seen in figure 1 where the case is shown closed.

There was considerable damage inside the compressor case both to the case lining and to some of the stator blades. The two halves of the open compressor case are shown in figures 2a and 2b. The lining on the inside of the case appears to have been wiped between the end of the case and the first stator blade stage, and between the first and second, second and third, third and fourth, and fourth and fifth stator blade stages. These regions would be opposite the first, second, third, fourth, and fifth stages, respectively, of the compressor blades when the compressor is assembled for operation. In figure 2, wiped areas generally appear darker than adjacent unwiped areas. Some examples of wiped areas are indicated by arrows A in figures 2a and 2b. One wiped area between stator blade stages one and two is shown at higher magnification in figure 2c.

Between the third and fourth stator blade stages, the lining was cracked and had begun to pull away from the case (arrow B, figure 2b). On the half of the case shown in figure 2a, there are cracks in the lining at the edges of some of the stator blades, and there are two cracks parallel to the fourth stage (arrows C, figure 2a). One of these cracks spans seven blades. Varying amounts of the lining are missing between several pairs of the fourth stage blades exposing the metal case (arrows D, figure 2b).

Severe damage is exhibited by the case lining between the fourth and fifth, and the fifth and sixth stator stages. In some areas, the bare metal case was exposed (arrows E, figure 2b). Where the bare metal is not exposed, there are a number of cracks (arrows F, figure 2a) in the lining adjacent to the fifth stage blades, and the lining had been gouged and/or galled in a number of places (arrows G, figures 2a and 2b).

There appears to have been no visible damage to any of the stator blades in the first three stages. The fourth stage blades in the half of the case shown in figure 2a did not appear to be damaged, but at least eleven of the fourth stage blades in the half of the case shown in figure 2b were either bent or partially torn loose or both near the blade base on the side closest to the fifth stage. Typical examples are indicated by arrows H in figures 3a and 3b. The compressor half shown in figure 2b is also shown in figure 3a, photographed at a different angle.

Every stator blade in the fifth and sixth stages was damaged. All were bent and nearly all exhibited tears. One blade from the sixth stage had broken off (arrow I, figure 3a).

All of the compressor blades of the fifth and sixth stages of the wheel assembly were damaged. Much of this damage can be seen in figure 4. The ends of the fifth stage blades were wiped or "smeared" (arrows A, figure 4), and about 1/16 inch of the sides of the blades adjacent to the blade ends and facing the sixth stage was smeared. This can not be seen in figure 4, but arrow B indicates the location of the damage on one of the blades. The damage was more severe to the sixth stage blades than to the fifth stage blades. The ends were smeared (arrows C, figure 4). There was smearing and tearing on the sides of the blades facing the fifth stage (arrows D, figure 4), and there was some smearing and bending on the other sides of the blades (arrows E, figure 4). In addition, there was one completely fractured blade on the fifth stage, and two completely fractured blades on the sixth stage. Two of these are indicated by the letters F and G in figure 4. One fractured blade from the sixth stage cannot be seen in the figure. It is designated H.

The separated parts of one of the fractured compressor blades and the fractured stator blade are shown in figure 5. The compressor blade fragment was severely damaged. The stator blade appeared to have damage similar to that sustained by other stator blades from the sixth stage. There was a small spot on each, indicated by arrows in figure 5, which was yellowish-orange in color. Similar spots were found on other blades.

3.2 Fractographic Examination

The fracture surfaces of the three completely fractured compressor blades were examined. The fracture surfaces of blades F and G (location indicated in figure 4), which are shown in the photomacrographs of figures 6a and 6b, were relatively smooth but showed definite evidence of slowly propagating cracks. The fracture surface of blade H, shown in figure 6c and not visible in figure 4, exhibited severe mechanical damage but no evidence of slowly propagating cracks. The locations of the apparent primary crack origins are indicated by arrows in figures 6a and 6b.

The fracture surface features of blades F and G can be more readily seen, on a macro scale, in the scanning electron photomicrographs (SEM) in figures 7a and 7b, respectively. The apparent primary crack origins are again indicated by arrows. There appears to be a number of crack arrest lines on both fracture surfaces. These are quite evident in figure 7a.

A scanning electron microscope (SEM) examination at higher magnifications revealed evidence of apparent fatigue striations in the slowly propagating regions of the fracture surfaces of both blades F and G. Examples are shown in figures 8 and 9 for blade F, and in figures 10 and 11 for blade G. Features indicating the cast structure can also be seen in these four figures.

In the overload regions, the fracture surfaces of blades F and G exhibited dimpled rupture. An example of this is shown in figure 12 for the fracture surface of blade F.

No evidence of a slowly propagating crack was found on the fracture surface of blade H. Although mechanical damage obscured the fracture features in some areas, dimpled rupture was exhibited over most of the fracture surface (figure 13).

3.3 Metallographic Examination

Cross sections intersecting the fracture surfaces were taken through the remaining part of each of the three fractured compressor blades. The unetched microstructure appeared similar for the material from all three blades. An unetched field from the cross section through blade G considered to have a typical inclusion content for the three cross sections is shown in figure 14. Two areas judged to have the highest inclusion contents for the cross sections through blades F and G are shown in figures 15 and 16, respectively. Nearly

all of the inclusions appear to be of the oxide type. A total of six fields, including those shown in figures 14 through 16, plus one typical field each from the cross sections through blades F and G, and one "worst" field from the cross section through blade H were rated for inclusion content according to the inclusion charts given in ASTM Standard E-45. All six fields were rated 5 for the D thin series, and the field shown in figure 16 was rated between 1 and 2 for the D heavy series. There is a relatively large inclusion in the field shown in figure 15 which does not appear to be of the oxide type.

Etched cross sections intersecting the fracture surfaces of each of the three fractured compressor blades are shown in figures 17, 18, and 19 for blades F, G, and H, respectively. Each of the fractures is transgranular in nature. Considerable deformation is exhibited by blade H adjacent to the fracture. Part of the cross section through blade G is shown at a higher magnification in figure 20. The microstructure appears to consist primarily of tempered martensite with stringer-shaped patches of ferrite. This would be the expected microstructure for an austenitized and aged material of the composition specified in AMS Specification 5355B.[1]

3.4 Qualitative Chemical Analyses

Qualitative chemical analyses were performed on the fracture surface of blade G, on the etched cross section through blade G, and on one of the yellowish-orange spots on the end of one of the compressor blades in order to determine if any significant amounts of elements foreign to this alloy could be detected. The analyses were carried out with the non-dispersive X-ray analyzer used in conjunction with the scanning electron microscope. AMS Specification 5355B calls for the following chemical composition limits for the material used in the fifth and sixth stage compressor wheel assembly:

Element	Min %	Max %
Carbon	---	0.06
Manganese	---	0.70
Silicon	0.5	1.0
Phosphorus	---	0.04
Sulfur	---	0.03
Chromium	15.5	16.7
Nickel	3.6	4.6
Columbium+Tantalum	0.15	0.40
Copper	2.8	3.5
Nitrogen	---	0.05

No element was detected that was not included in the specification, and there were no significant differences among the various analyses.

3.5 Hardness Measurements

Knoop microhardness measurements (KHN) at a load of 500 grams were made on cross sections through blades F and H. For blade F, the average of eight measurements was KHN 398 (R_C 40), and the values ranged from KHN 420 (R_C 41.5) adjacent to the fracture to KHN 373 (R_C 37.5) at the blade base. The average KHN for six measurements on blade H was 393 (R_C 39) and the values ranged from KHN 402 (R_C 40) adjacent to the fracture to KHN 386 (R_C 38.5) at the blade base.

The specified hardness for this material after precipitation heat treatment is R_C 40 minimum or equivalent.

4. DISCUSSION OF RESULTS

The apparent wiping of the compressor case lining opposite the first, second, third, fourth, and fifth compressor wheel stages appears to have been caused by contact with the blades of the rotating compressor wheel. Several conditions may have permitted the wiping action, such as 1) the compressor wheel was oversize, 2) the compressor wheel bearings were worn or off center, allowing the wheel to wobble, 3) the axes of the case and the wheel were not coincident, or 4) the compressor case was undersize, or not truly cylindrical. It would seem that the most probable of these four conditions would be wobbling of the wheel.

The severe damage suffered by the compressor case lining and to both the stator and compressor blades in the area of the fifth and sixth stages might have been caused by motion in the assembly of one or more of the fractured blades, or by motion of a foreign object in the assembly.

Compressor blades F (sixth stage) and G (fifth stage) appear to have failed due to the propagation of fatigue cracks. Compressor blade H (sixth stage) appears to have failed from overload as evidenced by the fracture surface features and the deformation exhibited in the microstructure near the fracture surface. The blade (H) also appeared to have been bent.

Although no specification was submitted for inclusion content, there appeared to be a rather large number of inclusions in the compressor blade material. Otherwise, the microstructure of the compressor blade material appeared to be normal.

The Rockwell C hardness values given are approximate equivalents converted from the measured Knoop values. The conversion from KHN to R_C is not exact, and although some of the converted values were below the specified R_C minimum, it can not be stated with certainty that the material does not meet hardness specifications. The lowest converted value was 2.5 R_C points below the minimum allowed. The hardness is generally close to the minimum specified.

Qualitative chemical analyses (by X-ray emission) of the material in some of the compressor blades detected nothing abnormal, all elements detected being included in the specifications for the material.

5. CONCLUSIONS

1. Two of the three fractured compressor wheel blades (one from the fifth stage and one from the sixth stage) failed due to the propagation of fatigue cracks.

2. The other fractured compressor wheel blade (from the sixth stage) apparently failed from tensile overload.

3. Wiping of the compressor case lining may have been caused by worn or off-center compressor wheel bearings.

4. The extensive damage to the fifth and sixth stage regions of the compressor case lining, and the damage to the fifth and sixth stage compressor blades and to the fourth, fifth, and sixth stage stator blades, may have been caused by motion of either one or more of the pieces of the fractured blades or a foreign object in the operating compressor assembly.

5. The inclusion content in the compressor blade material appears to be somewhat high, though there is no specification requirement. Otherwise, the microstructure appeared to be normal.

6. The hardness of the compressor blade material was close to, and perhaps in some instances below, the specified minimum.

6. ACKNOWLEDGEMENT

Messrs L. C. Smith and C. H. Brady performed the metallographic specimen preparation, and Mr. Smith assisted in other areas of the examination.

REFERENCE

1. Metals Handbook, 8th edition, volume 7, American Society for Metals, 1972.

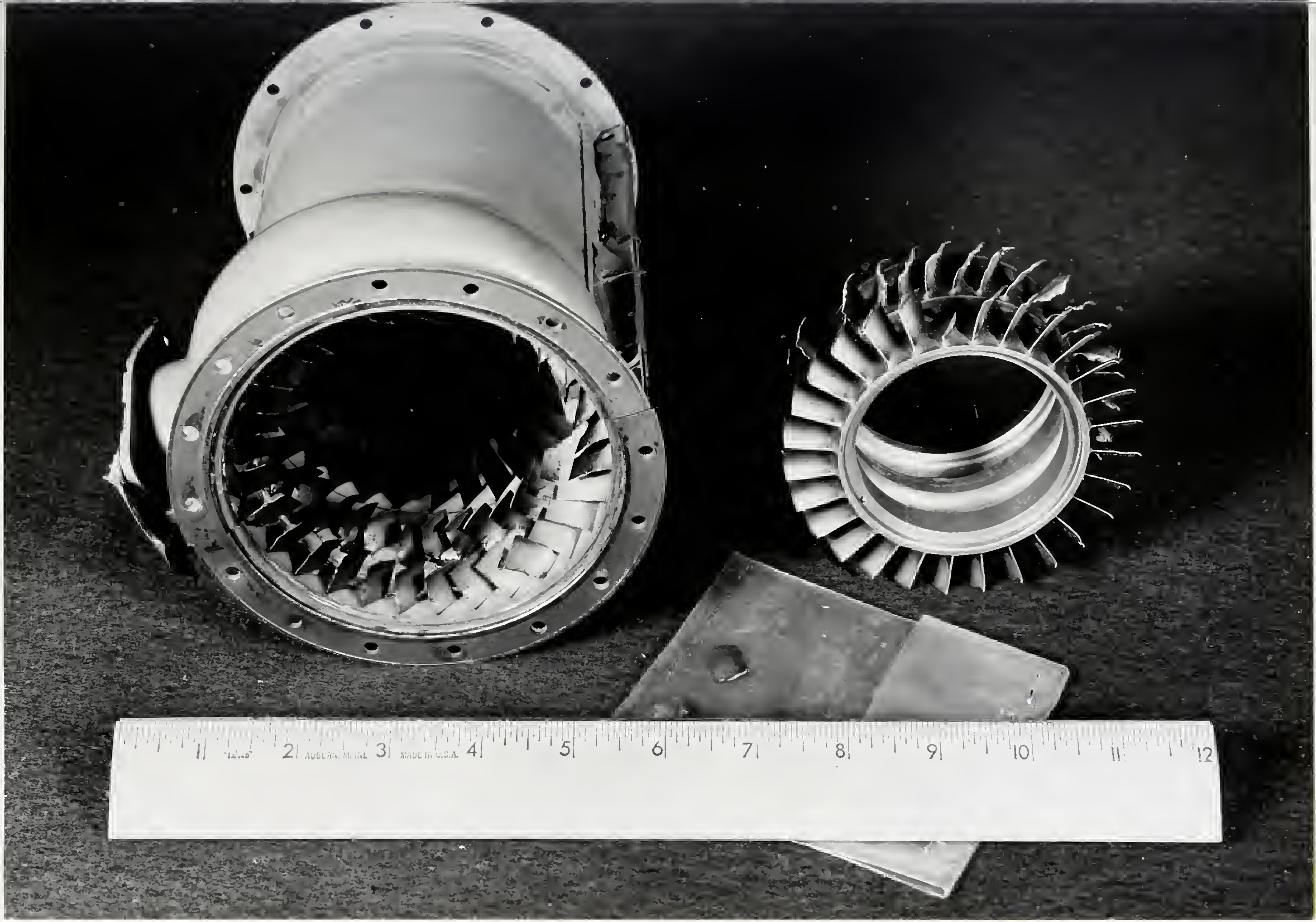


Figure 1. Compressor case, fifth and sixth stage wheel assembly, and a fragment of a compressor blade and a stator blade (in plastic envelope) as received. X 2/3

Figure 2. Open compressor case as received.

a. Half of open compressor case. X 1

b. Second half of open compressor case. X 1

c. Example of wiped area of case lining between the first and second stator stages at higher magnification than in figure 2b. X 4

The numbers to the left of the case in figures 2a and 2b designate the positions and numbers of the mating compressor stages.

Damage to the compressor case lining and to the stator blades can be seen. Specific locations of damage are indicated as follows:

Arrows A indicate examples of areas where the case lining had apparently been wiped by the compressor blades.

Arrow B, figure 2b, indicates where the lining is cracked and is pulling away from the case.

Arrows C, figure 2a, indicate cracks in the lining parallel to and adjacent to the fourth stage stator blades.

Arrows D, figure 2b, indicate examples of areas where the lining is missing between the blades of the fourth stator stage.

Arrows E, figures 2a and 2b, indicate examples of areas between the fourth and fifth stator stages where the lining is missing.

Arrows F, figures 2a and 2b, indicate examples of cracks in the lining adjacent to the fifth stage stator blades.

Arrows G, figures 2a and 2b, indicate examples of gouged or galled areas in the case lining between the fifth and sixth stator stages.

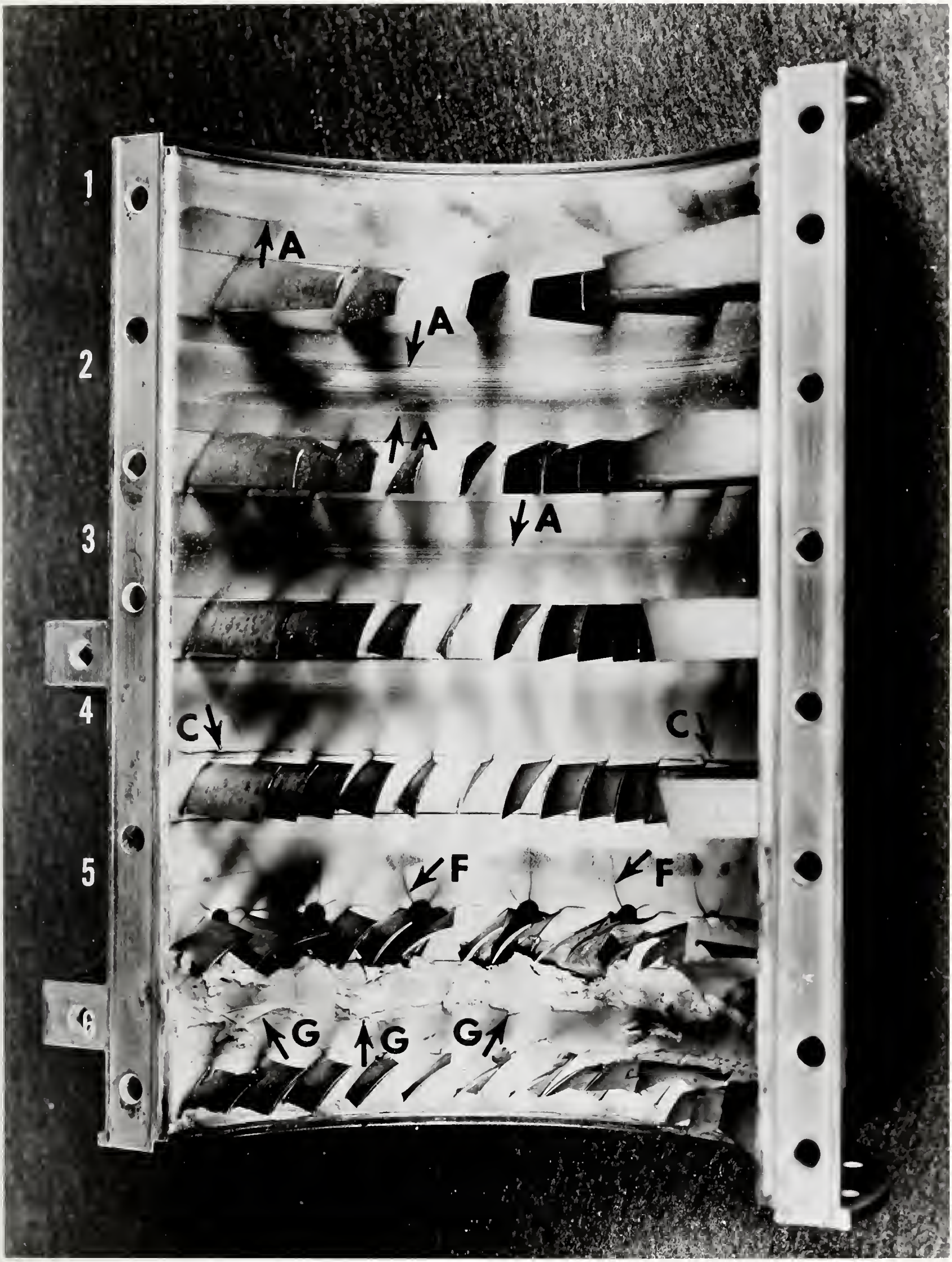


Figure 2a. Half of open compressor case. X 1

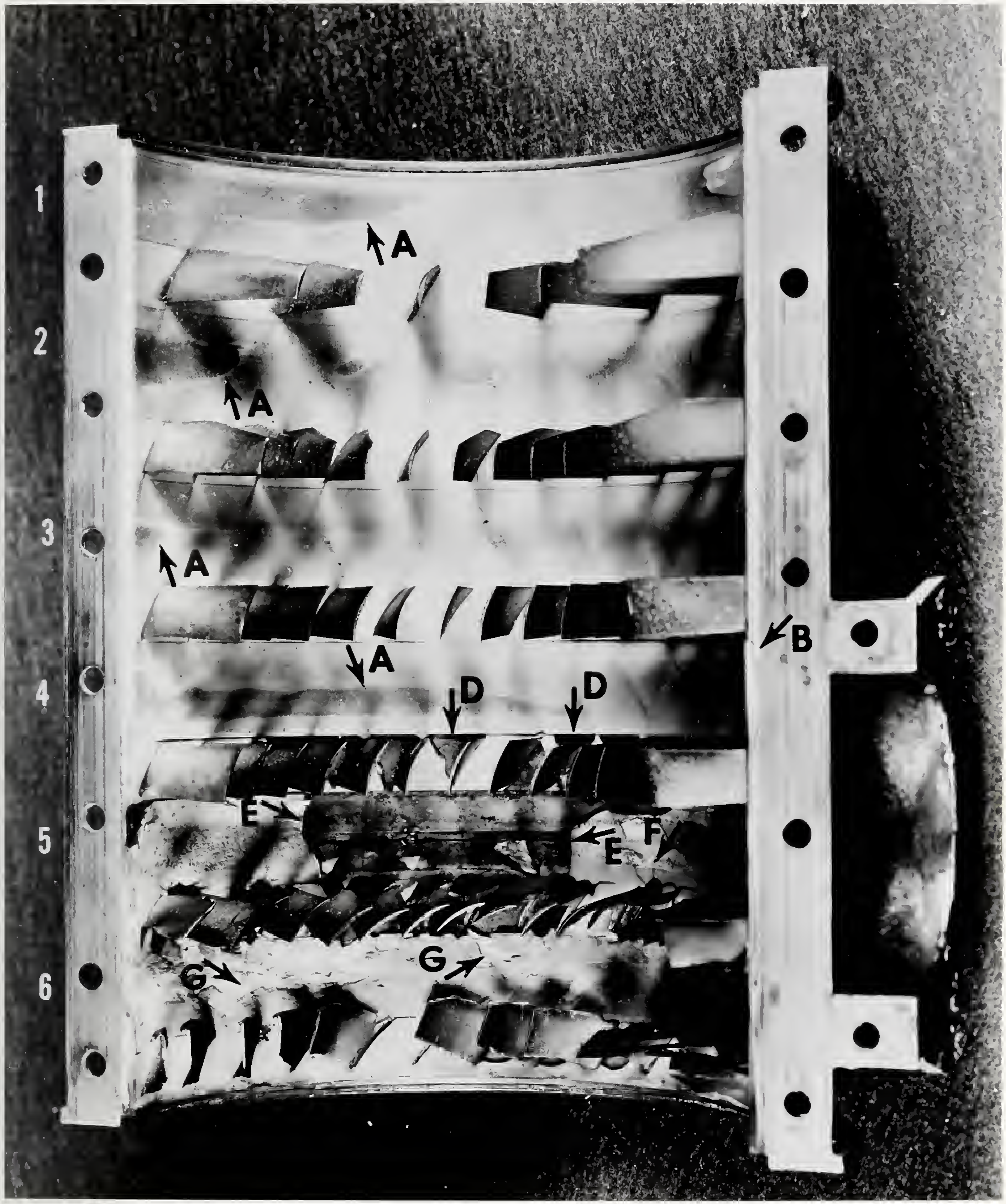


Figure 2b. Second half of open compressor case. X 1

Figure 2c. Example of wiped area of case lining between the first and second stator stages at higher magnification than in figure 2b. X 4

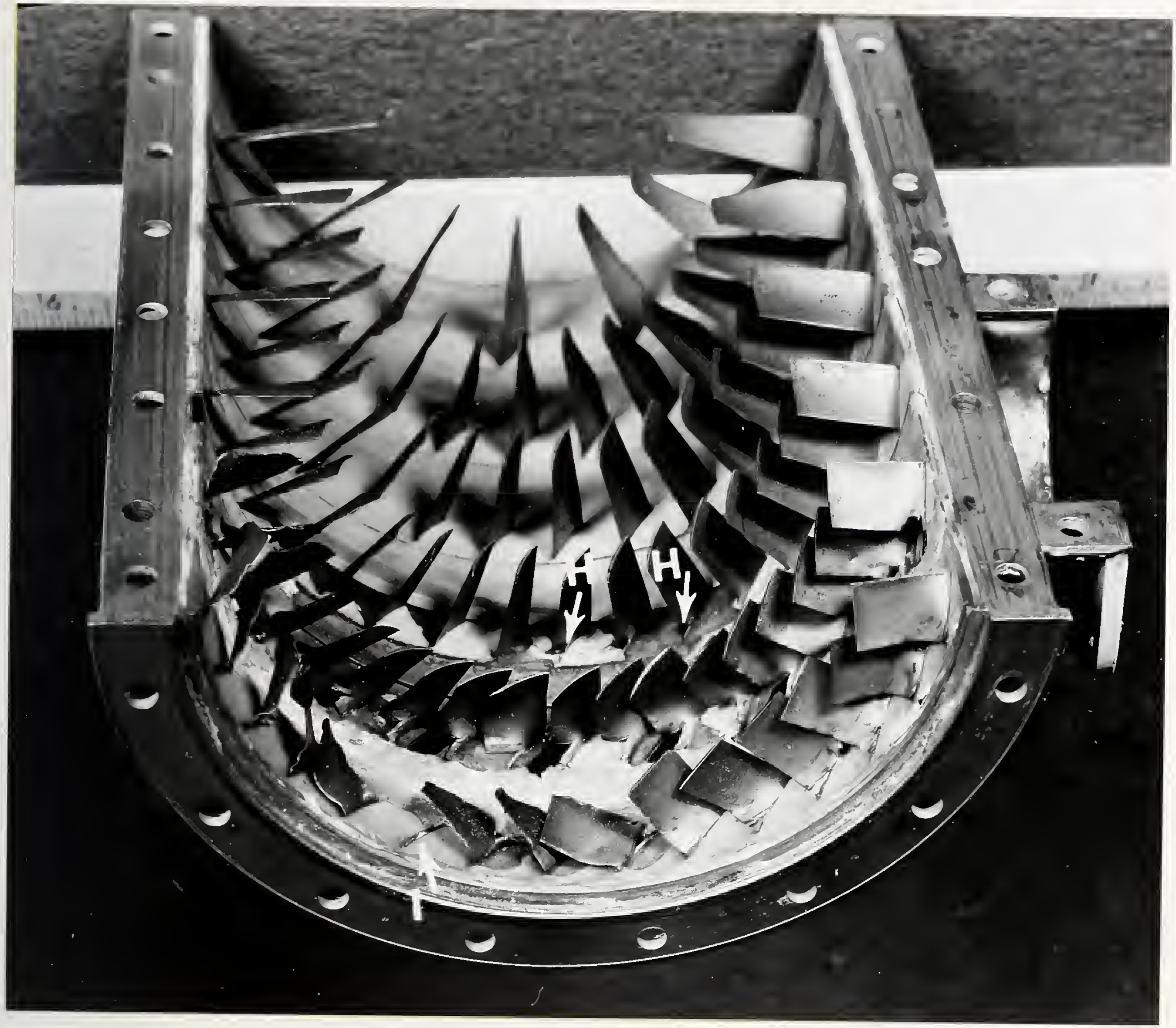


Figure 3a. Half of open compressor case shown in figure 2b.

Examples of damaged fourth stage stator blades are indicated by arrows H. A missing sixth stage stator blade is indicated by arrow I. Damage to the fifth and sixth stage blades can be seen. X 1

Figure 3b. Part of the half of the compressor case shown in figure 3a, but at higher magnification. Arrows H indicate examples of the damaged fourth stage stator blades. X 4

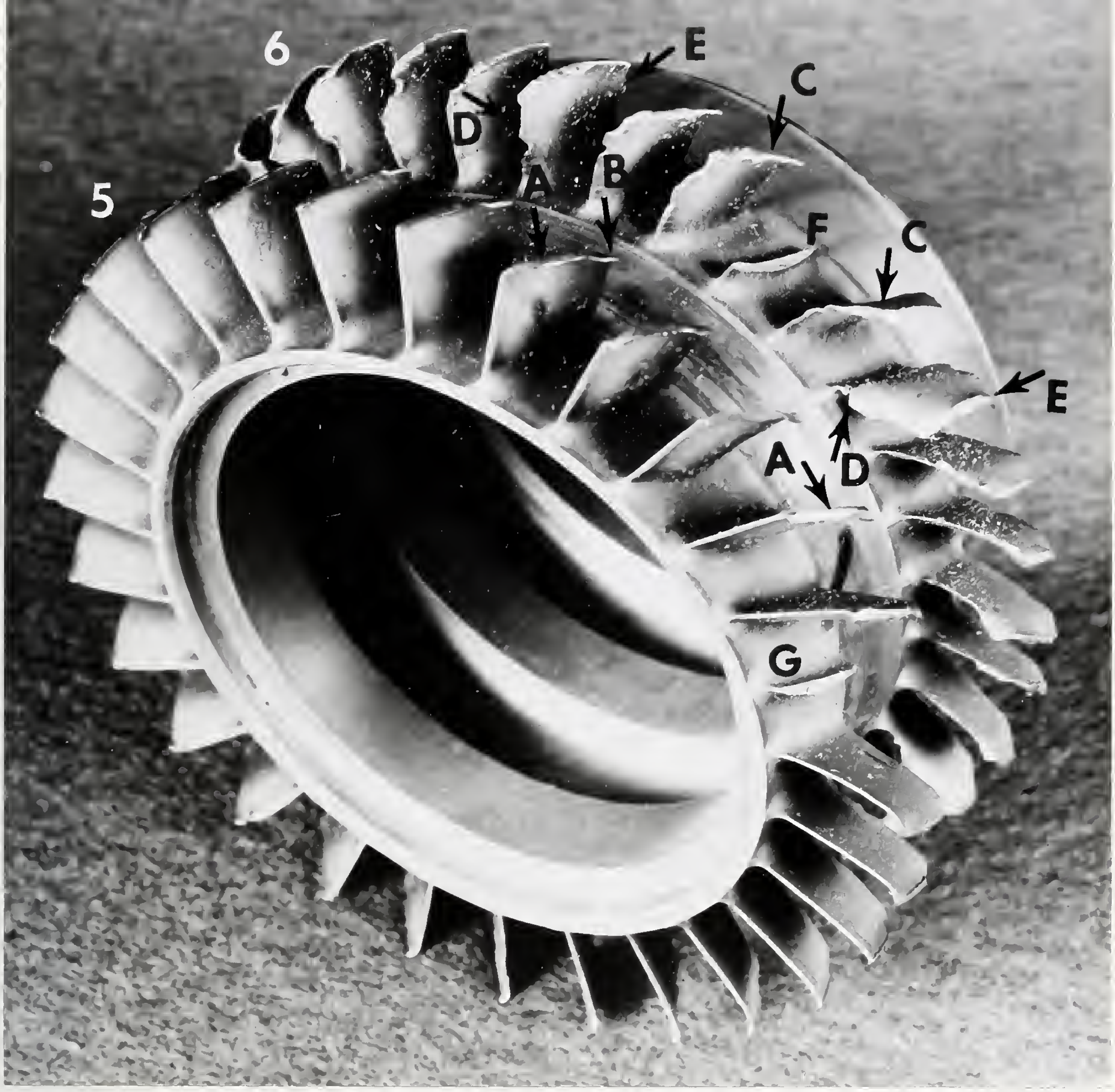


Figure 4. Fifth and sixth stage compressor wheel assembly as received. X 1

The numbers in the upper left indicate the stage number.
Arrows A indicate examples of wiping or smearing of the fifth stage blades.
Arrow B indicates the location of smearing on the side of one of the fifth stage blades.
Arrows C indicate examples of smearing of the ends of the sixth stage blades.
Arrows D indicate examples of tearing on the sides of the sixth stage blades.
Arrows E indicate examples of bending and smearing on the sides of the blades opposite to that indicated by arrows D.
F indicates a fractured sixth stage blade.
G indicates a fractured fifth stage blade.

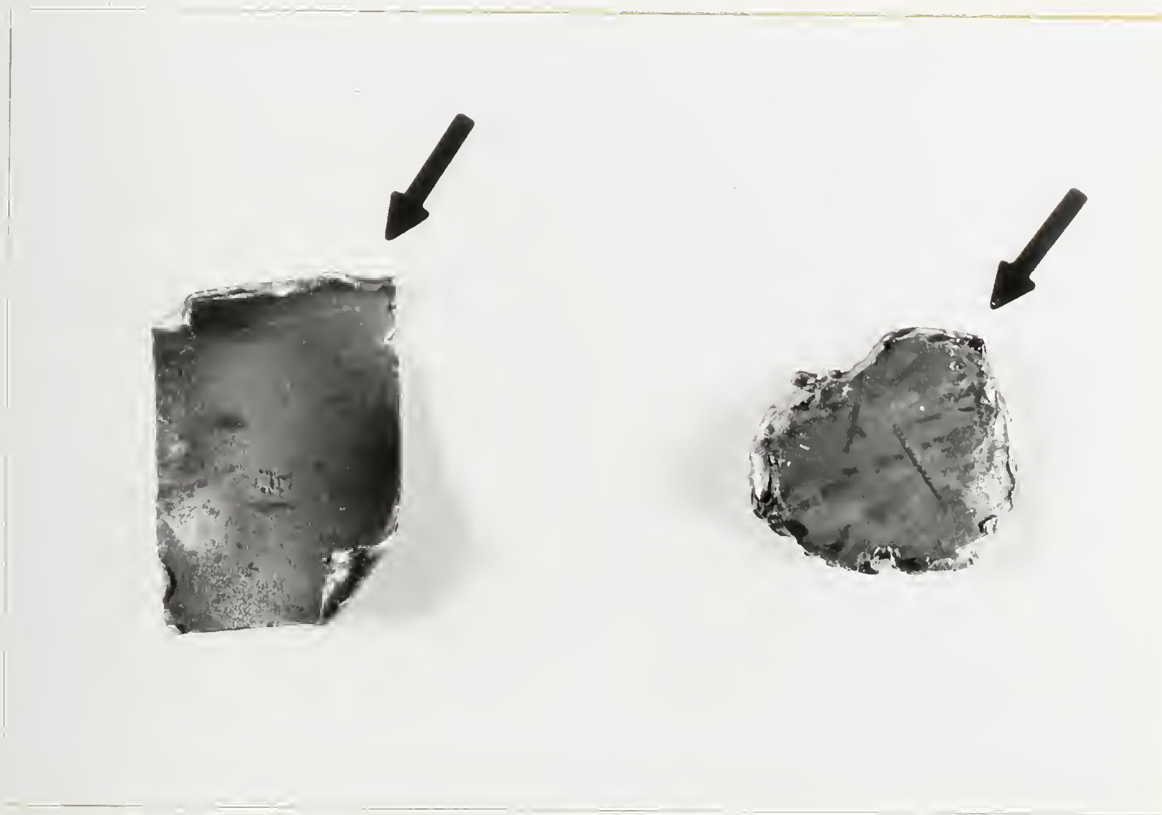
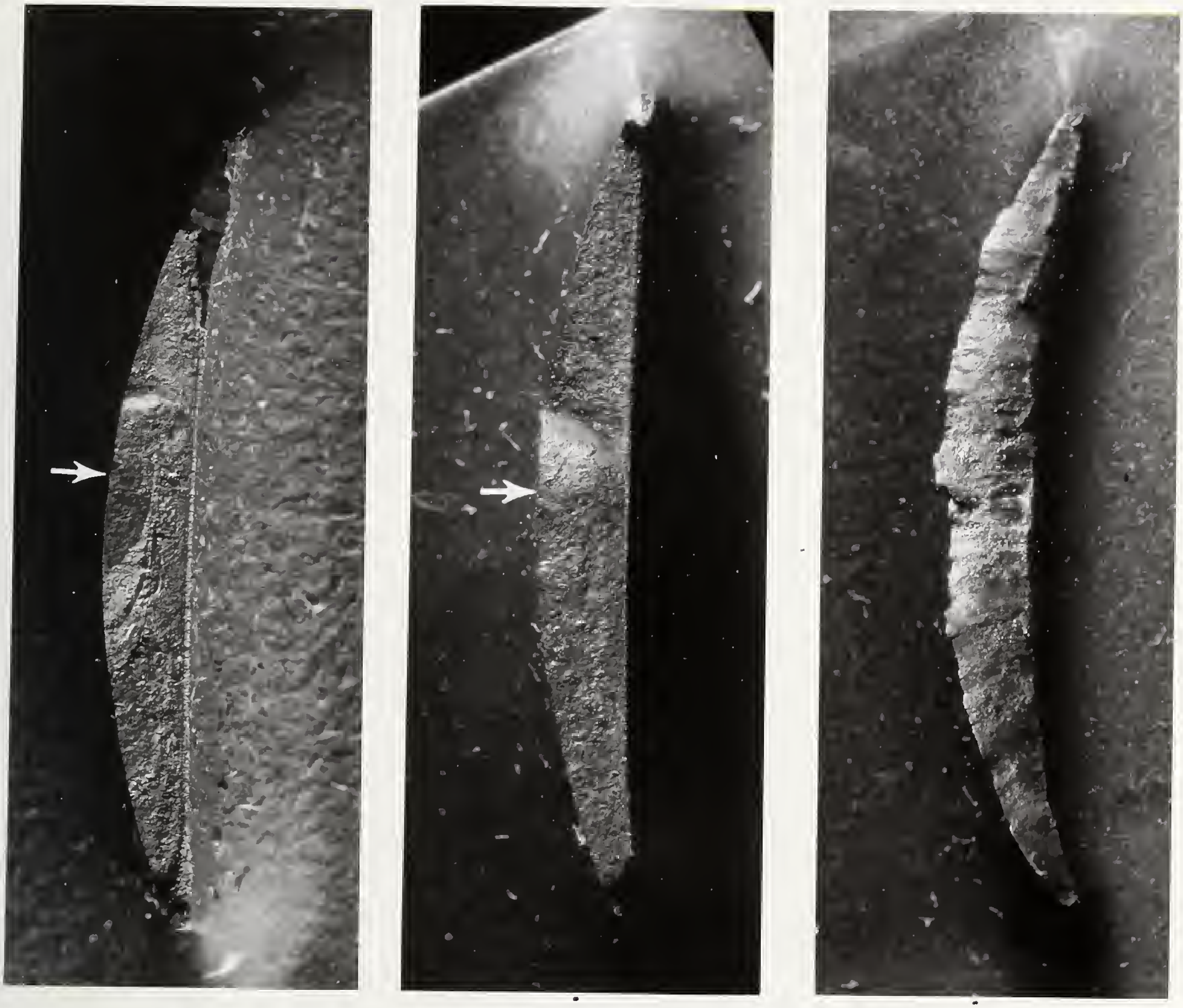


Figure 5. The separated portions of a stator blade (left) and a compressor blade (right). The arrows indicate spots which were yellowish-orange in color. X 3



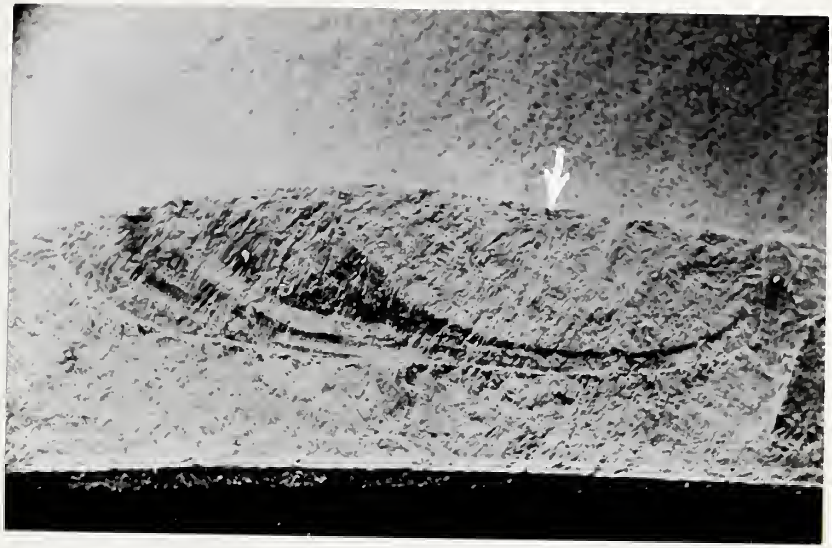
a b c

Figure 6. Fracture surfaces of the three fractured compressor blades. Arrows indicate the apparent primary crack origins in 6a and 6b. X 10

a. Blade F.

b. Blade G.

c. Blade H.



a

b

Figure 7. Scanning electron photomicrographs of parts of fracture surfaces. Apparent primary crack origins are indicated by arrows.

a. Blade F. Crack arrest lines are prominant. X 21.5

b. Blade G. Crack arrest lines are less evident than in a. X 20

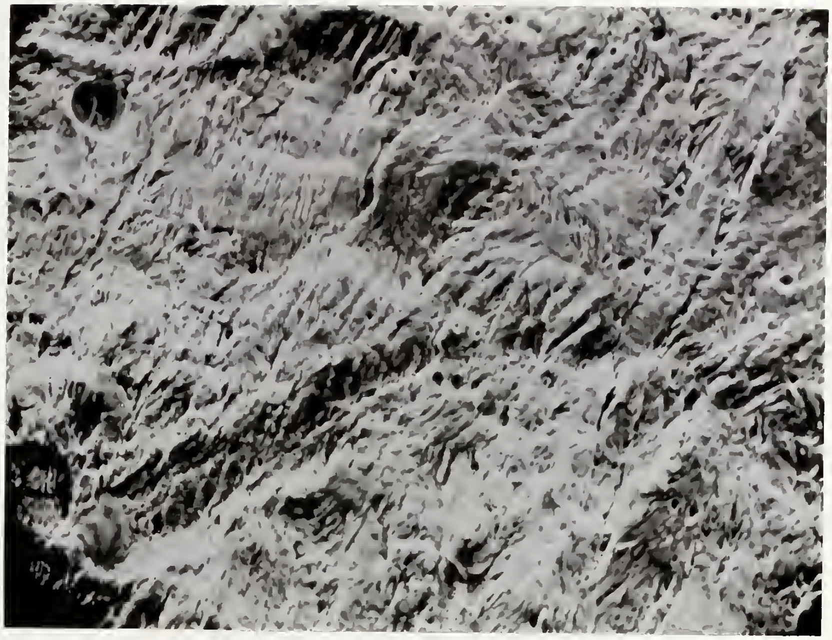


Figure 8. SEM of fracture surface of blade F in slowly propagating crack region showing evidence of apparent fatigue striations. X 540

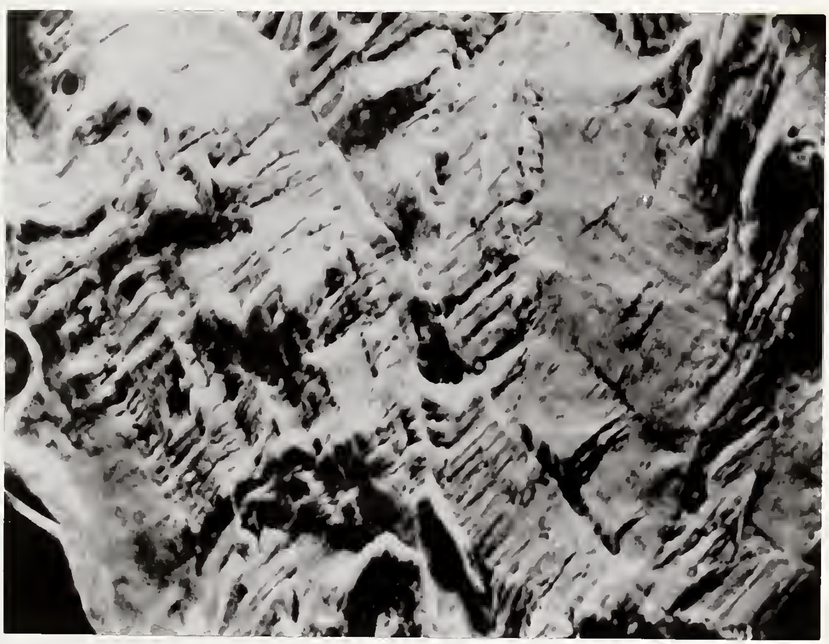


Figure 9. SEM of fracture surface of blade F in slowly propagating crack region showing evidence of apparent fatigue striations. X 2200

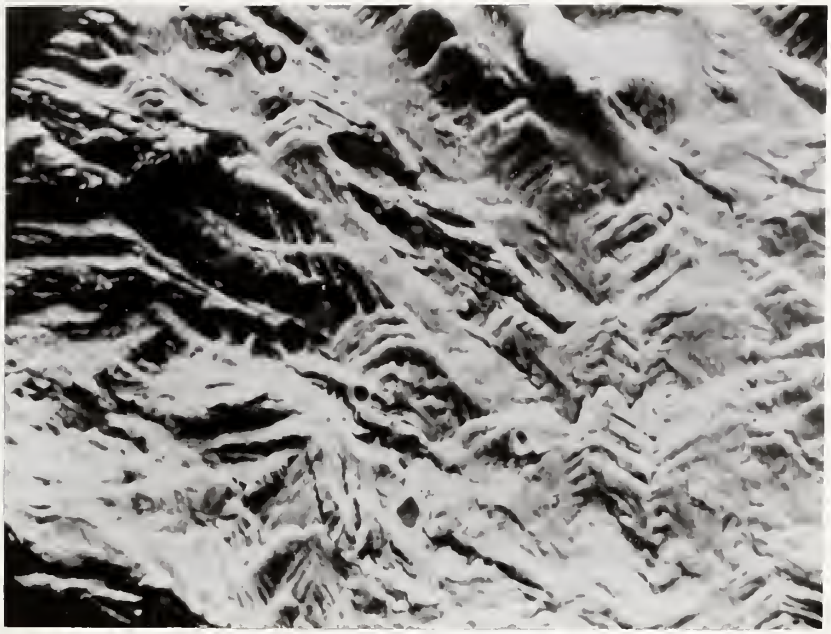


Figure 10. SEM of fracture surface of blade G in slowly propagating crack region showing evidence of apparent fatigue striations. X 1000

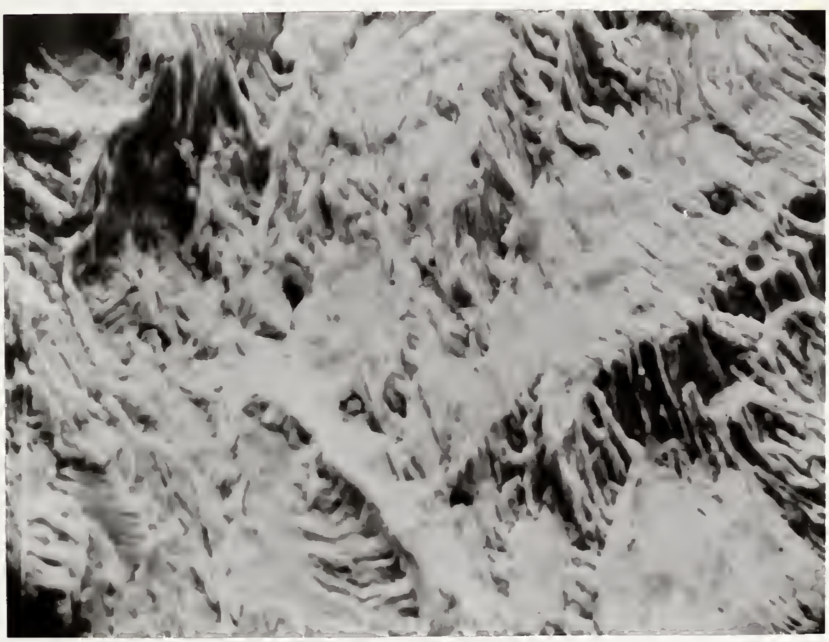


Figure 11. SEM of fracture surface of blade G in slowly propagating crack region showing evidence of apparent fatigue striations. X 1200

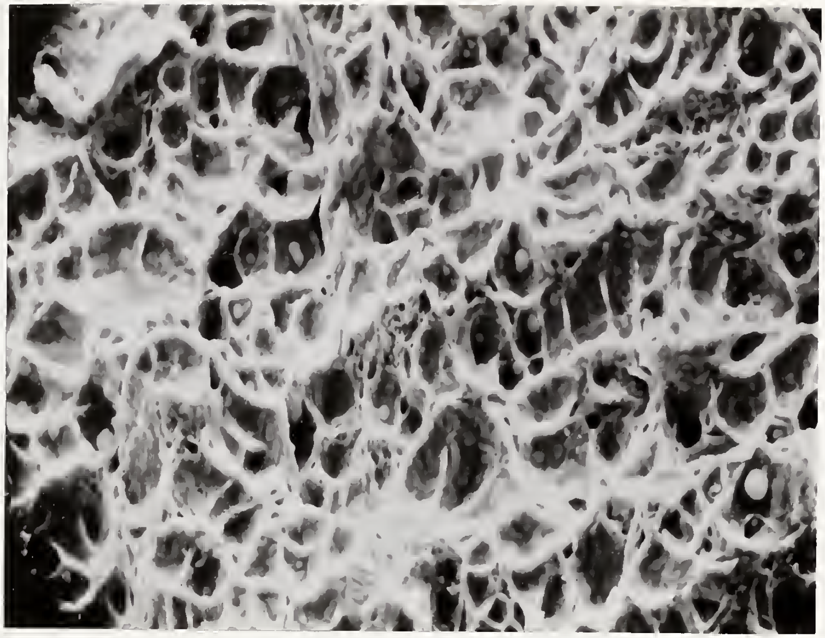


Figure 12. SEM in overload region of fracture surface of blade F showing dimpled rupture. X 550

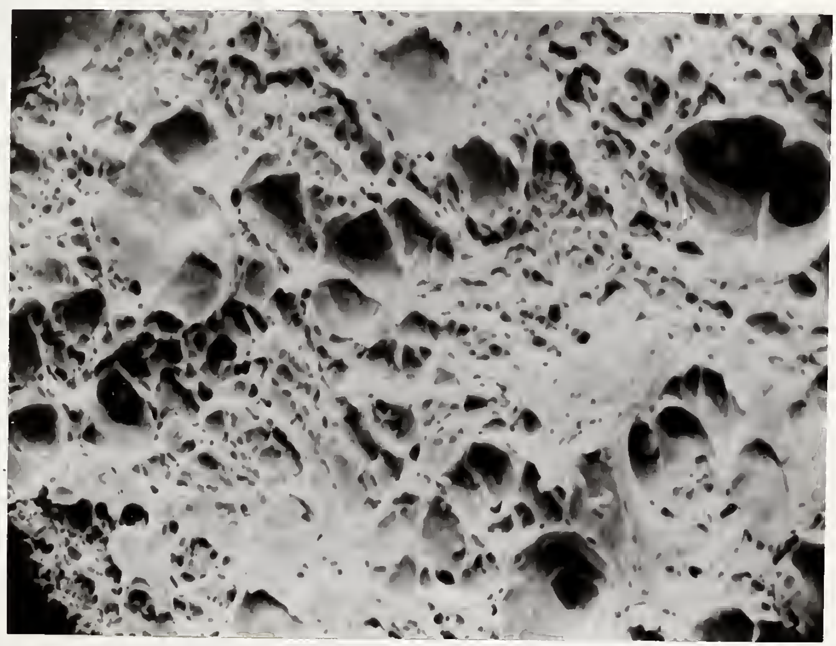


Figure 13. SEM of fracture surface of blade H showing dimpled rupture. X 1150

Figure 14. Unetched microstructure of cross section through blade G. This field was considered to have an inclusion content typical of the three cross sections examined. X 100

Figure 15. Unetched microstructure of cross section through blade F. This field was considered to have the greatest inclusion content for this cross section. X 100

Figure 16. Unetched microstructure of cross section through blade G. This field was considered to have the greatest inclusion content for this cross section. X 100

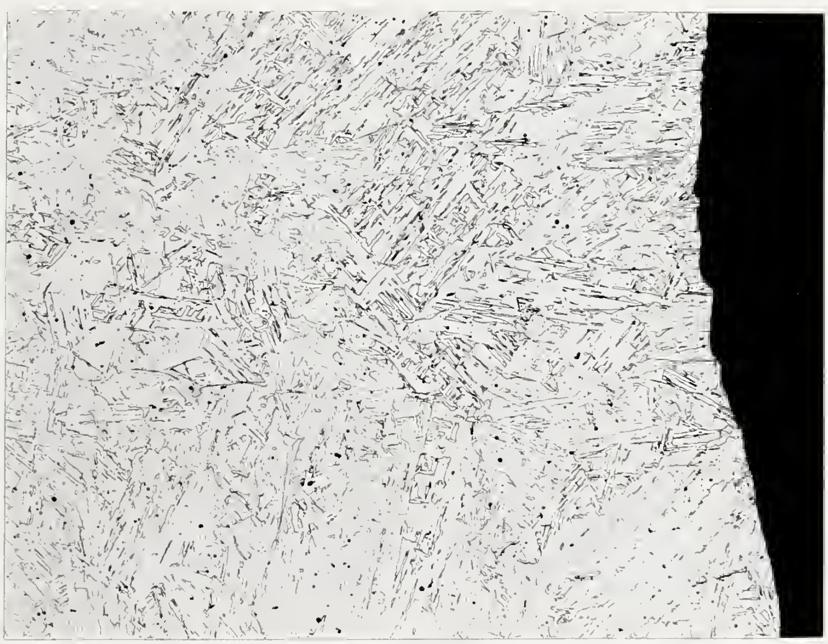


Figure 17. Etched microstructure of cross section through blade F showing fracture profile at right. Fracture is transgranular. Microstructure consists primarily of tempered martensite and "stringer" shaped patches of ferrite. Etch: Acidified picral. X 100

Figure 18. Etched microstructure of cross section through blade G showing fracture profile at right. Fracture is transgranular. Microstructure consists primarily of tempered martensite and "stringer" shaped areas of ferrite. Etch: Acidified picral. X 100

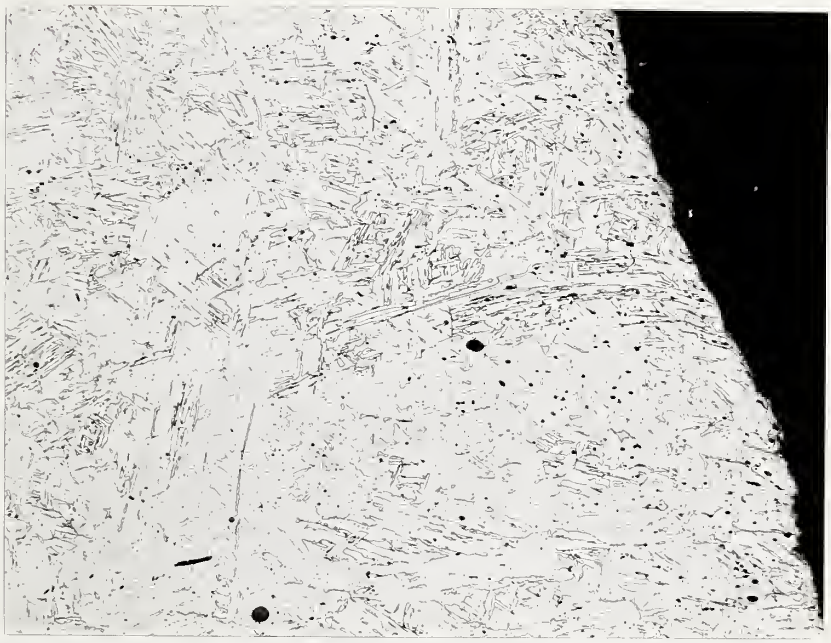


Figure 19. Etched microstructure of cross section through blade H showing fracture profile at right. Fracture is transgranular and there is considerable deformation adjacent to the fracture. Microstructure consists primarily of tempered martensite and "stringer" shaped areas of ferrite. Etch: Acidified picral. X 100

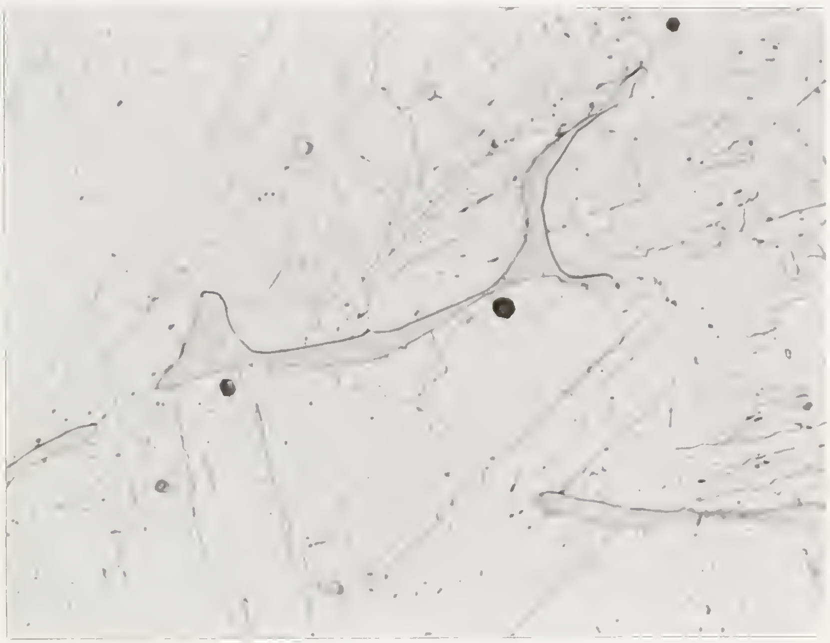


Figure 20. Etched microstructure of cross section through blade G at higher magnification than figures 17 through 19. The elongated "stringer" shaped areas appear to be ferrite. The matrix is tempered martensite. Etch: Acidified picral. X 1000

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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.)

The compressor case and the fifth and sixth stage compressor wheel assembly from an Allison helicopter engine which had failed were examined. Parts of the compressor case lining had been wiped, apparently by contact with the compressor blades. This may have been caused by, among other things, worn or off center compressor wheel bearings. The fifth and sixth stage regions of the case lining were severely damaged as were the fifth and sixth stage compressor and stator blades. The fourth stage stator blades were damaged to a lesser extent. Two of the three completely fractured compressor blades had failed in fatigue. The extensive damage to the case and to the blades may have been caused by motion in the operating compressor of one or more of the fractured blades or a foreign object.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Compressor; fatigue; fatigue fracture; helicopter engine

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