NBSIR 83-2774 (NTSB) (R)

Examination of Failed Tension-Torsion Strap from Bell 206B, N90071, Helicopter

Fracture and Deformation Division
Center for Materials Science
National Measurement Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

April 1983

Failure Analysis Report

Prepared for

National Transportation Safety Board
Washington, D.C. 20594

NBSIR 83-2774 (NTSB) (R)

EXAMINATION OF FAILED TENSION-TORSION STRAP FROM BELL 206B, N90071, HELICOPTER

T. Robert Shives

Fracture and Deformation Division
Center for Materials Science
National Measurement Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

April 1983

Failure Analysis Report

Prepared for
National Transportation Safety Board
Washington, D.C. 20594

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Examination of Failed Tension-Torsion Strap from Bell 206B, N90071, Helicopter

1. INTRODUCTION

1.1 Reference

National Transportation Safety Board, Washington, DC 20594. This investigation was conducted at the request of Mr. Jerry A. Houck of the National Transportation Safety Board in a letter received at NBS on October 17, 1977.

1.2 Parts Submitted

Two tension-torsion straps from Bell 206B, N90071 helicopter were submitted to the National Bureau of Standards for examination. Essentially all of the wires in one of the straps had fractured, and much of the polyurethane molding had been removed. This strap is shown as received at NBS in figure 1. The wires in the other strap were essentially intact, but the polyurethane molding had been removed from one side exposing the wires. This strap is shown as received at NBS in figure 2.

1.3 Background Information

The information in this section was furnished by the National Transportation Safety Board. The tension-torsion straps reportedly consist of more than eight thousand 0.0058 inch diameter AM 355 stainless steel wires wrapped around 17-7PH stainless steel spools at either end of the assembly. The parts of the spools in contact with the wires were coated with teflon before the wires were attached. Each of the individual wires was coated with a polyurethane batter before being wound onto the spools. After assembly, the whole unit except for the faces of the spools was molded in a polyurethane covering cured with Cature 21.

The aircraft to which the failed tension-torsion strap had been attached had been used in off-shore oil well drilling rig service. Thus, the tension-torsion straps were subjected to a marine environment.

2. PURPOSE

It was requested by the National Transportation Safety Board that NBS perform a failure analysis of the fractured wires in the failed tension-torsion strap.

3. PREPARATION OF WIRES FOR EXAMINATION

In order to characterize the wire fractures, it was necessary to clean the fracture surfaces and surfaces of the wires in the vicinity of the fractures of foreign material, including the polyurethane coating. In several cases, what appeared to be the polyurethane batter used to coat the wires before assembly protruded over part of the fracture surface. Several different cleaning procedures were employed for different groups of wires. These procedures are as follows:

(1) Cleaning ultrasonically in petroleum ether.
(2) Cleaning ultrasonically successively in (1) petroleum ether, (2) amyl acetate, and (3) commercial paint remover followed by rinsing in petroleum ether.
(3) Cleaning by soaking in a commercial polyurethane solvent followed by rinsing in petroleum ether.
(4) Cleaning by soaking in the same polyurethane solvent as in (3) followed by rinsing in ethanol.
(5) Cleaning by soaking in another commercial polyurethane solvent followed by rinsing in petroleum ether.

None of the above procedures was able to remove all of the foreign material from the fracture surfaces or from the surfaces of the wires. The above procedures seemed to work well on some wires but not on others. In some instances, a considerable amount of debris remained on the wires after cleaning. Much of this debris may have been the partially loosened polyurethane batter that had been used to coat the wires before assembly of the tension-torsion strap.

4. RESULTS OF THE EXAMINATION

4.1 Fractographic Examination

In order to have a fracture produced under known conditions for comparison with the field fractures, a length of wire was taken from the region of the failed strap identified by the letter A in figure 1 and fractured in the NBS laboratory by pulling in tension with pliers. Scanning electron microscope (SEM) fractographs of the fracture are shown in figure 3. The fracture is quite ductile with dimpled rupture being the predominant fracture mode. Significant necking is evident adjacent to the fracture. There is a considerable amount of debris on this fracture surface, especially for a fresh, laboratory-produced fracture. Most of this debris is probably from the polyurethane coating from the wire surface that stretched and loosened when the wire was pulled in tension.

A number of randomly selected field wire fractures from two separate locations on the failed strap (identified by letters A and B in figure 1) were taken for examination. As received at NBS, all the wires in the strap had failed at location B, whereas only some of the wires had fractured at location A. Each fracture was cleaned by one of the procedures listed in Section 3 above and then examined with the SEM in order to characterize the fractures. Fracture profiles and fractographs of many of these wires are shown in figures 4 through 25. Each of the wires examined was given a number designation which appears in the figure legend (such as 4-13 in figure 3). These designations are only for convenience during the examination and have no significance with respect to location in the assembly. The fractures shown in these figures have been classified into several groups according to fracture features. Eight of the fractures (figures 4 through 11) have characteristics of cup-cone or a combination of cup-cone and shear fracture. The predominant fracture mode in at least seven of these eight fractures is dimpled rupture which is indicative of ductile overload failure. The fracture mode for the eighth specimen was unclear due to the presence of foreign material on the fracture surface. Although there is considerable variation in the amount of necking associated with the fractures of these eight specimens, there was significant necking associated with all of them. Necking is another indication of ductile overload failure.

One wire fracture (figure 12) is relatively flat with a small amount of necking. There are numerous small holes on the fracture surface. The fracture mode is unclear.

Eight of the wires (figures 13 through 20) exhibit apparent shear fractures. For two of these fractures (figures 13 and 14), there was considerable necking. Dimpled rupture was the predominant fracture mode for at least one of the fractures. The fracture mode for the other one is unclear. There was some necking associated with the fractures shown in figures 15 through 19, although less than with the fractures shown in figures 13 and 14. Dimpled rupture is the predominant fracture mode for at least three and possibly four of these five specimens. The fracture mode is unclear for the fifth specimen (figure 17), although there is some evidence of striations. Striations normally are an indication of a time-dependent fracture mechanism such as fatigue or stress corrosion cracking. The fracture shown in figure 20 exhibits little if any necking, but the predominant fracture mode is still dimpled rupture. There is a large longitudinal crack intersecting the fractures shown in figures 17 through 20.

The fracture shown in figure 21 appears to be a combination of cup-cone and shear, but it has a configuration dissimilar to those of the other fractures examined. The predominant fracture mode is dimpled rupture, although there is some evidence of striations.

In four cases (figures 22 through 25), the fractures have substantial longitudinal components. These fractures may be somewhat similar to those shown in figures 17 through 20 where a longitudinal crack intersected the fracture surface. In the two cases where the mode could be determined (figures 24 and 25), the predominant fracture mode of the transverse components of these fractures is dimpled rupture. There is also some evidence of striations on the transverse components of the two fractures shown in figures 24 and 25. The fracture mode(s) of the longitudinal components of the fractures shown in figures 22 through 25 is unclear. These components have a "woody" appearance that may indicate intergranular fracture along the boundaries between the elongated grains of the wire.

A number of other fractured wires from the failed tension-torsion strap were examined. All of these fractures fit into one of the classifications described above.

4.2 Metallographic Examination

An etched longitudinal section through wire 1-11 at the fracture shown in figure 23a is shown in figure 26. Part of the fracture is shown at higher magnification in figure 27. The fracture is "stepped", being comprised of a series of alternate transverse and longitudinal segments. The microstructure appears to be highly worked with the grains elongated in the direction parallel to the longitudinal axis of the wire. The transverse components of the fracture appear to be transgranular. Even with the high magnification photomicrograph shown in figure 27, it is not clear whether the fracture path of the longitudinal components is transgranular or intergranular. No secondary cracking is evident in the section shown in figures 26 and 27. There are some stringer type inclusions evident. Such inclusions could act as initiation sites for longitudinal cracking. In general, the microstructure appears typical for a highly worked austenitic stainless steel.

4.3 Hardness Measurements

Knoop hardness measurements were made on longitudinal sections through two of the fractured wires. Measurements were made at loads of 500 and 1000 grams force. Average hardness values are 663 HK.5 and 592 HK.1. These Knoop values correspond approximately to Rockwell hardness values of 57 HRC and 53 HRC, respectively. Approximately equivalent tensile strength values range from slightly in excess of 300,000 psi to about 273,000 psi.

5. DISCUSSION AND CONCLUSIONS

Of the field fractures described in this report, seven are from location A and fifteen are from location B, as shown in figure 1. There does not appear to be any relationship between fracture configuration and location of the fracture within the tension-torsion strap.

Eight of the 22 wire field fractures shown in this report have substantial longitudinal cracks or longitudinal fracture components. The longitudinal component of the four fractures, where it was exposed (figures 22 through 25), had a "woody" appearance suggesting the possibility of intergranular fracture. It could not be determined from the metallographic examination whether the fracture path was primarily intergranular or transgranular. The transverse components of these fractures as well as of the four fractures where longitudinal cracks intersect the fracture surface exhibit dimpled rupture as the predominant fracture mode where the mode can be determined. Even though dimpled rupture is the predominant fracture mode, there is evidence of striations on at least four of the eight fracture surfaces. Striations suggest a time-dependent mechanism such as fatigue or stress corrosion cracking. Stress corrosion cracking is often accompanied by secondary cracking, no evidence for which was found in the metallographic study. Without discounting the possibility of stress corrosion cracking, fatigue or corrosion fatigue appears more likely to be the time-dependent mechanism involved, if indeed a time-dependent mechanism is involved at all. Because of the large longitudinal components of these fractures, it is possible that torsional stresses may be responsible for these longitudinal components.

Dimpled rupture is the predominant fracture mode for all the wires examined in this investigation where ever the fracture mode could be determined. Many of the fractures are similar in appearance to the fracture produced in the NBS laboratory by essentially uniaxial tensile overload. These fractures had a cup-cone appearance. A number of the other wire fractures appeared to have occurred in shear. Many of the wires exhibited considerable necking in the vicinity of the fracture. Both dimpled rupture and necking are indicative of ductile overload fracture.

A very small percentage of the total wire fractures was examined in this investigation, but the following hypothetical scenario appears reasonable based on the results obtained. In certain of the wires, cracks initiated and propagated essentially longitudinally by a time-dependent mechanism such as fatigue due to the application of torsional stresses. Although the principal directional component of these cracks is longitudinal, they gradually propagated transversely in small steps. Eventually, the transverse direction of propagation dominated. After the crack had propagated far enough in the transverse direction to reduce the effective cross sectional area of the wire sufficiently so that it could no longer support the applied load, final failure occurred in ductile overload. Whenever a wire fractured in this manner, the effective cross sectional area of the whole assembly was decreased, although very slightly. As more and more wires fractured in this way, however, the applied load eventually became too great for the reduced cross sectional area to support and the remaining wires fractured in ductile overload -- hence the large number of ductile overload failures.

Figure 1. Failed tension-torsion strap with the fractured wires as-received at NBS. The letters A and B indicate locations where wire fracture samples were taken for examination. X 3/5

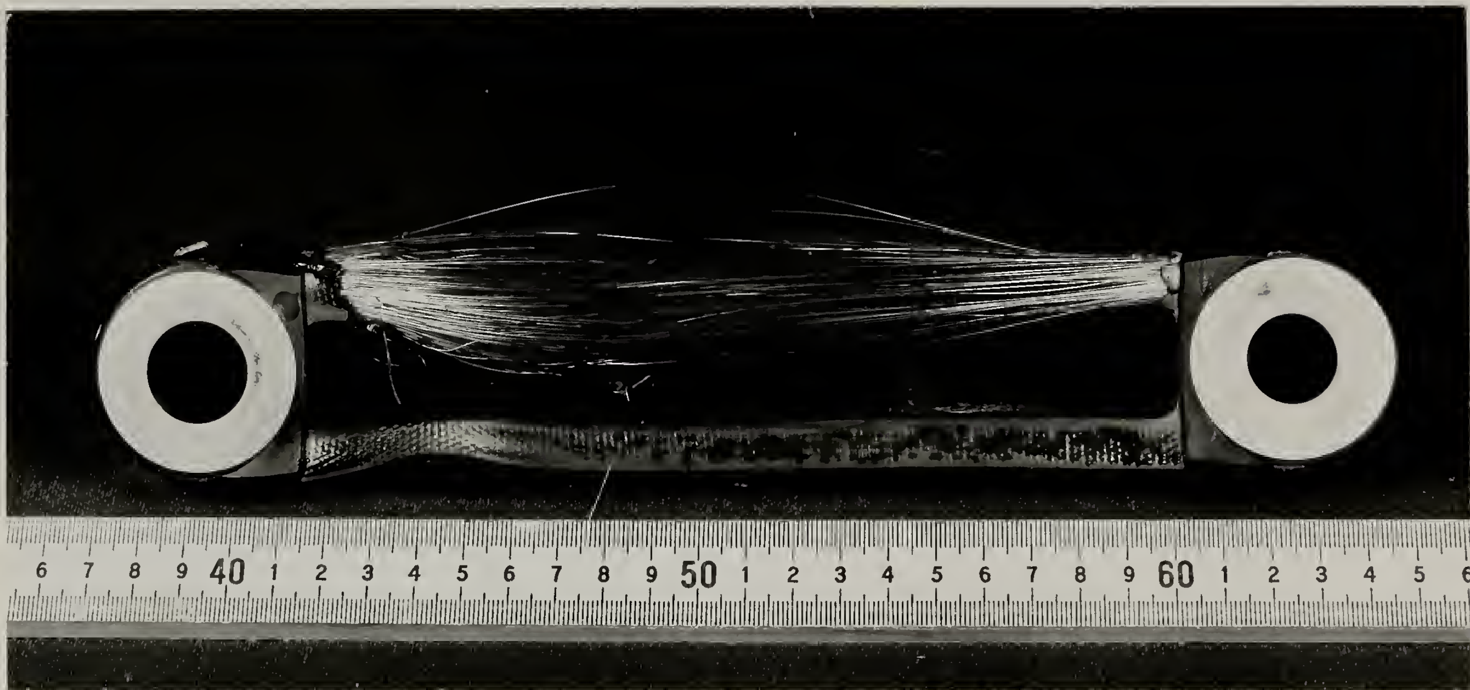


Figure 2. Tension-torsion strap with the wires essentially intact, as-received at NBS. Much of the polyurethane molding has been removed. X 3/5

a. X 210 b. X1050

Figure 3. Wire no. 4-13, location A. This fracture was produced in the NBS laboratory by pulling the wire in tension. The fracture is a cup-cone type with significant necking. The primary fracture mode is dimpled rupture.

a. X 180 b. X 900

Figure 4. Wire no. 4-3, location A, cleaned in petroleum ether. The fracture is a cup-cone type with significant necking. The primary fracture mode is dimpled rupture.

a. X 190

b. X 950

Figure 5. Wire no. 4-6, location A, cleaned in petroleum ether. The fracture is primarily cup-cone with considerable necking. There is a significant transverse component. The predominant fracture mode is dimpled rupture.

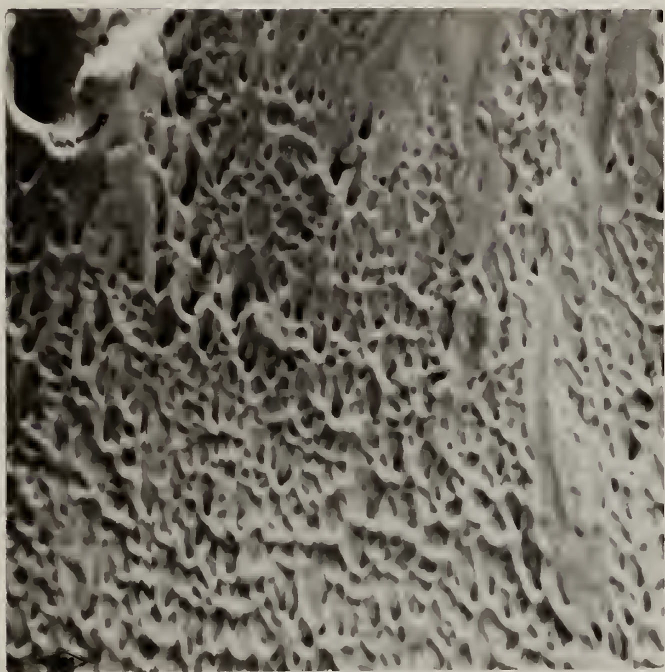
a. X 300

b. X 1400

Figure 6. Wire no. 2-2, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. The fracture appears to be basically cup-cone with some necking. Dimpled rupture is the predominant fracture mode. There is a considerable amount of foreign material adhering to the surface of the wire.

a. X 220

b. X 1100

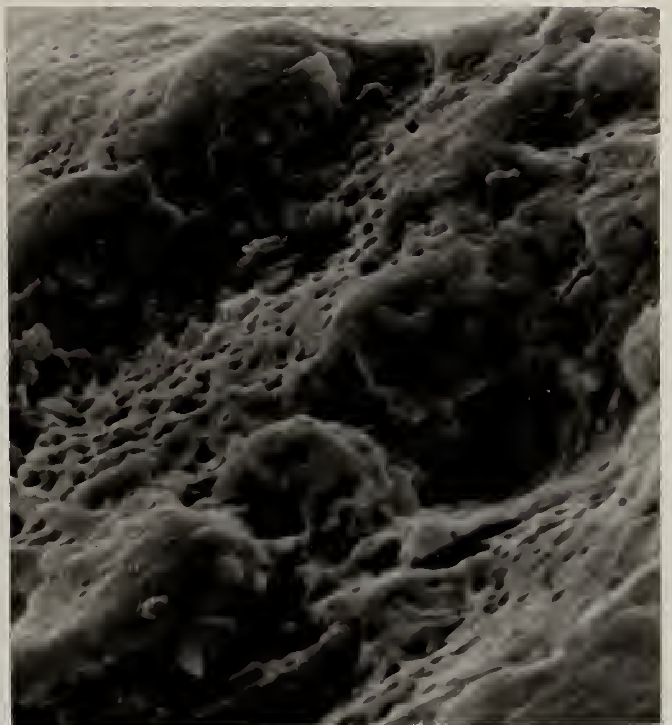


c. X 2200

Figure 7. Wire no. 1-2, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. The fracture is basically cup-cone with significant necking. Dimpled rupture is the predominant fracture mode. The fractograph shown in figure 7c was taken in the area indicated by the arrow in 7a. There appear to be imperfections or mechanical damage in the coating or surface of the wire as can be seen in figure 7a.

a. X 300

b. X 2000



c. X 2000

Figure 8. Wire no. 2-3, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in petroleum ether. The fracture is basically cup-cone. Some necking is evident. What appears to be the polyurethane batter used to coat the wire is covering part of the fracture adjacent to the wire surface (figure 8b). The fractograph shown in figure 8c was taken near the center of the fracture. There appears to be foreign material on the fracture surface and the fracture mode is unclear.

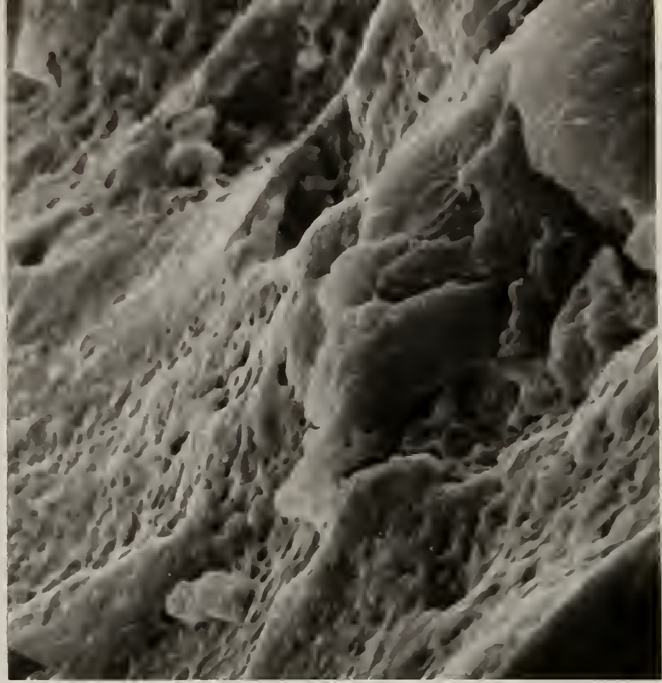
a. X 210 b. X 1680

Figure 9. Wire no. 1-6, location B, cleaned ultrasonically in petroleum ether. The fracture appears to be primarily cup-cone with considerable necking. Dimpled rupture is the predominant fracture mode.

a. X 190 b. X 1520

Figure 10. Wire no. 1-5, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. The fracture appears to be primarily cup-cone with significant necking adjacent to the fracture. The primary fracture mode is dimpled rupture.

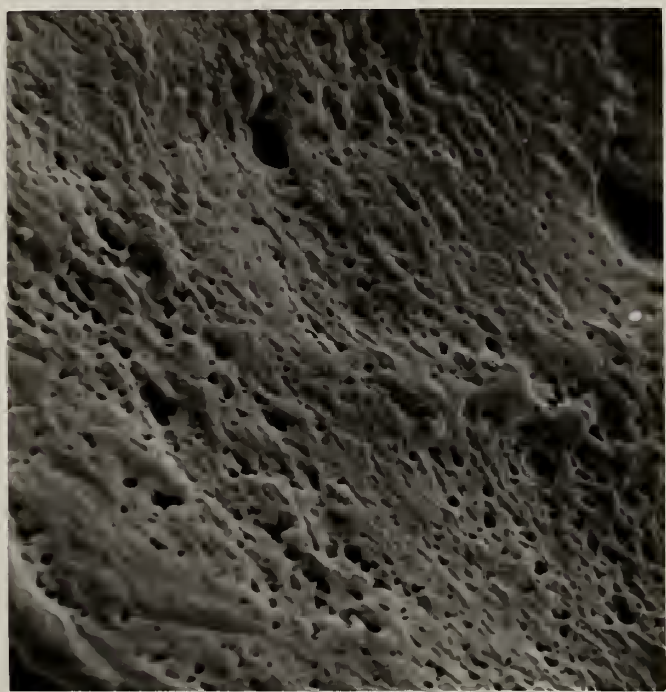
a. X 300



b. X 2000

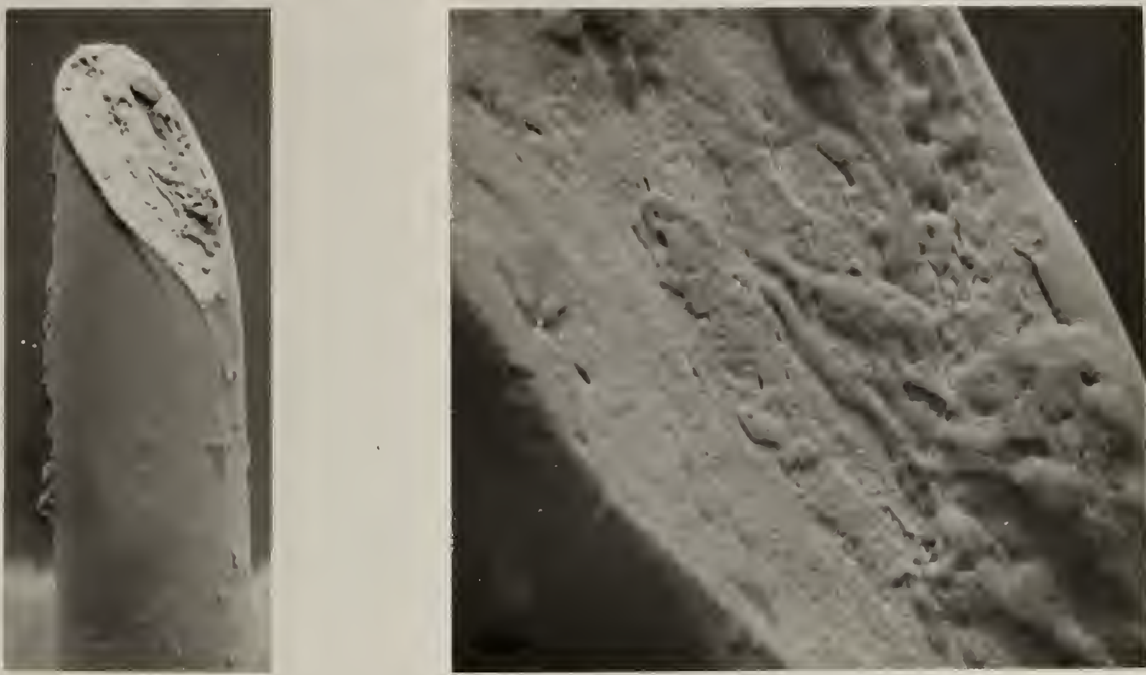
Figure 11. Wire no. 2-4, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in petroleum ether. The fracture appears to be a combination of cup-cone and shear with significant necking. The predominant fracture mode is dimpled rupture. There is a considerable amount of debris on both the fracture surface and on the surface of the wire.

a. X 300



b. X 2000

Figure 12. Wire no. 2-1, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in petroleum ether. The fracture is relatively flat and is about 90° to the longitudinal axis of the wire. There are numerous small holes in the fracture surface. The fractograph shown in figure 12b was taken at the lower right of the fracture as shown in figure 12a where the concentration of holes appeared to be greatest. There is very little necking and the fracture mode is unclear.



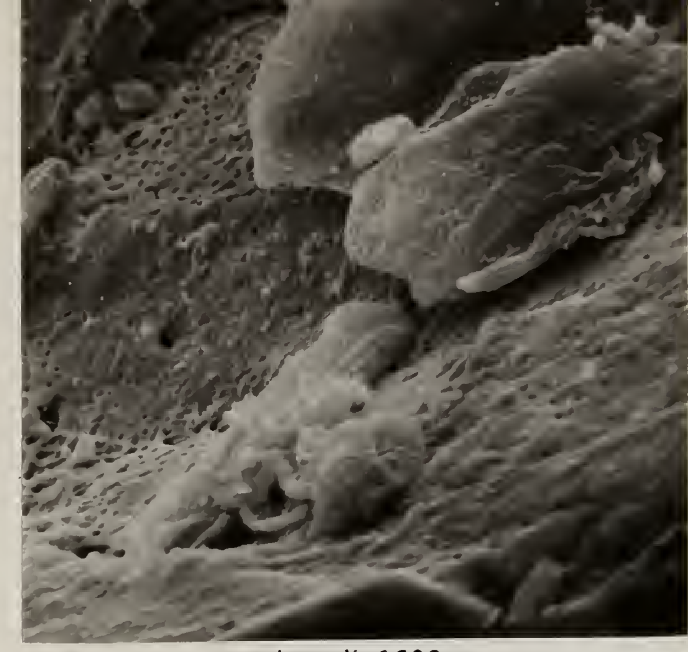
a. X 180 b. X 900

Figure 13. Wire no. 3-5, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in ethanol. Apparent shear fracture with small amount of necking. The fracture mode is unclear, but the necking indicates some ductility. There is considerable debris on both the fracture surface and on the surface of the wire.

a. X 165 b. X 1650

Figure 14. Wire no. 3-2, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in ethanol. Primarily shear fracture with some necking. Dimpled rupture is the predominant fracture mode. There is considerable debris on both the fracture surface and on the surface of the wire.

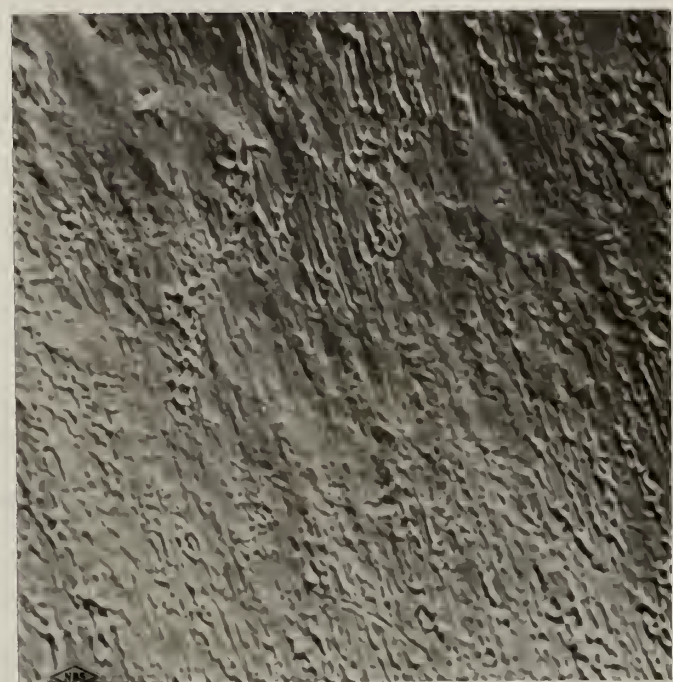
a. X 300



b. X 1600

Figure 15. Wire no. 2-5, location B, cleaned by soaking in a commercial polyurethane solvent followed by rinsing in petroleum ether. The fracture is primarily shear with a small amount of necking. The predominant fracture mode is dimpled rupture. There is a considerable amount of debris on both the fracture surface and the surface of the wire.

a. X 160



b. X 1050

Figure 16. Wire no. 1-1, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. Shear fracture with little or no necking. The fracture mode is unclear, although there is some evidence to indicate dimpled rupture.

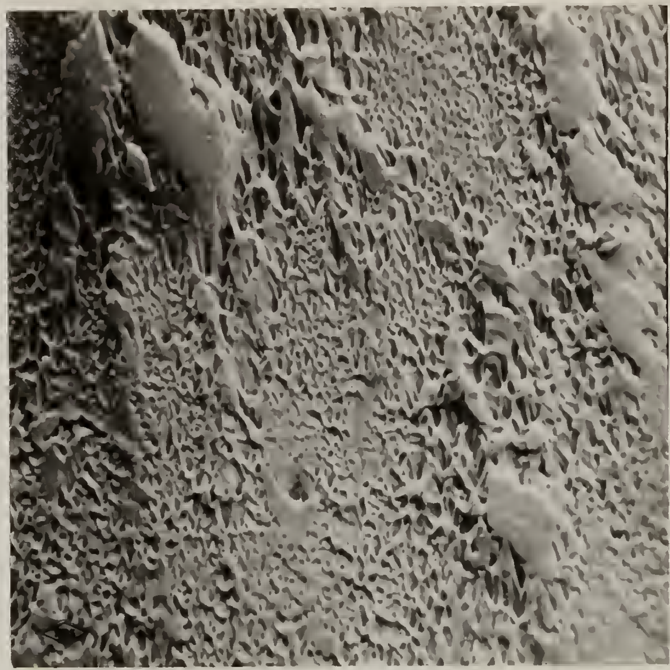
a. X 400 b. X 1600

Figure 17. Wire no. 1-3, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. The shear fracture follows two different planes over about the upper 2/3 of figure 15a. There is a longitudinal crack intersecting the fracture at the dividing line between the two fracture planes. The fracture mode is unclear, but there is some evidence of striations.

a. X 215 b. X 1050

Figure 18. Wire no. 1-7, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. This is a shear fracture with some necking. There is a longitudinal crack intersecting the fracture. The predominant fracture mode is dimpled rupture.

a. X 215



b. X 1125

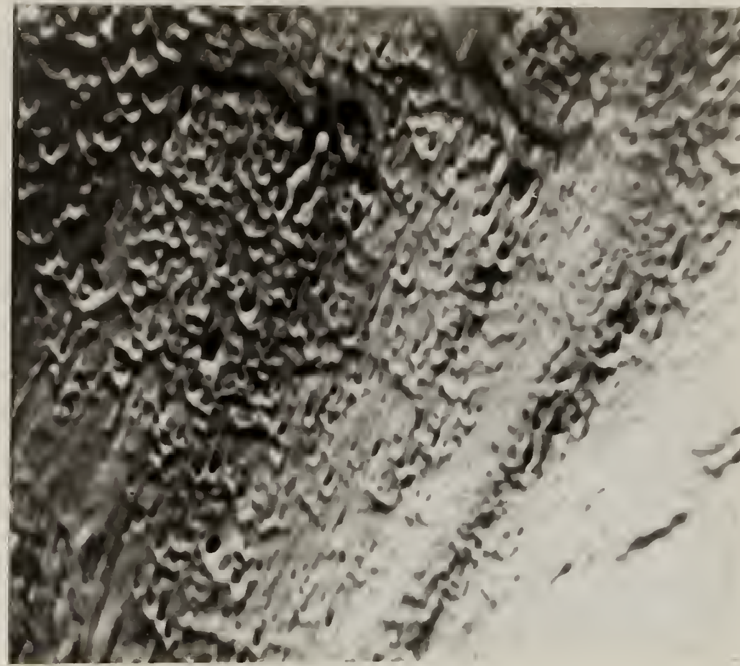
Figure 19. Wire no. 1-10, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. This is an apparent shear fracture with a small amount of necking. The predominant fracture mode is dimpled rupture.

a. X 190

b. X 610

Figure 20. Wire no. 4-7, location A, cleaned in petroleum ether. The fracture is primarily shear with little necking. The predominant fracture mode is dimpled rupture. A longitudinal crack intersects the fracture. There is considerable debris on the fracture surface.

a. X 190



b. X 1900

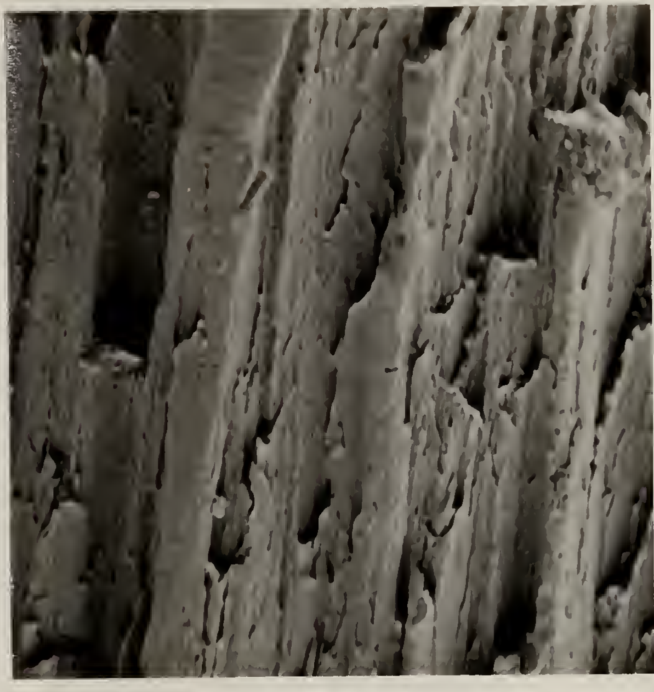
Figure 21. Wire no. 4-5, location A, cleaned in petroleum ether. The fracture appears to be a combination of cup-cone and shear with some necking. The predominant fracture mode is dimpled rupture, although there is evidence of striations. Some of the apparent striations are actually elongated dimples.

a. X 190

b. X 950

Figure 22. Wire no. 4-2, location A, cleaned with petroleum ether. The longitudinal part of the fracture has a woody appearance. The nearly transverse part of the fracture is covered with debris and the features can not be seen.

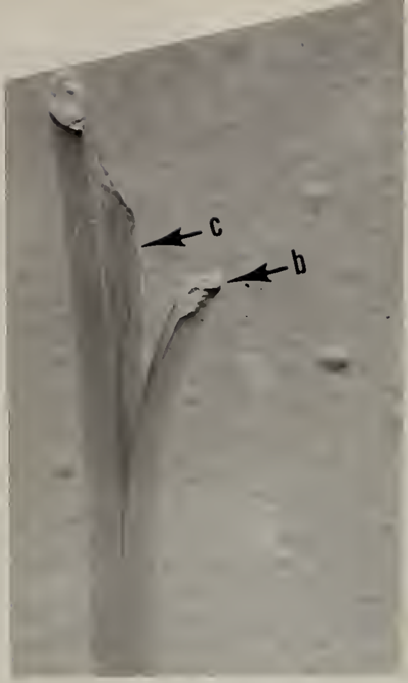
a. X 95



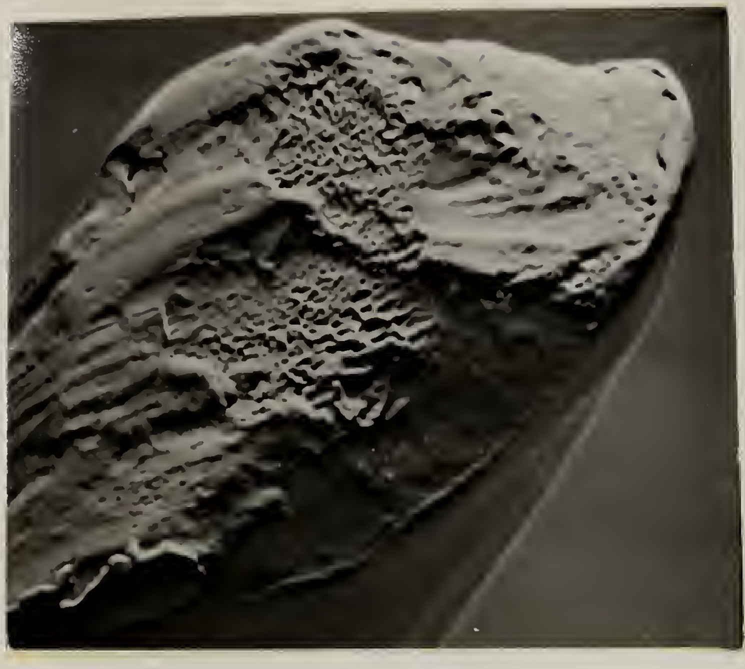
b. X 1200

c. X 1200

Figure 23. Wire no. 1-11, location B, cleaned ultrasonically in (1) petroleum ether, (2) amyl acetate, (3) commercial paint remover followed by rinsing in petroleum ether. The longitudinal part of the fracture has a woody appearance (figure b). For the most part, the transverse portion of the fracture (figure c) appeared to be covered with a foreign substance; therefore, the fracture mode was not determined. The foreign material is likely the polyurethane batter used to coat the wires at the time of assembly during manufacture.



a. X 68



b. X 950

c. X 1360

Figure 24. Wire no. 5-1, location A, cleaned in commercial polyurethane solvent and rinsed in ethanol. The fracture mode of the transverse part of the fracture in the vicinity of arrow b is dimpled rupture (figure 24b). There is a hint of striations in the left part of figure 24b. The longitudinal component of the fracture has a woody appearance. (figure 24c)

a. X 48

b. X 940

c. X 940

Figure 25. Wire no. 5-2, location A, cleaned in commercial polyurethane solvent and rinsed in ethanol. There is some dimpled rupture on the nearly transverse component of the fracture (figure 25b). There is also evidence of striations in some areas of this part of the fracture. The longitudinal component of the fracture exhibits considerable mechanical damage and has a somewhat woody appearance where the features have not been obliterated.

Figure 26. Longitudinal section through wire shown in figure 23 exhibiting the fracture profile. The longitudinal axis of the wire is vertical.
Etchant: 4% picral + 1% HCL X 500

Figure 27. Part of the field shown in figure 26 above, but at higher magnification.
Etchant: 4% picral + 1% HCL X 2500

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR 83-2774	2. Performing Organ. Report No.	3. Publication Date November 1983

4. TITLE AND SUBTITLE

Examination of Failed Tension-Torsion Strap from Bell 206B, N90071, Helicopter

5. AUTHOR(S)

T. Robert Shives

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

National Transportation Safety Board
Washington, D.C. 20594

10. SUPPLEMENTARY NOTES

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

11. 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 submitted a failed tension torsion strap to the NBS Fracture and Deformation Division for examination. The strap consisted of more than eight thousand 0.0058 inch diameter AM 355 stainless steel wires wrapped around 17-7PH stainless steel spools at either end of the assembly. The unit was molded in polyurethane. All of the wires had fractured. NBS was requested to characterize the fractures. It appeared that in certain of the wires, cracks had initiated and propagated essentially longitudinally by a time-dependent mechanism such as fatigue due to the application of torsional stresses.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

AM355 stainless steel; helicopter; tension-torsion strap; time-dependent fracture mechanism.

13. AVAILABILITY

☐ Unlimited
☒ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

15. Price