

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



WPR23LA004

MATERIALS LABORATORY

Factual Report 23-081

October 17, 2023

(This page intentionally left blank)

A. ACCIDENT INFORMATION

Location: Fresno, California
Date: October 1, 2022
Vehicle: Bell 206B, N284CA
Investigator: Joshua Cawthra

B. COMPONENTS EXAMINED

Tail rotor drive shaft assembly.

C. EXAMINATION PARTICIPANTS

Group Chair Frank Zakar
 NTSB
 Washington DC

Member Ruben Cortez
 Bell Flight
 Dallas, Texas

D. DETAILS OF THE EXAMINATION

Figure 1 shows a photograph of the as-received tail rotor drive shaft assembly. This assembly was the 4th drive shaft segment from the forward end. At the time of manufacture, the forward end of the tail rotor drive shaft is inserted approximately 2 inches into the bore of the splined adapter and the two pieces are permanently joined by an adhesive. The splined adapter separated from the drive shaft at the adhesive bond joint (along the entire length of the bond joint). The aft end of the tail rotor drive shaft was bonded to a fixed (non-splined) adapter. The bonded joint at the fixed adapter remained intact.

The serial number "VN12657" of the tail rotor drive shaft assembly was vibropencil marked on the outer surface of the splined adapter. The part number of the tail rotor assembly was not stamped on the drive shaft but was deduced by looking at distinct features that differentiated one part number from another (refer to Appendix 1 titled "Rational for Determining the Tail Rotor Drive Shaft Part Number"). The serial number of the tail rotor drive shaft assembly was determined to be part number 206-040-931-101.

SPLINED ADAPTER END

The tail rotor drive shaft and bearing hanger assembly were disassembled. The bearing assembly rotated freely. The nut, washer, and plate (disk with hole in the middle) were disassembled from the aft end of the coupling adapter, after which the coupling adapter (containing internal splines) was removed from the external spline (see figure 2). The exposed splines contained contact marks, typical of normal contact between mating parts, with no evidence of mechanical damage.

The splined adapter at the aft end contained a longitudinal crack. The length of the longitudinal crack measured approximately 1.5 inches. A circumferential cut was made through the splined adapter that intersected the forward end of the 1.5 inch portion of the crack. The cut portion was unrolled and flatted by hand into a flat sheet to expose the inner bonded surface (see figure 3). Bench binocular microscope examination of the flattened inner surface revealed mixed adhesive and bare metal areas that contained evidence of rotational mechanical damage (rotation between drive shaft and mating adapter). The adhesive material showed evidence of heating and re-solidification. Appendix 2 shows the surface finish on the inner surface in an isolated area of exposed bare metal containing no rotational mechanical damage. The mating bonded surface (on the shaft) showed evidence of adhesive material that extended all around the bond zone with extensive rotational mechanical damage.

The outer diameter of the splined adapter at the aft end is tapered (the thickness of the outer diameter continuously decreases towards the aft end), while the inner diameter remains constant. The thickness of the wall was measured with a point micrometer from the aft end to the forward end of the tapered section (thinner to thicker wall), see table 1. The measurements were made along a straight line at specific locations (intervals) indicated by Bell engineering drawing, in areas that contained no evidence of rotational mechanical damage. The thickness measurements for the tapered wall were below the specified limits.

The unrolled/flattened splined adapter sheet contained mating longitudinal fracture faces. One longitudinal fracture face was immersed into a beaker that contained acetone and was ultrasonic cleaned to remove loose adhesive material. The cleaned fracture face was bent 90 degrees by hand (bend was parallel to the length of the fracture face) to facilitate scanning electron microscope (SEM) examination of the longitudinal fracture face. SEM examination of the fracture face showed evidence of micro-void coalescent features typical of overstress separation.

The outer face of the splined adapter on diametrically opposite sides (area corresponding to the largest diameter) were cleaned with grit paper to remove the primer and paint coatings. Hardness testing of the exposed bare metal areas produced an average hardness of 76 HRB, which was greater than the minimum specified hardness. Electrical conductivity testing of the bare metal surface produced

an average reading of 28% International Annealed Copper Standard (IACS), which was less than the maximum specified value.

As indicated earlier, a 0.1 inch long portion of the drive shaft fractured circumferentially from the forward end of the drive shaft (see figure 4). Bench binocular microscope examination of the 0.1-inch long separated portion revealed it had turned inside-out. The original black inner surface was facing out and the rotational damaged outer surface was facing in. The manufactured aft end which remained flat (perpendicular to the length of the drive shaft). The aft end of the drive shaft contained a total of 13 axial cracks. The axial cracks were randomly distributed around the drive shaft portion. The fracture faces showed evidence of micro-void coalescent features typical of overstress separation.

Inspection of the inside surface of splined adapter revealed evidence of circumferential galling from contact with the forward end of the drive shaft.

Fixed (non-splined) adapter

A circumferential saw cut was made on the drive shaft at an area that was located approximately 4 inches from the aft end of the fixed adapter, resulting in a 4-inch length portion that contained the fixed adapter and drive shaft. The 4-inch length portion was longitudinally sectioned in half (see figure 5). One half of the longitudinal section was dipped in a stainless steel tank that was filled with liquid nitrogen, to aid in separating the fixed adapter from the drive shaft portion. After soaking for several minutes, the drive shaft portion was forcibly separated from its mating fixed adapter half. The same procedure was repeated for the mating longitudinal half of the section. Bench binocular microscope examination of the exposed bond surfaces showed mixed bare metal and adhesive material, with no evidence of discoloration or degradation of adhesive material, and no evidence of porosity that exceed the manufacture drawing requirements (see figure 6). Appendix 2 shows the surface finish on the inner surface in an isolated area of exposed bare metal containing no rotational mechanical damage, both on the drive shaft and fixed adapter side.

The outer diameter at the aft end of the fixed adapter is tapered (the thickness of the outer diameter continuously decreases towards the aft end), while the inner diameter remains constant. The wall thickness of the fixed adapter was measured from the aft end to the forward end of the tapered section (thinner to thicker). The measurements were made along a straight line at specific locations (intervals) indicated by Bell engineering drawing. The measured thickness were within specified limits (see table 2). The specified tapered wall thickness profile on the fixed adapter is different from that on the splined adapter (both adapters have different thickness wall profiles).

Drive Shaft

The wall thickness of the drive shaft measured approximately 0.051 inch, which is within the specified thickness. The outer diameter measured approximately 1.004 inches, which was within specified limits. The inner diameter measured approximately 0.9 inches, which was within specified limits.

Submitted by:

Frank Zakar
Senior Metallurgist

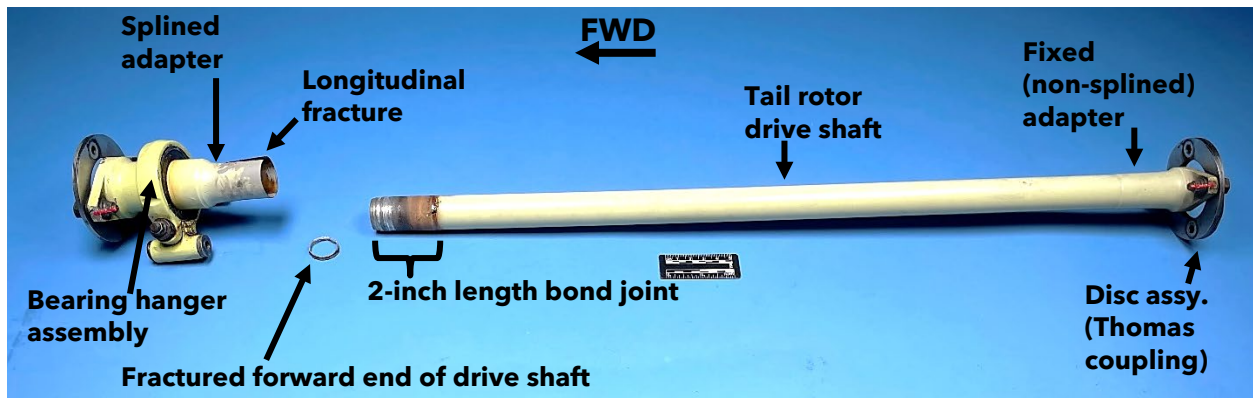


Figure 1. As-received tail rotor drive shaft assembly. The tail rotor drive shaft splined adapter separated from the forward end of the shaft at the bond joint.

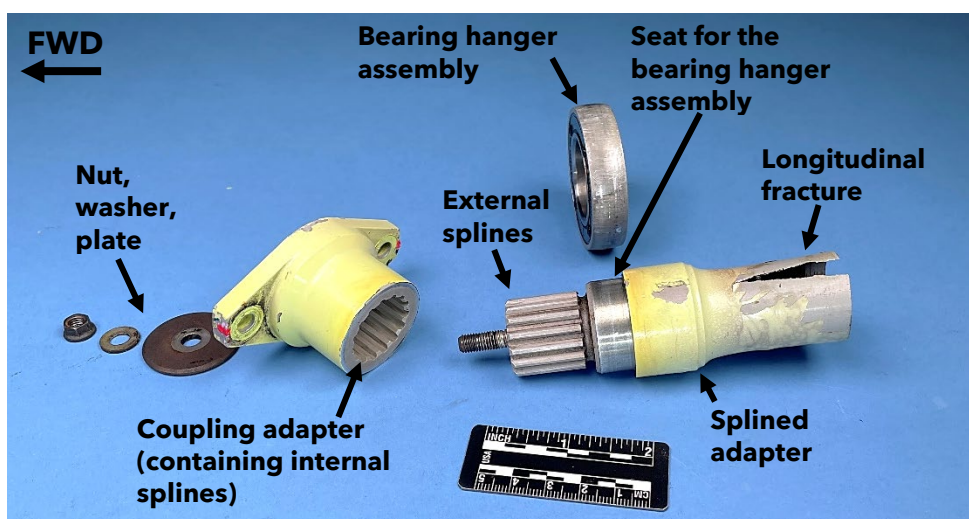


Figure 2. Disassembled coupling adapter and exposed splines.

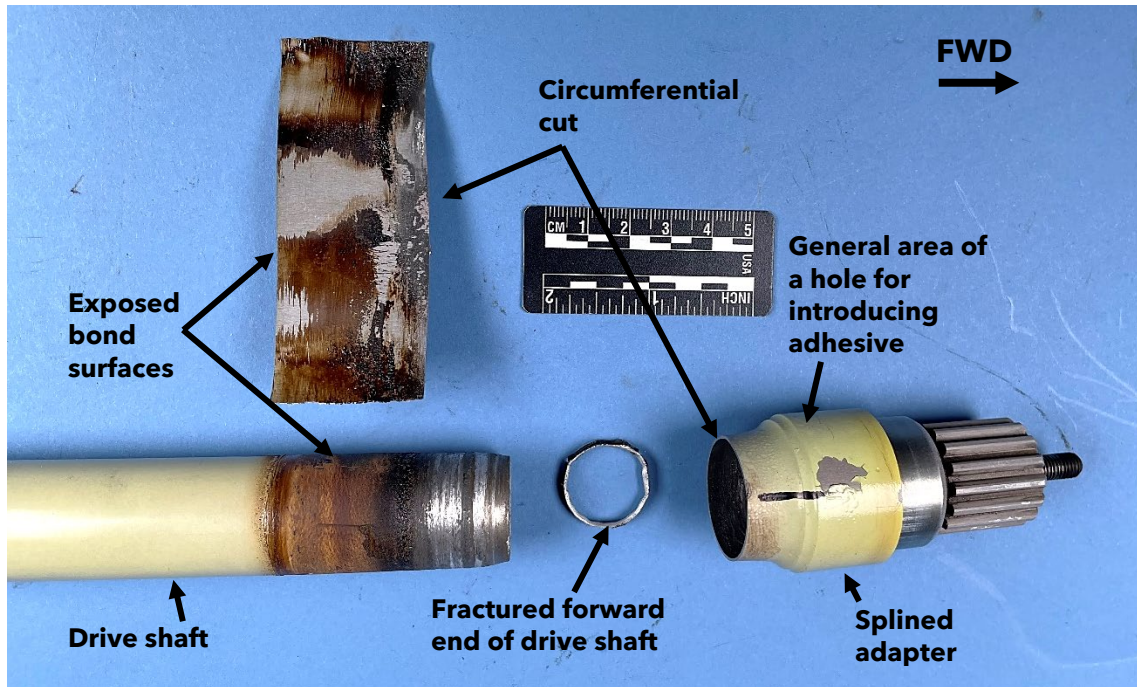


Figure 3. The aft end of splined adapter was cut (circumferentially) in the area indicated by arrows to expose the bonding surfaces. At time of manufacture, the drive shaft is inserted into the bore of the splined adapter, and adhesive is introduced into the bond joint through a hole in the splined adapter. The hole is sealed by the adhesive.

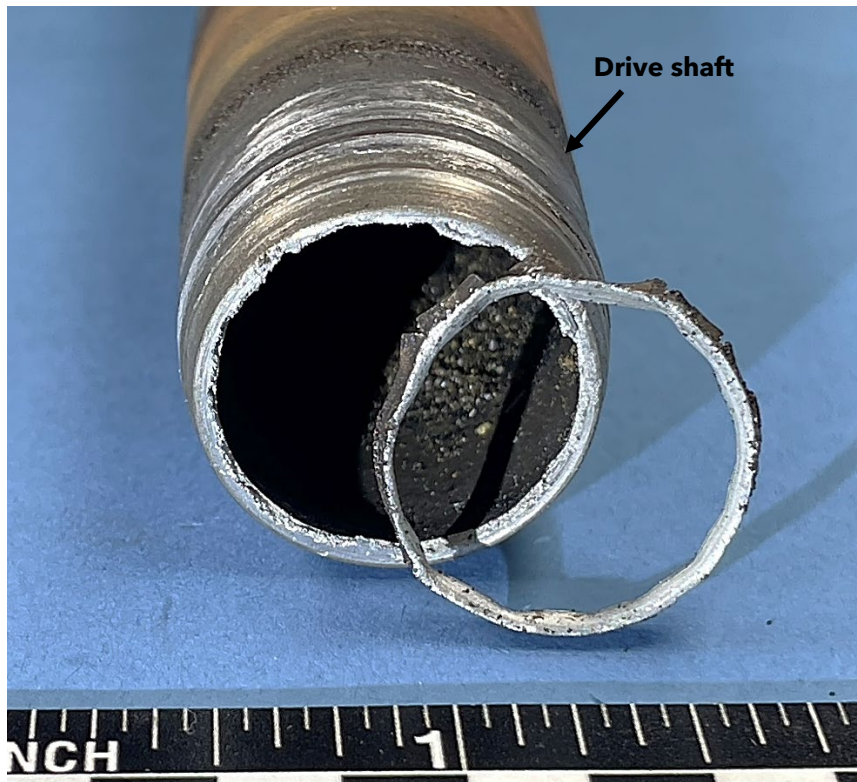


Figure 4. View of the forward end of the drive shaft showing a 0.1 inch length portion that fractured circumferentially from the forward end.

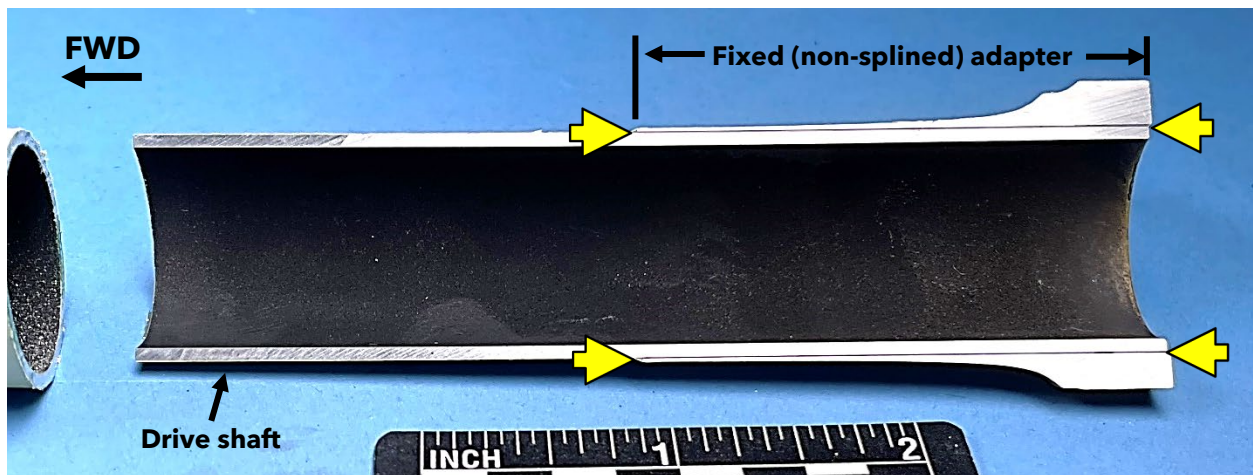


Figure 5. Longitudinal cross section that was made through the fixed adapter showing the adhesive bonded interfaces (bond lines) located between unmarked arrows.

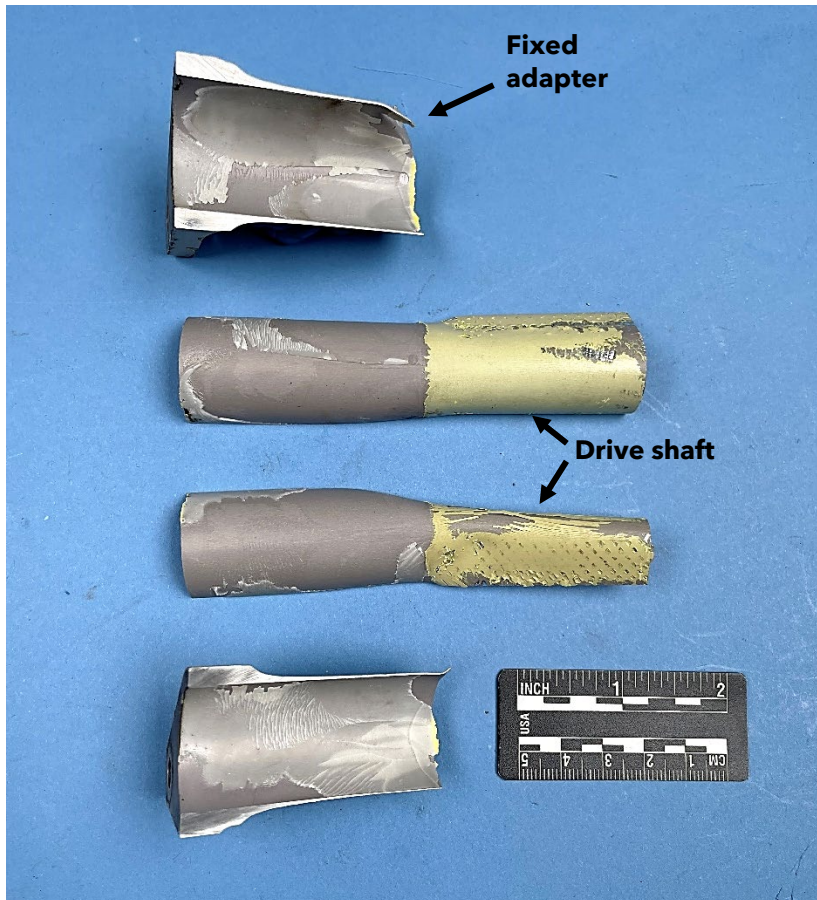


Figure 6. Exposed bond surfaces shown after separating the drive shaft from the fixed adapter, post dipping parts in liquid nitrogen.

Table 1. Splined Adapter	
Part Station Number	Measured Wall Thickness (inch)
0.000	0.010
0.400	0.011
0.800	0.012
1.000	0.016
1.200	0.019
1.400	*
1.600	*
1.650	*
1.700	*
1.740	*

Note: (*) This portion of the adapter was not sectioned and wall thickness was not measured.

Table 2. Fixed Adapter	
Part Station Number	Measured Wall Thickness (inch)
0.000	0.008
0.400	0.010
0.800	0.014
1.000	0.017
1.200	0.022
1.400	0.031
1.600	0.058
1.650	0.073
1.700	0.102
1.740	0.138

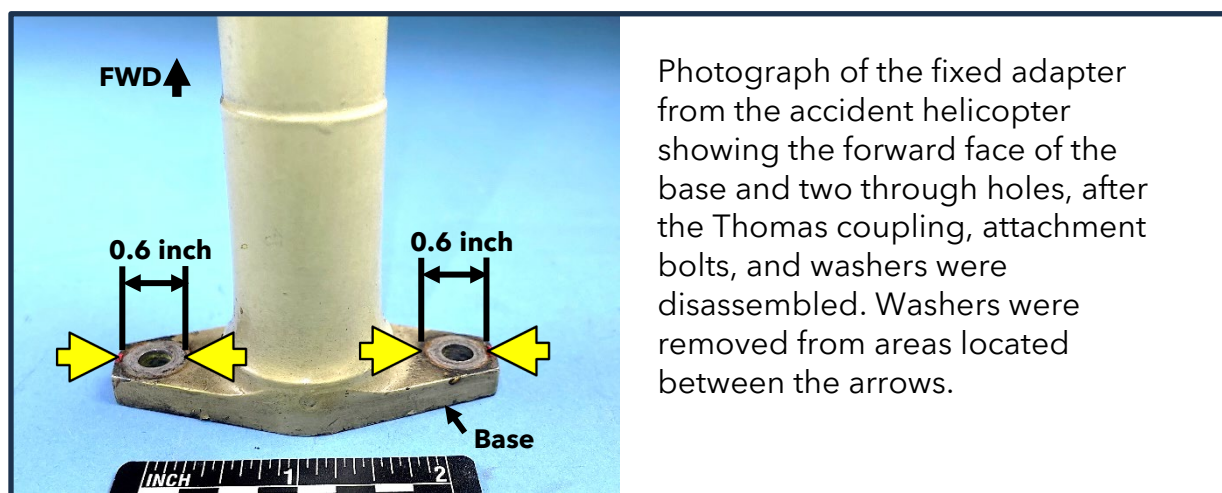
APPENDIX 1

Rational for Determining the Tail Rotor Drive Shaft Assembly Part Number

This section presents the rationale for arriving at the 206-040-931-101 tail rotor drive shaft assembly part number.

According to Bell engineering drawings, the tail rotor drive shaft assembly from the accident helicopter was either a -9 or -101 assembly. The length of the drive shaft was measured. Based on the drive shaft lengths, the assembly was a -101 as opposed to the -9 assembly.

The base of the fixed adapter was attached to a Thomas coupling assembly (see figure 1) by two attachment bolts and washers. The figure below shows a photograph of the base for the fixed coupling after the bolts and washers were removed. The forward side of the base contained impressions of the washers. Based on the treatment and coatings at the base of the fixed adapter, the assembly was consistent with a -101 drive shaft assembly as opposed to the -9 assembly.



The tail rotor drive shaft assemblies were manufactured with a -3 or -1 forward end splined adapter assembly. The size of the seat for the bearing hanger assembly differentiates a -3 assembly from a -1 assembly (see figure 2). The length and diameter of the seat for the bearing hanger assembly were measured. Based on the measurements of the bearing seat, the splined adapter was consistent with a -101 drive shaft assembly as opposed to the -9 assembly. These observations are consistent the accident helicopter having been installed with a -101 tail rotor drive assembly.

APPENDIX 2

Metal Surface Finish In Isolated Areas that Contained No Rotational Mechanical Damage



Splined adapter inner surface showing uniform circumferential surface finish scratch pattern.



Fixed adapter inner surface showing criss-cross¹ surface finish scratch pattern, similar to an "X" pattern.



Drive shaft inner surface at the fixed adapter end showing uniform circumferential surface finish scratch pattern.

¹ Criss-cross is a pattern of intersecting (crossing) lines.