National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 10, 2006

In reply to refer to: A-06-24 through -26

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

The National Transportation Safety Board is currently investigating two accidents involving fractures of tension-torsion (T-T) straps in MD Helicopters, Inc. (MDHI), model MD900 helicopters. Thirteen T-T straps are part of the anti-torque fan assembly in the no tail rotor (NOTAR®) systems in the MD900 helicopter. Fracture of a T-T strap results in failure of the anti-torque fan and loss of thrust for yaw control.

On September 8, 2004, about 1600 mountain standard time, an MD900, N9016W, operated by MDHI, experienced a failure of the NOTAR® anti-torque fan during the initial climb from the Boeing Heliport, Mesa, Arizona.[1] The certified flight instructor, the sole occupant, was not injured; the helicopter sustained minor additional damage upon landing.

On September 14, 2004, another MD900, JA6757, experienced a failure of the NOTAR® anti-torque fan while en route from Shizuoka City, Japan, to Tokyo, Japan, and made an emergency landing in Atsugi, Japan.[2] The occupants were slightly injured; the helicopter sustained substantial damage upon landing.

Post-accident inspections of the accident helicopters revealed that in each case, 1 of the 13 T-T straps in the anti-torque fan had fractured. The fractured strap for N9016W failed after 1,694 hours time in service (TIS) and for JA6757, after 1,724 hours TIS. These fractures resulted in liberation of anti-torque fan blades from the anti-torque fan and a loss of thrust for helicopter yaw control. Figure 1 shows one of the fractured straps. All 26 of the straps from both accident helicopters were sent to the Safety Board's Materials Laboratory for examination.

A schematic cross-section of the MD900 anti-torque fan assembly is shown in figure 2. Within the fan assembly, each T-T strap extends radially from the center spline assembly like spokes from a hub, connecting the blade assemblies at their outer spools to the center spline assembly at their inner spools. The fan assembly rotates counterclockwise about the center spline assembly axis as viewed looking forward. In addition, the blade assemblies rotate within openings in the inner and outer rims of the fan hub, producing changes in pitch, which are controlled through a sliding pitch

[1] Safety Board accident number: LAX04LA333.

[2] Safety Board accident number: ENG04RA033. The Board is participating as an accredited representative in the accident investigation, which is led by Japan's Aircraft and Railway Accidents Investigation Commission.

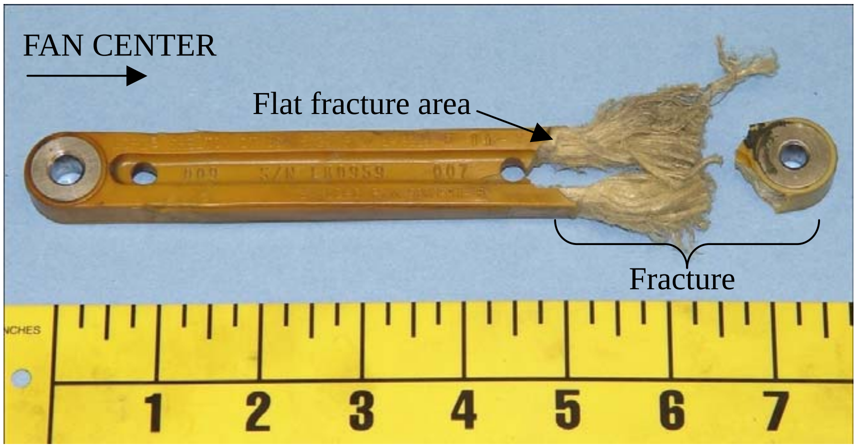

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Figure 1. View of the fractured strap from one of the accident helicopters showing the side with identifying markings.

change plate that is attached to arms on the blade assemblies. The centrifugal force produced by the fan blade assemblies rotating about the center of the anti-torque fan assembly causes the straps to be loaded in tension while changes in pitch cause the straps to be twisted.

A cutaway schematic showing the T-T strap construction is shown in figure 3. The T-T straps are made of continuous-wound Kevlar® fibers wrapped around corrosion-resistant steel spools. The spools have circular flanges at each end of a cylindrical spindle, and the strap attachment hardware is inserted through bolt holes at the center of the spool spindles. Polyurethane is incorporated between the individual Kevlar® fibers, creating a fiber-reinforced region, which is surrounded by an exterior of pure polyurethane. The legs of the strap are the two fiber-reinforced regions located between the spools and are separated by a distance equal to the diameter of the spool hub.

Both the model 500N series helicopters and the model 600N helicopter use part number 500N5311-5 straps. The model MD900 helicopter uses part number 500N5311-5, 900R3442009-101, 900R3442009-103, or 900R6442009-103 straps.

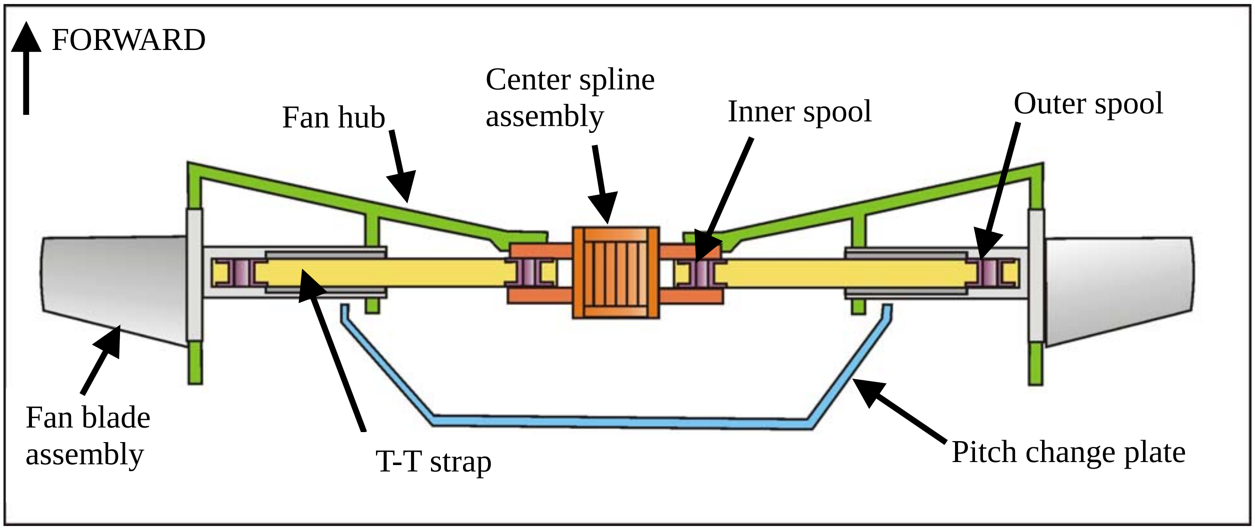

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Figure 2. Schematic of the anti-torque fan assembly cross-section.

Materials Laboratory Examination

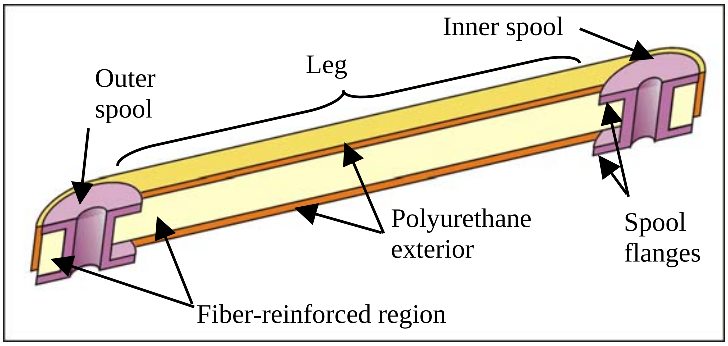

Figure 3. Cutaway schematic showing the T-T strap construction.

All 26 of the T-T straps from the two accident helicopter anti-torque fan assemblies were submitted to the Safety Board's Materials Laboratory for examination. Prior to arrival in the Materials Laboratory, 22 of the 24 intact straps had been subjected to mechanical tests in tension and torsion loading conditions at the strap manufacturer's facility, and all tested straps were within specifications for strength and stiffness. All straps were inspected before and after mechanical testing by means of x-ray radiography.[3] The resulting radiographs were submitted with the components for Safety Board evaluation.

The Safety Board's examination showed that both of the broken straps fractured because of progressive transverse cracking through the fiber-reinforced region of the composite straps, which gradually degraded the strength of the straps until they could no longer support the expected in-service tensile loads. If an overstress fracture of the entire fiber-reinforced area of the straps had occurred under the tension loads that would have been acting on the accident straps at the time they failed, an irregular and frayed appearance of the fibers would be expected throughout the fracture surface. However, portions of the fractures in the failed straps were on a flat transverse plane, and likely existed prior to the final fracture of the straps. Upon further examination, other intact straps also had fiber fractures on a flat transverse plane. The locations and shapes of the flat areas were consistent with damage associated with torsion (twist) loading.[4] Transverse cracks like those indicated in the polished cross-section of an intact spool area shown in figure 4 were associated with kinked fibers, a feature that is consistent with longitudinal compression and/or

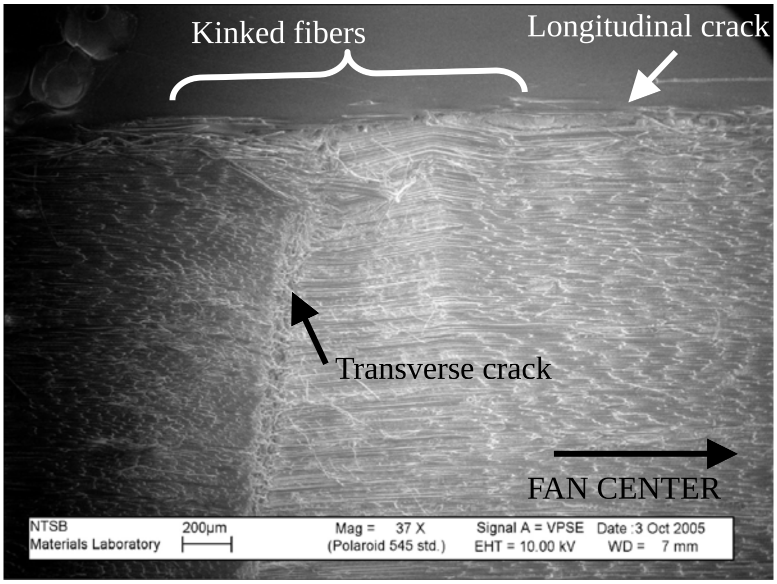

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Figure 4. Scanning electron microscope view of fiber kinking and cracks in a polished cross-section of an intact spool area of one strap.

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[3] Inspections were conducted at US Inspection in Dayton, Ohio, and at Longview Inspection in Erie, Pennsylvania.

[4] The flat areas were located on diametrically opposite corners of the legs of the straps.

transverse shear stresses at that location. Kevlar® fibers, which are relatively weak in compression and transverse shear when compared to other structural composite fibers like glass or carbon, will buckle or kink at relatively low strains.[5]

Stress Analysis

In service, T-T straps are exposed to tensile loads due to centrifugal forces (CF loads) induced by the fan blade rotating about the anti-torque fan axis. The straps are also exposed to torsion loads as they are twisted about their longitudinal axes as the blade pitch is changed. The diametrically opposite locations of the fiber kinking areas found in the fractured and intact straps indicate that compression or transverse shear stresses associated with torsion loads were instrumental to the failure. In its Materials Laboratory, the Safety Board developed a finite element model to analyze the stress state of the strap in various load conditions.

In one case, the finite element analysis was used to study the stresses that develop in the strap subjected to torsion loads only, with no CF loads. Such loads can be routinely imposed on the T-T straps by pilots doing preflight checks of the pedal controls before running up the engine. The analysis showed that, under such conditions, longitudinal stresses develop in the legs of the strap with some regions in tension and others in compression. In addition to these longitudinal stresses, the legs of the straps will be exposed to a transverse shear stress acting across the fibers. The highest compression and transverse shear stresses will occur where the fibers closest to the center of the spool intersect the spool flanges, a location that corresponds to the locations of transverse cracking and flat fracture observed in the straps from the accident helicopters. The finite element analysis showed that, for a twist angle of 36 degrees, the maximum longitudinal compression strains were relatively high compared to the reported compression buckling strain for Kevlar® fibers, and in combined transverse shear and compression loading, the longitudinal compression strain required for buckling is expected to be even lower.

When CF loads were added to the twisted strap, finite element analysis showed that longitudinal compression strains produced from a 36-degree twist in the strap were completely eliminated at a CF load corresponding to fan rotation at speeds approximately 66 percent of maximum power and greater. During fatigue testing for certification, twist loads were applied only when the fan was rotated at maximum speed, which means that the fatigue test articles were not subjected to compression strains in the tests.

The finite element analysis indicated that twist loads that occur without applied CF loads comprise an important and potentially critical load case that should be included in the fatigue testing and analysis of these straps. The stresses associated with this load case were consistent with the fiber kinking and associated cracking observed in the accident straps. As further discussed below, the manufacturer's certification testing did not include this potentially critical load case, which could be routinely imposed in service.

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[5] J. H. Greenwood and P. G. Rose, "Compressive Behaviour of Kevlar 49 Fibres and Composites," *Journal of Materials Science*, 9 (1971), pp. 1809 – 1814.

Summary Report of Certification Testing

On October 27, 2004, MDHI presented a report to the Federal Aviation Administration (FAA) summarizing the static and fatigue testing of the T-T straps in anti-torque fans, which was performed as part of certification for the model 500N series and MD900 helicopters. (The model 600N helicopter uses the same part number straps as those used in the model 500N series helicopters.) The report also included a statistical analysis of crack growth and failure times. Specific information contained within the summary report is considered proprietary and is therefore not disclosed in this public document.

Certification testing documented in the summary report included static tension tests of individual straps, fatigue testing of individual straps, and fatigue testing of straps installed in fans. Data from the static tests showed that the straps were able to withstand loads that were consistently well above expected in-service loads. However, the fatigue test data were relatively sparse and contained a number of inconsistencies between tests of individual straps and tests of straps installed in fans. For example, the mean time to failure of 1 of the 13 straps during testing of a fan assembly for the model MD900 helicopter was less than half the time at which cracks were detected in 2 straps tested individually, and no additional test data or analysis was provided in the summary report to explain this discrepancy. Furthermore, the fatigue load spectrum used for testing did not account for all critical load cases that could occur in service but included twist loads only when a simultaneous CF load was applied. Although twisting without a CF load is clearly a critical loading that could occur with each flight cycle (for example, during preflight control system checks), the summary report contained no analysis or testing to account for twist loads without CF load.

The integrity of the anti-torque fan is critical to the safe operation of the MDHI model 500N series, 600N, and MD900 helicopters. The Safety Board believes that the analysis and testing were insufficient for certification of the anti-torque fan installed in model 500N series, 600N, and MD900 helicopters and that the fatigue test load spectrum did not include critical compression or transverse shear loads in the T-T straps installed in anti-torque fans. Therefore, the Safety Board recommends that the FAA require MDHI to conduct additional tests to enable the full analysis of all critical load cases for T-T straps installed in the anti-torque fan of MDHI model 500N series, 600N, and MD900 helicopters, including load cases that create regions of transverse shear or compression in the fiber-reinforced areas of the straps.

Previous Actions

After the MD900 helicopter accidents in Arizona and Japan, and effective December 7, 2004, the FAA issued Airworthiness Directive (AD) 2004-23-15, which reduces the safe life of T-T straps in MD900 helicopters from 2,500 hours TIS to 1,200 hours TIS and incorporates repetitive x-ray inspections as described in MDHI Safety Bulletin SB 900-095. AD 2004-23-15 requires that, after 1,200 hours TIS, inspections occur at 300-hour TIS intervals until the straps are removed from service at no more than 2,500 hours TIS. If during inspections, any indication of progressive fiber fracture (transverse cracking) is found, straps are to be removed from service and results reported to the FAA. According to representatives of the FAA and MDHI, no progressive fiber fracture indications were reported in the first 9 months after the AD became effective. However, as of September 2004, the average age of the 101-helicopter

MD900 fleet was estimated to be 1,250 hours TIS, significantly below the 1,694 hours TIS and the 1,724 hours TIS on the broken straps from the accident helicopters.

Calculations based on certification testing results and in-service failure times suggest that the times for initial and repetitive inspections required by AD 2004-23-15 are reasonable as an interim action. However, these inspection intervals are based on a small amount of inconsistent data that have been extrapolated from tests that do not represent the critical load cases. For the long-term solution, the necessary inspection to ensure the safe life of the T-T straps must be derived from a sufficient amount of consistent data that are generated using loads that are representative of the critical in-service loads.

The additional testing and analysis of all critical load cases could indicate failure times less than those expected based on current fatigue test data. Therefore, the Safety Board recommends that the FAA, based on existing data and additional data acquired during accomplishment of recommendation A-06-24, take regulatory action as appropriate to require changes in the inspection and replacement of T-T straps installed in anti-torque fans of MDHI model 500N series, 600N, and MD900 helicopters.

X-Ray Radiograph Inspection

All straps from the two accident helicopters were x-ray inspected after the accidents, and the resulting radiographs were examined in the Board's Materials Laboratory. Among the 24 intact inner spool areas and 26 intact outer spool areas, identifiable transverse crack indications were observed emanating from the inner spool of one strap. Figure 5 shows the x-ray radiograph for this spool with the transverse crack indications on each side of the inner spool. When several intact strap ends were sectioned and polished, nearly all of them had some amount of fiber fracture on a transverse plane. For the strap spool area shown in figure 5, the transverse cracks that were visible in the radiograph were gaped open in the polished cross-sections.[6] In

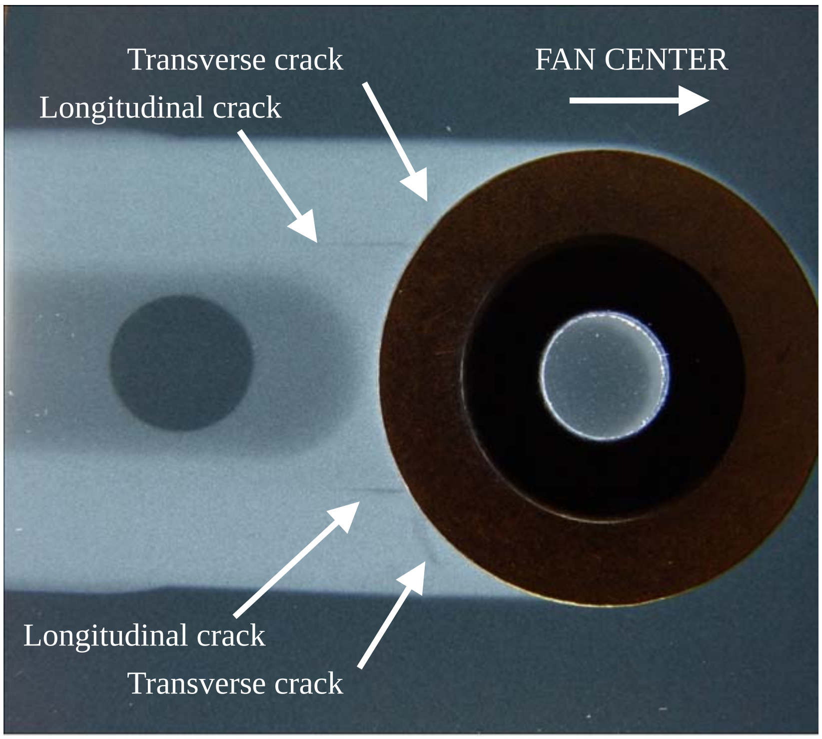

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Figure 5. Photograph of an x-ray radiograph of the inner spool area of an intact strap from one of the accident helicopters. Transverse and longitudinal crack indications were visible in the radiograph.

[6] See Materials Laboratory Factual Report 05-102 for more information and photographs.

another of the sectioned straps, a transverse crack was observed across the width of the leg in the polished cross-section, but the crack was not visible on the radiographs.

The radiographs showed that most of the straps had longitudinal crack indications that in many cases were more visible than the transverse crack indications in the same strap. These longitudinal crack indications (see figure 5) corresponded to longitudinal separations that ran approximately along the boundary between the fiber-reinforced region and the polyurethane-only region. Based on observations of the strap cross-sections, longitudinal crack indications detectable in the radiographs appeared to correlate strongly to the presence of significant fiber kinking and to the progression of fiber fracture on a transverse plane. Such longitudinal crack indications are an indicator of a damaged strap with transverse cracking, even if transverse crack indications are not present on a radiograph. Because the longitudinal indications are more readily visible on the radiographs, they may provide an earlier warning that transverse cracking is progressing. To improve the safety of continued operation after x-ray inspection of the straps, the Safety Board therefore recommends that, during the non-destructive inspections of T-T straps installed in anti-torque fans in MDHI model MD900 helicopters and any other models requiring x-ray inspections, require that the x-ray film be examined for indications of both progressive fiber fractures and for longitudinal cracks in the T-T straps, and require that any T-T straps in which progressive fiber fractures or longitudinal cracks are found be removed from service.

The integrity of the anti-torque fan is critical to the safe operation of the MDHI model 500N series, 600N, and MD900 helicopters. The Safety Board believes that the analysis and testing of the anti-torque fan installed in model 500N series, 600N, and MD900 helicopters were insufficient for certification and that potentially critical compression or transverse shear loads in the T-T straps in anti-torque fans were not included in the fatigue test load spectrum. Additionally, a more conservative inspection criterion that rejects straps containing longitudinal crack indications detected during x-ray inspections is warranted.

Therefore, the National Transportation Safety Board recommends the following to the Federal Aviation Administration:

> Require MD Helicopters, Inc. (MDHI), to conduct additional tests to enable the full analysis of all critical load cases for tension-torsion straps installed in the anti-torque fan of MDHI model 500N series, 600N, and MD900 helicopters, including load cases that create regions of transverse shear or compression in the fiber-reinforced areas of the straps. (A-06-24)
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> Based on existing data and additional data acquired during accomplishment of recommendation A-06-24, take regulatory action as appropriate to require changes in the inspection and replacement of tension-torsion straps installed in anti-torque fans of MD Helicopters, Inc., model 500N series, 600N, and MD900 helicopters. (A-06-25)
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> During the non-destructive inspections of tension-torsion (T-T) straps installed in anti-torque fans in MD Helicopters, Inc., model MD900 helicopters and any other models requiring x-ray inspections, require that the x-ray film be examined for indications of both progressive fiber fractures and for longitudinal cracks in the

T-T straps, and require that any T-T straps in which progressive fiber fractures or longitudinal cracks are found be removed from service. (A-06-26)

In your response to the recommendations in this letter, please refer to Safety Recommendations A-06-24 through A-06-26.

Acting Chairman ROSENKER and Members ENGLEMAN CONNORS, HERSMAN, and HIGGINS concurred in these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Acting Chairman