# National Transportation Safety Board
# Aviation Accident Final Report

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| **Location:** | Mesa, AZ | **Accident Number:** | LAX04LA333 |
| **Date & Time:** | 09/08/2004, 1600 MST | **Registration:** | N9016W |
| **Aircraft:** | McDonnell Douglas MD 900 | **Aircraft Damage:** | Substantial |
| **Defining Event:** | | **Injuries:** | 1 None |
| **Flight Conducted Under:** | Part 91: General Aviation - Flight Test | | |

## Analysis

The helicopter experienced a NOTAR (no tail rotor) fan failure during the initial climb from the airport and made a subsequent hard landing. Immediately after takeoff, about 30 to 40 feet above ground level (agl), the helicopter began to vibrate. The pilot lowered the collective to the full down position, and the helicopter touched down about 30 to 40 knots ground speed. Upon touchdown, the pilot had difficulty maintaining directional control and the helicopter slid about 300 feet across terrain. The helicopter's NOTAR anti-torque yaw control system utilizes a transmission driven fan with variable pitch blades to supply air to circulation control slots on the tail boom and a pilot controlled directional jet thruster nozzle. Movement of the anti-torque control pedals changes the fan blade pitch to produce more or less airflow to the circulation control slots and the anti-torque thruster nozzle. As the pedals are displaced from center toward either extreme of travel, the airflow increases or decreases proportionally. A post-accident examination of the NOTAR fan system revealed that one of the thirteen Tension-Torsion (T-T) straps located on the variable-pitch fan assembly had failed. The failed strap had accumulated about 1,694 hours of time in service, though the design safe life for the strap was 2,500 hours of time in service. An examination of the strap revealed that it had fractured as a result of the progressive failure of its reinforcement fibers. This progressive fiber failure gradually degraded the strap's integrity until it could no longer support normal in-service tensile loads. In normal operation, the T-T straps are exposed to tensile loads due to the centrifugal force induced by the blade rotation about the anti-torque fan axis. The straps are additionally exposed to torsional loads about their longitudinal axis as the blade pitch is changed. The point-symmetric locations of the failure areas were consistent with loading that would occur as the strap was twisted with limited centrifugal force loads present; the twisting direction corresponds to an increase in blade pitch. The Safety Board Materials Laboratory performed load analyses of the straps, revealing that when the strap is twisted without the presence of centrifugal force, portions of the fiber reinforced region of the strap are subjected to compression and transverse shear stresses. Furthermore, the compression and transverse shear stresses are highest in the locations where the subject strap failed. When the anti-torque fan is rotated at speeds less than an approximate 75 percent of maximum power, compression, and transverse shear stresses can develop in the straps when the blade pitch is adjusted. Additionally, with no fan rotation (and therefore no centrifugal force) critical buckling strains on the strap's fibers can be achieved by increasing the blade pitch to near the design limits. This could plausibly occur during a preflight inspection when the pilot checks pedal control surface movement prior to starting the engine.  All T-T strap load and fatigue tests preformed by the helicopter manufacturer incorporate centrifugal force loads, and therefore, do not test the full load spectrum.

## Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: fracture of a Tension-Torsion strap in the anti-torque fan due to progressive fiber failure of the composite strap material from compression and/or transverse shear stresses that occurred with repeated manipulation of the cockpit anti-torque control pedals without the fan operating at full rpm.  A factor in the accident was the helicopter manufacturer's inadequate fatigue and load testing on the strap.

### Findings

Occurrence #1: AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
Phase of Operation: TAKEOFF - INITIAL CLIMB

Findings
1. (C) ROTORCRAFT FLIGHT CONTROL SYSTEM,NOTAR - FAILURE
2. (C) ROTORCRAFT FLIGHT CONTROL SYSTEM,NOTAR - FRACTURED
3. (F) PROCEDURE INADEQUATE - MANUFACTURER
4. (F) INSUFFICIENT STANDARDS/REQUIREMENTS,MANUFACTURER - MANUFACTURER
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Occurrence #2: FORCED LANDING
Phase of Operation: DESCENT - EMERGENCY

Findings
5. AIRCRAFT CONTROL - NOT POSSIBLE - PILOT IN COMMAND
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Occurrence #3: HARD LANDING
Phase of Operation: DESCENT - EMERGENCY

Findings
6. TERRAIN CONDITION - RUNWAY

## Factual Information

HISTORY OF FLIGHT

On September 8, 2004, about 1600 mountain standard time, a McDonald Douglas Helicopter MD 900, N9016W, experienced a NOTAR fan failure during the initial climb from the Boeing Heliport, Mesa, Arizona. MD Helicopters, Inc., was operating the helicopter under the provisions of 14 CFR Part 91. The commercial pilot, the sole occupant, was not injured; the helicopter sustained substantial damage. The local company test flight was originating at the time of the accident. Visual meteorological conditions prevailed, and a flight plan had not been filed.

In a written statement, the pilot reported that immediately after takeoff, about 30 to 40 feet above ground level (agl), the helicopter began a severe high frequency vibration. The pilot lowered the collective to the full down position, and the helicopter touched down about 30 to 40 knots ground speed. Upon touchdown, the pilot had difficulty maintaining direction control. The helicopter slid about 300 feet across terrain, coming to rest 4 feet off the departure end of the runway. After egressing the helicopter, the pilot found three complete NOTAR fan blades scattered on the runway surface.

The disassembly of the NOTAR fan system revealed that a Tension-Torsion (TT) strap on the fan assembly had been compromised.

HELICOPTER INFORMATION

The helicopter was a 1995 McDonald Douglas Helicopter MD900, serial number 900-00016. A review of the helicopter's maintenance information revealed that the airframe had undergone an annual inspection on April 30, 2004. At the last 50-hour inspection the helicopter had accumulated a total time of 1,686.96 hours. At the time of the accident the helicopter had accumulated a total time of 1693.2 hours, with the engine hours at 1,241.39 and 2202.74.

NOTAR Anti-Torque system.

According to MD Helicopters, the MD900 anti-torque system, entitled NOTAR (no tail rotor), consists of an enclosed variable-pitch fan that is controlled by the main transmission. The fan produces a low pressure and high volume of ambient air, which in turn pressurizes the composite tail boom. As low pressure air is directed through two circulation control slots located in the tail boom, the main rotor downwash follows that expelled air with the contours of the boom. This phenomenon of creating lateral lift to counteract main rotor torque provides a majority of the anti-torque force required while in a hover configuration, and is referred to as the "Coanda Effect." Additional anti-torque and directional controllability is accomplished by a rotating thruster affixed to the end of the tail boom, which is manipulated by the pilot via the use of anti-torque pedals. According to McDonnel-Douglas Helicopter, Inc. (MDHI) engineers, during hover the Coanda effect produces approximately 70 percent of the helicopter's anti-torque force, while the thruster produces the remaining 30 percent. During normal cruise, two parallel vertical stabilizers provide most of the anti-torque, while the thruster is the primary manipulator of directional control.

Tension-Torsion Straps

The variable-pitch rotating fan assembly is comprised of thirteen T-T straps, which extend radially from the center spline.  The straps are constructed from continuous-wound Kevlar fibers that are wrapped around corrosion-resistant steel spools at both ends of the strap.  The spools have circular flanges at each end of a cylindrical spindle, and the spindles have bolt holes in the centers where the strap is attached to its respective surfaces.  After manufacture, the strap is cast in a polyurethane material, creating a fiber reinforced region with a protective outer coating of polyurethane.  The straps measure 5.9 inches in length, 0.86 inches in width, 0.47 inches in thickness, and are rectangular in shape with semicircular ends.  A similarly shaped recess is impressed in the middle of the strap with the ends adjacent to the most inner part of the metal spools.  Inside the recess, at both ends, there is a cutout area of material, akin to a hole-punch shape.

The straps' outer spools are connected the blade assemblies, and the inner spools adjoin the center spline assembly.  The blade assemblies of the anti-torque fan have a variable pitch, which is controlled through a sliding pitch change plate that is attached to arms on the blade assemblies.  As the pitch changes, the blade assemblies rotate within openings in the inner and outer rims of the fan hub, loading the straps in torsion about their longitudinal axes.  Centrifugal forces are produced by the fan blade assemblies rotating about the center of the anti-torque fan assembly, resulting in the straps incurring a load in tension during fan operation.

TESTS AND RESEARCH

Under the auspice of a Federal Aviation Administration (FAA) inspector, 10 of the 12 intact T-T straps from the accident anti-torque fan assembly were spring rate tested in tension and torsion loading conditions at the T-T strap manufacturer, Lord Corporation, facilities.  One test subjected the straps to tensile loading where the pull direction was aligned with the longitudinal axis of the strap.  The other test was under angular displacement (torsional loading) with no tensile load, where the strap was twisted about the longitudinal axis.  As documented in manufacturing procedures, similar tests are conducted as proof tests on each newly manufactured strap.  The manufacturer provided data from the original proof tests for the two most recently manufactured straps that were tested.

The engineering drawings specify a minimum tensile stiffness for the strap as well as a maximum torsional stiffness with zero tensile loads.  All 10 of the tested straps were able to support the maximum tensile loads during the tensile tests and had tensile stiffnesses that exceeded the minimum value specified in the engineering drawings.  A direct comparison of the post accident stiffness to the original proof test values was not possible since a different preload procedure was used at the time of manufacturing versus post accident testing.  All 10 of the tested straps also were able to support the maximum angular displacement during the torsion tests and had torsional stiffnesses below the maximum value specified in the engineering drawings.

Upon the completion of the aforementioned testing, the straps were forwarded to the Safety Board Materials Laboratory for additional examinations.

Fractured Tension-Torsion Strap

The fractured T-T strap, part number 500N5311-5, had accumulated about 1,694 hours of time in service.  The design safe life for the straps was 2,500 hours of time in service.

The failed strap, marked serial number LK0959, was fractured at the inner end of the strap, and the respective spool was separated from the remainder of the strap.  Fibers extended from each leg of the strap, and the exposed ends of the fibers were frayed. Most of the fibers that had wrapped around the spool were pulled out from around the spool, creating a void between the metal spindle of the spool and the layer of polyurethane on the exterior surface of the strap assembly.

A detailed examination of the fracture revealed that there were two areas where multiple fibers had fractured at a similar location. The two relatively flat fracture areas were oriented in a plane perpendicular to the fiber direction. These flat fracture areas were located about 1 inch inboard from the inner end of the strap, where the fibers closest to the spool center intersect the spool flange.

X-ray radiographs and polished cross-sections of the straps revealed that cracking and fiber kinking was prevalent in the straps. Transverse cracks were observed in the x-ray radiograph of one of the intact straps. Longitudinal cracks were observed in the x-ray radiographs of half of the intact straps and in the fractured strap. As observed in polished cross-sections, both longitudinal and transverse cracks were associated with fiber kinking. The transverse cracks and fiber kinking in intact straps were located in the same area where the flat fracture areas were found in the fractured strap. The locations and shapes of the transverse cracks and flat fracture areas were point symmetric about the longitudinal centerline of the strap. The symmetry of the fractures was consistent with damage associated with torsional loading.

Microstructural Examination

The outer end of the fractured strap, LK0959, and both ends of two additional straps, LK0960 and LK1747, were sectioned for microstructural examination. Samples from strap LK0959 were prepared first. Cross sections A-A, B-B, and C-C were prepared at specific locations. Also, a sample was prepared from the cross section produced by one of the transverse cuts near the middle of Leg B. For samples in which the polished surface was oriented parallel to the fiber direction, such as cross section B-B, it was found that any exposed fiber ends that were pushed into the direction of the polishing media caused fibers to pull out of the matrix and to fray. In subsequently prepared samples from straps LK0960 and LK1747, the polished surfaces were prepared at a slight angle to the fiber direction, and the orientation of each sample on the polishing wheel was kept constant such that the polishing media intersected the line of the fibers at an acute angle, which minimized fiber pullout and fracture during preparation.

Two of the sections through strap LK0959 were transverse sections perpendicular to the fiber direction. In comparing the sizes of the areas containing fibers, the area of the cross section containing fibers at cross section C-C was greater than the area at cross section A-A, corresponding to a higher filament density at cross section A-A. The area encompassed by the fibers had average dimensions of approximately 0.151-inch by 0.343-inch at cross-section A-A, and 0.185-inch by 0.381-inch at cross-section C-C. No voids were observed in either of the transverse cross-sections.

Section B-B was ground and polished until the fibers located closest to the spool hub were exposed. Bands of fiber damage were observed in various locations along the length of the fibers, and much of this damage might have been produced during the sample grinding and polishing. However, one area of fiber damage had different features that were not consistent with having been produced during sample preparation. The fiber damage was longitudinally located where the fibers closest to the spool hub intersected the spool flange. Bands of kinked fibers were observed at the location, consistent with local compression or transverse shear stresses on the fibers. The direction of the kinking appeared to be out of the plane of the cross-section and was most severe closest to spool flange. An area near the center of the kink bands appeared white with bent fiber ends and fibrils, consistent with a crack emanating from the area closest to the spool flange. During subsequent destructive examination, a few layers of fibers were cut at a location away from the crack and were peeled by hand back toward the crack, which resulted in fibers separating at the crack location.

Each end of straps LK0960 and LK1747 were sectioned in a manner to prepare them for microstructural examination in two planes. On the sectioned pieces, the areas that would have had the same in-service loading as the flat areas on the fractured strap were circled with a black marker. The two larger sectioned pieces were polished in a plane nearly perpendicular to the spool axis, grinding and polishing inward toward the fibers from the outer surface that had the black circle. The two smaller sectioned pieces from each end were polished in a plane nearly parallel to the spool axis, grinding and polishing from the cut surface toward the fibers. When grinding or polishing in either plane, more material was removed from the end of the piece closest to the fan center, producing the slight angle to prevent fiber pull out and fraying. In each case, material was removed in the preparation process until the fibers nearest the spool hub were exposed where they intersected the edge of the spool flange.

The polished cross section of the larger piece from the sectioned outer end of strap LK0960 was examined. Fiber damage was observed at the location where the fibers closest to the spool hub intersected the edge of the spool flange. A transverse crack, characterized by white fibrils associated with fiber fractures, was observed extending across the fiber reinforced area intersecting the polishing plane in a line perpendicular to the longitudinal axis of the strap. Fiber kinking was observed in the fibers at the crack location. A longitudinal crack was observed in the area of the kinked fibers located adjacent to fibers closest to the spool hub.

The polished cross section of the smaller piece from the sectioned outer end of strap LK0960 was examined. Fiber kinking and fracture was observed at the location where the fibers closest to the spool hub intersected the edge of the spool flange. A transverse crack was observed at one side of the fiber reinforcement area. The location of the crack was at the circled side of the piece, corresponding to the location of the flat fracture area on the fractured strap. White fibrils consistent with fiber fracture were observed at the crack location. The crack was observed at the edge of the fiber reinforcement region and was approximately 0.102-inch long where it intersected the polished cross sectional plane.

The sectioned pieces from the inner end of strap LK0960 were polished in a procedure similar to that used on the pieces from the outer end. A transverse crack was observed across the width of the fiber reinforcement at a location corresponding to where the fibers intersected the edge of the spool flange. Fractured fibers were observed, and the crack was gaped open. Fiber kinking was observed in the crack area in fibers nearest the spool hub. A longitudinal crack also was observed adjacent to fibers nearest the spool hub. Bent fibers and fibrils associated with fiber fracture were observed in the crack opening.

A transverse crack was observed in the polished cross section of the smaller piece from the inner end of strap LK0960. The transverse crack was observed at the edge of the fiber reinforcement region on the circled side of the piece, corresponding to the same location of the flat fracture area on the fractured strap. The transverse crack was approximately 0.165-inch long where it intersected the polished cross sectional plane.

Sectioned pieces from each end of strap LK1747 were mounted and polished in a manner similar to that used on the pieces from strap LK0960. At the outer end, some fiber whitening was observed on the cross section of the larger piece polished nearly perpendicular to the spool axis. The whitening was somewhat diffuse and appeared consistent with fiber buckling but not fiber fracture. The whitening was in the fibers closest to the spool hub approximately where the fibers intersected the spool flange and was 0.019-inch long where it intersected the polished cross sectional plane. On the smaller piece from the outer end of strap LK1747 polished nearly parallel to the spool axis, no evidence of fiber damage was observed.

At the inner end of strap LK1747, some fiber whitening was observed on the cross section of the larger piece polished nearly perpendicular to the spool axis. The whitening was more focused than that at the outer end, more consistent with fiber fracture. The whitening was in the fibers closest to the spool hub approximately where the fibers intersected the spool flange and was 0.020-inch long where it intersected the polished cross sectional plane. On the smaller piece from the outer end of strap LK1747 polished nearly parallel to the spool axis, a transverse crack was observed at the edge of the fiber reinforced region at the circled side of the piece, corresponding to the same location of the flat fracture area on the fractured strap. The transverse crack was approximately 0.0.065-inch long where it intersected the polished cross sectional plane.

Hardness Tests

Shore A hardness tests of the polyurethane of several of the straps were conducted at an independent testing laboratory. Hardness tests were completed on a mounted specimen from each of the sectioned straps (LK0959, LK0960, and LK1747), and hardness was conducted on the surface of straps LK0964, LK1227, LK1631, and LK1747 at a location on the side of a leg where the polyurethane appeared to be thicker.

For the mounted samples, hardness was measured on the piece sectioned from the outer end of the strap that was polished in a plane nearly perpendicular to the spool axis, and average values were determined from two readings taken from an area near the spool hub. As measured on the mounted samples, average hardness was 92 Shore A, 90 Shore A, and 92 Shore A for straps LK0959, LK0960, and LK1747, respectively. Specified hardness for the polyurethane was 88 Shore A to 92 Shore A.

Hardness values from the surface measurements were determined from the average of five readings. Average hardness was 93 Shore A, 95 Shore A, 94 Shore A, and 93 Shore A for straps LK0964, LK1227, LK1631, and LK1747, respectively.

The results of the materials testing in its entirety can be found in the public docket.

## Pilot Information

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| **Certificate:** | Flight Instructor; Commercial | **Age:** | 49, Male |
| **Airplane Rating(s):** | None | **Seat Occupied:** | Right |
| **Other Aircraft Rating(s):** | Helicopter | **Restraint Used:** | Seatbelt, Shoulder harness |
| **Instrument Rating(s):** | Helicopter | **Second Pilot Present:** | No |
| **Instructor Rating(s):** | Helicopter | **Toxicology Performed:** | No |
| **Medical Certification:** | Class 2 Valid Medical--no waivers/lim. | **Last Medical Exam:** | 06/01/2004 |
| **Occupational Pilot:** | | **Last Flight Review or Equivalent:** | |
| **Flight Time:** | 6100 hours (Total, all aircraft), 40 hours (Total, this make and model) | | |

## Aircraft and Owner/Operator Information

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|---|---|---|---|
| **Aircraft Manufacturer:** | McDonnell Douglas | **Registration:** | N9016W |
| **Model/Series:** | MD 900 | **Aircraft Category:** | Helicopter |
| **Year of Manufacture:** | | **Amateur Built:** | No |
| **Airworthiness Certificate:** | Normal | **Serial Number:** | 900-00016 |
| **Landing Gear Type:** | Skid | **Seats:** | 4 |
| **Date/Type of Last Inspection:** | 08/18/2004, Annual | **Certified Max Gross Wt.:** | 6500 lbs |
| **Time Since Last Inspection:** | | **Engines:** | 2 Turbo Shaft |
| **Airframe Total Time:** | 1687 Hours | **Engine Manufacturer:** | Pratt & Whitney |
| **ELT:** | Installed, activated, did not aid in locating accident | **Engine Model/Series:** | 206A |
| **Registered Owner:** | WELLS FARGO BANK NORTHWEST NA TRUSTEE | **Rated Power:** | |
| **Operator:** | MD Helicopters Inc. | **Air Carrier Operating Certificate:** | None |

## Meteorological Information and Flight Plan

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| **Observation Facility, Elevation:** | IWA, 1382 ft msl | **Observation Time:** | 1549 MST |
| **Distance from Accident Site:** | 11 Nautical Miles | **Condition of Light:** | Day |
| **Direction from Accident Site:** | 180° | **Conditions at Accident Site:** | Visual Conditions |
| **Lowest Cloud Condition:** | Scattered / 9000 ft agl | **Temperature/Dew Point:** | 39°C / 5°C |
| **Lowest Ceiling:** | None | **Visibility** | 30 Miles |
| **Wind Speed/Gusts, Direction:** | 6 knots, 170° | **Visibility (RVR):** | |
| **Altimeter Setting:** | 29.82 inches Hg | **Visibility (RVV):** | |
| **Precipitation and Obscuration:** | No Obscuration; No Precipitation | | |
| **Departure Point:** | Mesa, AZ (AZ81) | **Type of Flight Plan Filed:** | None |
| **Destination:** | Mesa, AZ (AZ81) | **Type of Clearance:** | VFR |
| **Departure Time:** | 1600 MST | **Type of Airspace:** | Class G |

## Airport Information

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| **Airport:** | Boeing Heliport (AZ81) | **Runway Surface Type:** | Concrete |
| **Airport Elevation:** | 1385 ft | **Runway Surface Condition:** | Unknown |
| **Runway Used:** | NA | **IFR Approach:** | None |
| **Runway Length/Width:** | | **VFR Approach/Landing:** | Forced Landing |

## Wreckage and Impact Information

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| **Crew Injuries:** | 1 None | **Aircraft Damage:** | Substantial |
| **Passenger Injuries:** | N/A | **Aircraft Fire:** | None |
| **Ground Injuries:** | N/A | **Aircraft Explosion:** | None |
| **Total Injuries:** | 1 None | | |

## Administrative Information

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| **Investigator In Charge (IIC):** | Zoe Keliher | **Adopted Date:** | 05/30/2006 |
| **Additional Participating Persons:** | John Eller; Federal Aviation Administration; Scottsdale, AZ | | |
| **Publish Date:** | | | |
| **Investigation Docket:** | NTSB accident and incident dockets serve as permanent archival information for the NTSB's investigations. Dockets released prior to June 1, 2009 are publicly available from the NTSB's Record Management Division at pubinq@ntsb.gov, or at 800-877-6799. Dockets released after this date are available at http://dms.ntsb.gov/pubdms/. | | |