Aviation Investigation Final Report

Location:	Honolulu, Hawaii	**Accident Number:**	WPR18LA221
Date & Time:	August 8, 2018, 09:20 Local	**Registration:**	N369MH
Aircraft:	Hughes 369	**Aircraft Damage:**	Substantial
Defining Event:	Flight control sys malf/fail	**Injuries:**	4 None
Flight Conducted Under:	Part 135: Air taxi & commuter - Non-scheduled - Sightseeing		

Analysis

The pilot of the helicopter commercial air tour flight stated that the helicopter was in cruise flight at an altitude of about 1,800 ft when, about 11 minutes after takeoff, he felt "severe" vibrations and then heard a "loud bang," after which the helicopter began to shake "violently." The pilot entered a power-on autorotation and stated that the severity of the vibration caused the transponder to shake free of its mount in the instrument panel. He also stated that even small tail rotor pedal inputs significantly worsened the vibrations. The pilot conducted a partial run-on landing in a field. Examination revealed that multiple tail rotor blade and gearbox components had failed in flight, rendering the helicopter substantially damaged.

The helicopter tail rotor (TR) transmission was mounted on the aft end of the tail boom, and the four-blade TR assembly mounted onto a four-arm fork that mounted on the output shaft of the TR transmission. The TR blade assembly comprised a pair of two-blade rotor assemblies that attached to the fork. A teeter bearing mounted in each fork arm, and each two-blade rotor assembly was secured in its fork arm pair by a teeter bolt that suspended it between, and was suspended by, the two teeter bearings.

At least two different tail boom versions were available for the accident model helicopter. One was the original McDonnell-Douglas Helicopters, Inc (MDHI) version, and the other was an aftermarket version produced by a company called Aerometals. The accident helicopter was equipped with the Aerometals tail boom. The primary difference between the two tail boom versions was the attachment method of the TR transmission to the tail boom. The MDHI version used studs and locking nuts, whereas the Aerometals version used bolts and locking nut plates. Both versions used a total of four attach fasteners.

Postaccident examination revealed that the two bolts that attached the left side of the TR transmission to the tail boom had fractured and partially pulled through their nut plates. The two right side attach bolts were damaged, but had not failed; instead, their respective mounting lugs on the TR transmission had failed. The failure of all four attachments meant that the TR assembly was retained on the helicopter by only the TR drive shaft and the pitch control linkage. Neither of those components was designed to retain the TR transmission, and the pitch control system incurred damage during the event. The TR assembly was on the verge of imminent failure. Based on the observed damage, it is likely that with continued operation, the TR would have very shortly separated from the helicopter, rendering control difficult or impossible.

All four TR blades remained attached to the fork, but the outer (furthest from the transmission) blade pair remained only partially attached to the fork. The outer teeter bolt was fractured and only a portion of it was recovered. Of the two teeter bearings that were normally mounted in the outer pair of fork arms, one was absent and presumed lost in flight. The remaining outer teeter bearing had debonded from its fork arm, and both it and its fork arm seat exhibited fretting damage on their mating surfaces. The fretting indicated that there was relative motion between the bearing and its seat, caused by helicopter operation with a debonded bearing.

Detailed laboratory examinations revealed that the fractured teeter bolt and the two fractured attach bolts had all failed in fatigue. The examinations also revealed several discrepancies with the repair and installation of some of the TR components, as well as some discrepancies within the applicable maintenance and inspection guidance.

The teeter bearings had been improperly installed in the fork during overhaul or during maintenance by the operator. Contrary to MDHI overhaul guidance, none of the four teeter bearing installations, including the two debonded ones for the outer blade pair, displayed any evidence of the presence of either primer or scrim cloth. "Scrim cloth" was a single-ply layer of glass fabric that should have been installed at the bearing-fork mating juncture to ensure proper bonding of the adhesive that secured the bearing in its fork seat.

An overhauled fork includes installed teeter bearings, and the maintenance records indicated that the accident fork was overhauled by an outside vendor. Information provided by the operator indicated that it had not replaced or reinstalled any of the bearings, and the available records did not specify the serial numbers of the bearings installed during the overhaul. However, contrary to the operator-provided information, research revealed that the operator had independently purchased at least five bearings subsequent to the installation of the overhauled fork, and that at least two of those bearings, including one that had disbonded from the fork, were installed on the helicopter at the time of the accident. The operator was unable to provide any explanation for the improper repair or why their installation of new teeter bearings was absent from the maintenance records. Subsequent to these findings, an FAA search of the operator's premises did not locate any additional overhauled TR assemblies.

Contrary to the MDHI TR transmission installation guidance, paint was observed on the faying surfaces of the transmission-tail boom mounting pads. The operator had partially cleaned these surfaces during postaccident removal of the transmission before the investigative examination took place; therefore, the thickness or condition of that paint, or a reliable estimate of its effect on the joint clamp-up, could not be determined. Reduction in joint clamp up, due to compression or breakdown of the paint in the joint, particularly over time, has the potential to result in shear failure of the attachment hardware threads and/or fatigue and failure of the attach hardware, by allowing relative motion between the TR transmission and the tail boom. This condition can be aggravated by increased vibrations due to multiple sources, including but not limited to TR imbalance, disbonded or deteriorated elastomeric bearings, and improper torque of the TR transmission attach hardware. When asked, the operator was unable to provide any explanation for the improper paint application.

The available evidence indicates that the failure sequence began with the disbonding of one or both of the improperly installed outer teeter bearings from their respective fork seats. This permitted increased vibration of the TR, which then caused the outer teeter bolt to rapidly fatigue and fracture. The fracture failure of the outer teeter bolt resulted in the in-flight liberation of one outer teeter bearing and a segment of the outer teeter bolt. This further increased the vibration level, which caused the failure of all four structural attach points that secured the TR transmission (including the TR) to the tail boom and resulted in the TR being retained on the helicopter only by the TR drive shaft and the pitch control linkage. Neither of those components was designed to retain the TR transmission, and likely would have failed rapidly with continued operation, resulting in loss of the TR. The pilot's decision to land as quickly as possible likely prevented the loss of the TR and subsequent loss of control of the helicopter.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The operator's improper installation of the tail rotor (TR) teeter bearings, which resulted in cascading in-flight failures of the TR components and attach hardware.

Findings

Aircraft	Tail rotor blade - Incorrect service/maintenance
Personnel issues	Installation - Maintenance personnel
Personnel issues	Repair - Maintenance personnel

Factual Information

History of Flight

Prior to flight	Aircraft maintenance event
Enroute-cruise	Flight control sys malf/fail (Defining event)
Enroute-cruise	Sys/Comp malf/fail (non-power)
Enroute-cruise	Part(s) separation from AC

On August 8, 2018, about 0920 Hawaii time, a Hughes MD Helicopters, Inc. 369D helicopter, N369MH, was substantially damaged when it was involved in an accident near Honolulu, Hawaii. The commercial pilot sustained minor injuries; the three passengers did not report any injuries. The helicopter was operated as a Title 14 *Code of Federal Regulations* Part 136 revenue air tour flight.

The helicopter was the lead helicopter in a flight of two that departed Honolulu International Airport (HNL), Honolulu, Hawaii about 0909. The flight proceeded east/southeast from HNL approximately along the shoreline. The pilot stated that the helicopter was in cruise at an altitude of about 1,800 ft when he felt "severe" vibrations and heard a "loud bang," after which the helicopter began to shake "violently." The pilot lowered the collective control and entered a power-on autorotation, with the intent of landing the helicopter in a grassy clearing. He radioed his intentions to his colleague in the trailing helicopter and then advised his passengers of the same. The pilot reported that small tail rotor pedal inputs significantly worsened the vibrations.

The pilot made a partial run-on landing onto the targeted clearing, which was about 13 miles east of HNL. He reported that on first contact, the helicopter bounced about 1 ft into the air and that the remaining slide on the dry and rocky grass field was rougher than he expected. The helicopter came to a stop upright, and the pilot shut down the engine. The landing field was part of the grounds of a public school, and the pilot released the passengers to the care of the school staff while he examined the helicopter and coordinated with his company.

The helicopter came to rest upright on its landing skids; the right skid was fractured but able to support the helicopter. Postaccident photographs indicated that multiple tail rotor blade and gearbox components were damaged, rendering the helicopter substantially damaged. Without NTSB or FAA knowledge or approval, and contrary to applicable regulations, the operator recovered the helicopter back to its facility shortly after the accident and began disassembly for repair. More than a day after the accident, the NTSB became aware of these activities, and instructed the operator to cease repairs.

Pilot Information

Certificate:	Commercial; Flight instructor	**Age:**	54,Male
Airplane Rating(s):	None	**Seat Occupied:**	Front
Other Aircraft Rating(s):	Helicopter	**Restraint Used:**	4-point
Instrument Rating(s):	Helicopter	**Second Pilot Present:**	No
Instructor Rating(s):	Helicopter	**Toxicology Performed:**	No
Medical Certification:	Class 2 Without waivers/limitations	**Last FAA Medical Exam:**	January 24, 2018
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	March 29, 2018
Flight Time:	7300 hours (Total, all aircraft), 2400 hours (Total, this make and model)		

Aircraft and Owner/Operator Information

Aircraft Make:	Hughes	**Registration:**	N369MH
Model/Series:	369 D	**Aircraft Category:**	Helicopter
Year of Manufacture:	1978	**Amateur Built:**	
Airworthiness Certificate:	Normal	**Serial Number:**	380287D
Landing Gear Type:	Skid	**Seats:**	
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	
Time Since Last Inspection:		**Engines:**	Turbo shaft
Airframe Total Time:		**Engine Manufacturer:**	Rolls Royce
ELT:		**Engine Model/Series:**	250-C20B
Registered Owner:	Schuman Carriage Company Ltd	**Rated Power:**	420 Horsepower
Operator:	Schuman Carriage Company Ltd	**Operating Certificate(s) Held:**	Commercial air tour (136)
Operator Does Business As:	Magnum Helicopter	**Operator Designator Code:**	

Configuration & Design Information

The helicopter was equipped with a single 5-blade main rotor (MR) system, a tail boom, a 4-blade tail rotor (TR) system, and a T-configuration horizontal and vertical stabilizer assembly. The TR transmission attached to the aft end of the tail boom, and the TR assembly attached to the output shaft of the TR transmission. A TR driveshaft, routed inside the tail boom, provided torque from the main transmission to the TR transmission. Pitch links and a swash plate connected the flight controls to the TR blades.

At least two different tail boom versions were available for this model helicopter. One was the original Hughes Helicopters (MDHI) version, and the other was an aftermarket version produced by Aerometals. The Aerometals tail boom was approved as FAA supplemental type certificate (STC) SH5055NM. The accident helicopter was equipped with the Aerometals tail boom.

The vertical stabilizer attached via 4 bolts to the aft right side of the tail boom. The horizontal stabilizer was equipped with 4 studs that inserted into holes in 4 lugs atop the vertical stabilizer and was secured by nuts on the studs. The original Hughes Helicopters (MDHI) tail boom had an aft-facing threaded steel stud anchored in each of the tail boom pads of the cast-aluminum TR transmission attachment frame. The Aerometals tail boom eliminated the studs, incorporated a machined aluminum TR transmission attachment frame, and installed four self-locking nut plates (MS21075L4) forward of the attachment frame mounting pads. Through-bolts were installed through the TR transmission lugs and tail boom attachment frame and into the self-locking nut plates. The steel bolts (MS21250) were 1/4-28 standard aircraft hardware. The bolts and nut plates were cadmium plated.

The four-blade TR comprised of two, two-blade TR blade assemblies mounted 90° from one another. Each TR blade assembly comprised a central hub with a TR blade attached to each end. A tension-torsion strap pack was installed inside each TR hub. The TR blade assemblies were referred to as the "inboard" and "outboard," where "inboard" referred to the TR assembly closest to the TR transmission.

A four-arm fork, with two pairs of arms arranged 90° apart, referred to as the "inboard fork" and "outboard fork," served as the mount for the two TR blade assemblies. The fork installed directly onto the TR transmission output shaft. Each fork arm incorporated a machined conical receptacle near its end, with an elastomeric "teeter" bearing nested and secured in each receptacle. Each teeter bearing comprised an assembly of several alternating concentric cones of metal and elastomer, with an outer metal shell, and a central, axially oriented hollow metal cylinder that served as a bolt hole for the bearing. All components of each bearing were bonded together to form a single unit.

Each TR blade assembly was mounted in one pair of fork arms. It was suspended by its two teeter bearings, secured by a fork (or "teeter") bolt that extended through the TR hub, and through the bearing near each end of the fork bolt. The nickel alloy tension fork/teeter bolts (369A1602-3) and their nuts (VCU0001) were MDHI parts. (see Figures 1 through 3)

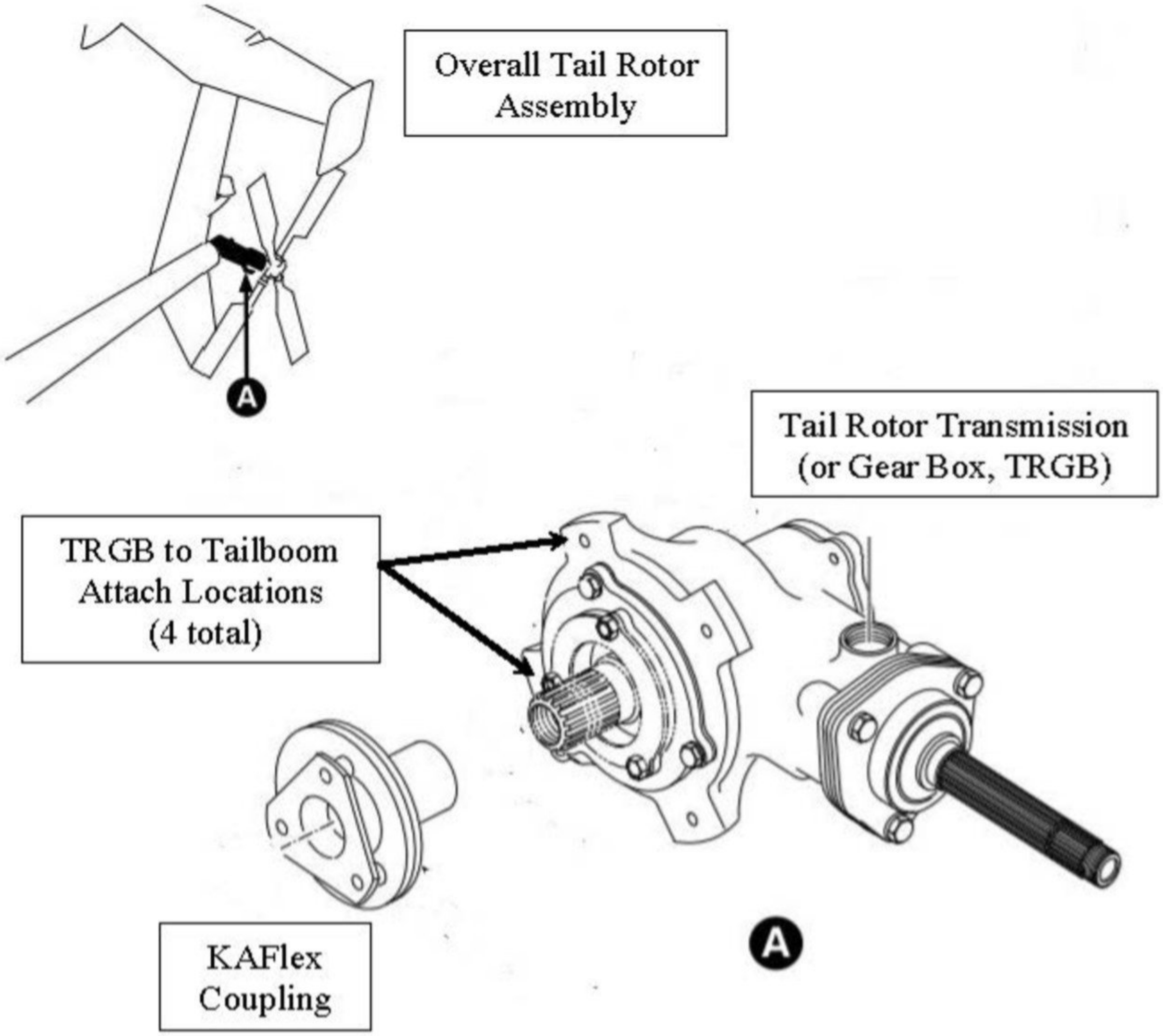

Figure 1. Overview of TR Assembly

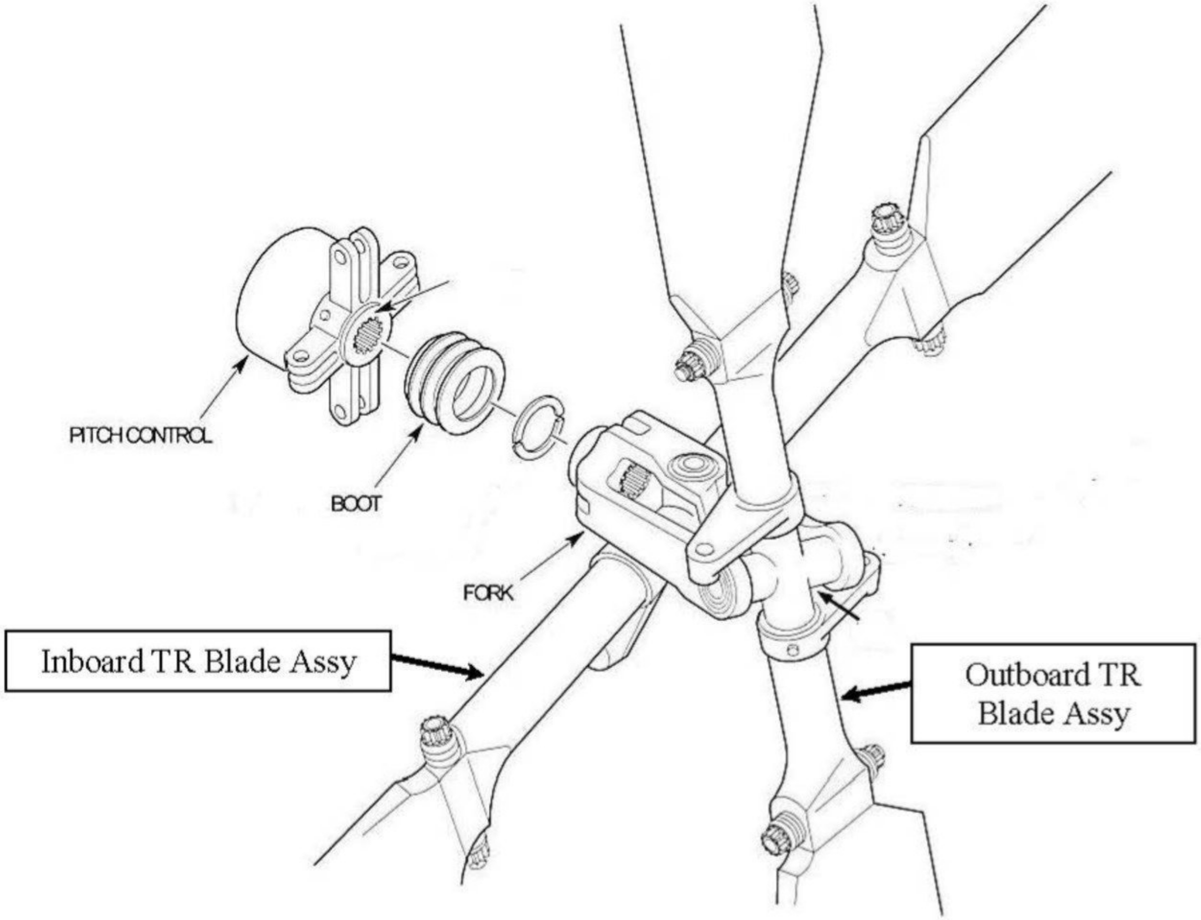

Figure 2. TR Forks and Blades

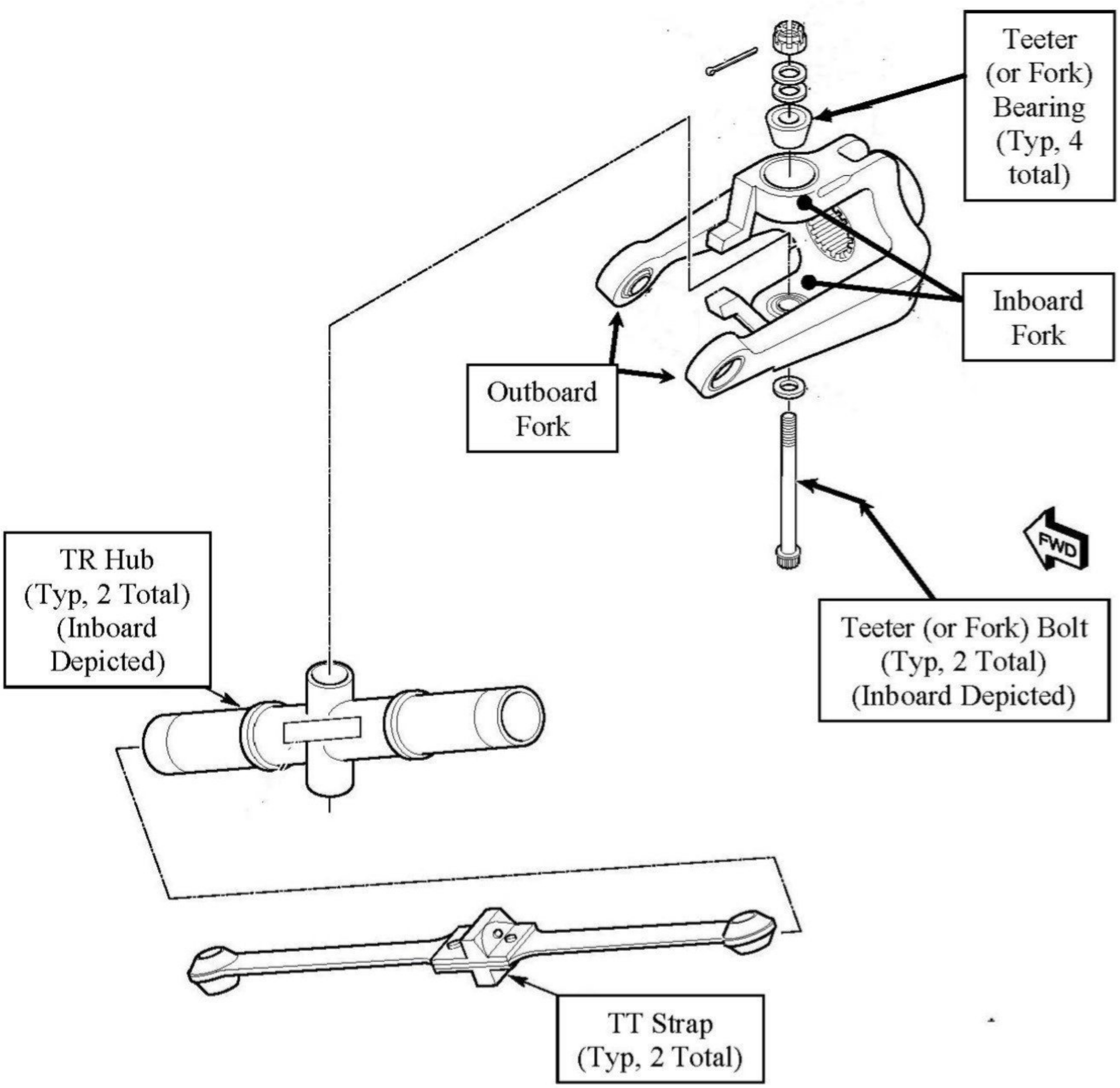

Figure 3. TR Hub and Forks

Fastener Torque Guidance

"Drag torque" is the term applied to the baseline torque value obtained when running a nut onto a bolt, or a bolt into a nut plate. Drag torque is unique to each bolt and nut/nut plate combination. FAA Advisory Circular 43.13-1B (Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair) states that for the installation of all torqued fasteners, the drag torque values are to be determined and recorded for each fastener combination, and that specific value is to be added to the specified installation torque value of the fastener. This drag torque procedure was to be used for installation of both locking and non-locking hardware.

According to the MDHI Maintenance Manual (MM) Torque Maintenance Practices section, the allowable drag torque range for 1/4-28 hardware was 3.5 to 30 in-lbs. The MM states that the following requirements governing torque loads apply throughout the manual except where otherwise specifically indicated.

1. Values apply to cadmium-plated bolts, cadmium-plated nuts coated with molybdenum disulfide (MoS_2)
2. Manufacturer applied lubricant must not be removed nor additional lubricant added.
3. Bolts, nuts and surfaces they bear on must be clean, dry and free of lubricant except as stated in requirement above.
4. Turning (drag) torque required to install self-locking nut or bolt up to point of final tightening must always be added to final torque value specified or the maintenance instruction, as applicable.

Aerometals Installation Guidance for TR Transmission

Aerometals document AMI-19, "INSTRUCTIONS FOR CONTINUED AIRWORTHINESS, 369X23500-505, -507, TAILBOOM ASSEMBLIES" was released in July 2000. The document included the following paragraphs:

This manual provides maintenance instructions for Aerometals 369X23500-505 and 369X23500-507 tailboom assemblies. These instructions are for installation, removal, inspections and intermediate levels of maintenance. No repairs are authorized that are not addressed in this manual.

With the exception of the tail rotor gearbox attachment hardware and the additional inspections outlined in this manual, the Aerometals tailboom assemblies are installed, inspected, and repaired in accordance with the tailboom installation, inspection and repair procedures identified in the MDHI Basic Handbook of Maintenance Instructions for the Model 369D/E/FF helicopters.

The AMI-19 document specified the following procedures for installation of the TR transmission:

(1) Apply primer (MIL-P-23377 or MIL-P-85582) to the four gearbox mounting bolts. While the primer is still wet, install bolts and washers through the transmission mount holes and into the aft tailboom frame.
(2) Torque bolts to 100-110 in-lbs (11.3-12.4 N-m) and apply torque stripe paint.
(3) Between 2 and 10 hours of helicopter operation (to allow parts to seat), check the torque of each MS21250-04026 bolt by applying 100 in-lbs (11.3 N-m). Reapply torque stripe paint. If any movement of any bolts occurred, this procedure must be repeated after 2 to 10 hours of helicopter operation.

The AMI-19 document does not specify that drag torque be applied to the final torque values, however, AC 43-14B and the MDHI MM provide clear guidance as to the applicability of drag torque in this application and would be in accordance with normal practices.

MDHI did not participate in or contribute to either the Aerometals design or the Aerometals installation and maintenance procedures.

Aerometals Inspection Guidance

According to AMI-19, the Aerometals tail boom was limited to a service life of 10,300 hrs. The document cited the following inspection criteria:

The 100-Hour/Annual and Conditional Inspection requirements for tailbooms identified in the original helicopter manufacturer's Basic Handbook of Maintenance Instructions for the Model 369D/E/FF helicopters are still applicable and are required for the Aerometals 369X23500-505 and 369X23500-507 tailboom assemblies.

Additionally, the Aerometals AMI-19 document did cite mandatory inspections of the tail boom at 7,300; 8,300; and 9,300 hrs that required removal of the TR transmission; such inspections would result in TR transmission re-installation that would necessitate the previously-cited attach hardware torque checks.

MDHI Installation Guidance for TR Transmission

Chapter 63-25-10 of the MDHI Maintenance Manual (MM) for installation of the TR transmission stated:

NOTE: Ensure all paint and sealant is removed from mating surfaces. Remove excessive sealant, as required, from transmission to gain clean mounting surfaces. Ensure that no gap in sealant coverage exists around the transmission bearing cover assembly.

(3). Apply primer (CM318) in holes and on the grip area of the mounting studs. Install tail rotor transmission or tailboom extension while primer is still wet.

(4). With assistance, support transmission and shaft in line for minimum deflection of coupling and install tail rotor drive shaft and transmission as a unit (Ref. Sec. 63-15-10).
NOTE: Record the drag torque for each nut and its location on the transmission in the helicopter for later use.

(a). (369D/E) Secure tail rotor transmission to four tailboom mounting studs with washers and nuts. Torque nuts to 75—95 inch-pounds (8.47—10.73 Nm) plus drag torque.

(5). Apply torque stripe paint.

(6). Between 2 and 10 hours of helicopter operation (to allow parts to seat), check the torque of each mounting nut as follows:
(a). Use the drag torque as measured and apply a torque load of 75—95-inch pounds (8.47—10.73 Nm) plus the noted drag torque (noted for each individual nut) to each mounting nut of the transmission.
(b). Re-apply torque stripe paint.

Paint is prohibited from the joint in order to maintain joint clamping force. Reduction in joint clamping force, due to compression or breakdown of paint in the joint has the potential, especially over time, to allow relative motion between the TR transmission and the tail boom, which can result in fatigue *fracture of the attach hardware. In cases where more severe vibrations are present, the relative motion between the TR transmission and the tail boom can result in shear fracture of the attachment threads. Increased vibrations and increased component relative motion can be due to multiple sources, including but not limited to TR imbalance, disbonded or deteriorated elastomeric bearings, and improper torque of the TR transmission attach hardware.*

MDHI Inspection Guidance for TR Transmission Attach Hardware

The MDHI MM contained sections for 100-hour/Annual and 300-hour inspections. The 100-hr inspection required a torque check of the fasteners. However, the specified torque values are not included in the inspection section of the MDHI MM but are part of the tail rotor transmission installation section of the MDHI MM. The appropriate torque values for the Aerometals tail boom are included in the installation section of AMI-19. The 300-hr inspection required removal of TR drive shaft, which necessitated removal of the TR transmission.

MDHI Installation Guidance for Teeter Bearings & Bolts

The MDHI Component Overhaul Manual specified the procedures for installation of the teeter bearings into the fork. The mating surfaces of the bearings and fork seats were to be coated with primer. After the primer was dry, a single ply of glass fiber fabric (referred to as a "scrim cloth") was to be installed on the bearing mating surface, and adhesive then used to secure each bearing, with its scrim cloth, to the fork. The purpose of the scrim cloth was to control the thickness of the adhesive, which promoted a consistent bond strength and prevented excessive squeeze-out of the adhesive during the installation and curing process. The adhesive was a two-part epoxy, gray in color.

Each 2-blade TR assembly attached to the fork via a teeter bolt, which installed through the two teeter bearings and the TR hub. The bearings were designed to be preloaded on installation, which was accomplished by proper shimming and teeter bolt tension. The shimming procedures were described in detail in the MM. Proper teeter bolt tension was obtained by tightening the nut to elongate the bolt a specified amount more than its zero-torque length. The specified elongation range was from 0.008 to 0.011 inches, and the bolt must not be used if the bolt was elongated more than 0.011 inches for any reason. There was no FAA or MDHI-specified bolt life limit; replacement was based upon on-condition or if the fork bolt is elongated over 0.011 inch, for any reason.

The 100-hr and 300-hr inspections required examination of the teeter bearings for debonding of their internal (metal-to-elastomer) bonds, bonds to the fork arms, and clamp up of the assembly by verifying the radial molded ridges on each bearing when teetering the blades stop to stop by hand takes place. If ridges assume continuous curved shape, bearings are intact, bearing bonded to the fork and clap up of the fork, elastomeric bearings and TR hub assembly. The inspection also required a torque check of the teeter bolt and confirmation of the absence of any axial or radial play in the bearing.

In addition to the 100-hr and 300-hr inspection, a daily preflight visual inspection of the tail rotor drive fork elastomeric bearings is included in the MDHI Rotorcraft Flight Manual.

Preflight Checks of the Tail Rotor

The MD 369D Rotorcraft Flight Manual (RFM) directs, as part of the daily preflight checks, inspection of the tail rotor drive fork elastomeric bearings as follows:

T*ail rotor drive fork elastomeric bearings (if installed):*

*NOTE**:** Check bearing for general condition. Elastomeric bearings are suspected of being unserviceable if rubber deterioration or separation, or a vibration is noted. Evidence of light swelling, pock marks and crumbs are surface conditions and are not indications of bearing failure.*

CHECK -_ _ Apply teetering force by hand to tail rotor blades (stop-to-stop). Check for fork-to-bearing bond failure. Failure is indicated by any motion between outer bearing cage and fork (bearing turns in fork).

CHECK -_ _ Teeter blades stop-to-stop. Observe four radial molded ridges on each bearing as teetering takes place. If ridges assume continuous curved shape, bearings are intact. Discontinuity in molded ridges indicates bearing failure.

Teeter Bearing Serial Numbers

Lord Corporation was a manufacturer of the teeter bearings specified by MDHI for installation in the TR fork. The Lord part number for these bearings was LB2-1056, and Lord serialized these bearings.

N369MH TR Inspection History

Maintenance records indicated that at the time of the accident, the helicopter had a total time (TT) in service of about 14,419 hours. The helicopter's most recent 100-hour/annual inspection was completed on July 12, 2018, at a helicopter TT of about 14,328 hours. The most recent 300-hour inspection was completed on May 22, 2018, at a helicopter TT of about 14,157 hours. The records indicated a regular history of 100- and 300-hr inspections. Both the 100-hr/annual and 300-hr inspections contain several TR-specific inspection items, including teeter bearing wear, condition, and security.

N369MH Maintenance History

According to the available maintenance records, the Aerometals tail boom was installed on the helicopter in May 2006, at a helicopter TT of about 6,482 hours. In August 2016, a TR transmission overhauled by California Aero Components was installed on the helicopter at a TT of about 11,535 hrs; this was the TR transmission on the helicopter at the time of the accident.

In September 2016, at a helicopter TT of about 11,643 hrs, a fork/teeter bolt fractured. According to the repair station, Hawaii Aviation Services (HAS), their policy was to replace fork/teeter bolts whenever any maintenance activity resulted in the removal of that bolt. HAS sent the fractured bolt to MDHI for failure analysis but reported that MDHI did not provide any response to that request. MDHI was unable to provide any additional information regarding this bolt.

As a result of the September 2016 bolt fracture, several TR components were replaced; replacement parts included new pitch control links, new fork/teeter bolts, and an overhauled fork assembly; this fork assembly was the one installed on the helicopter at the time of the accident, and contained the improperly-installed teeter bearings.

According to the operator's maintenance records, the accident fork was installed on the helicopter about 23 months before the accident and had accumulated about 2,685 hours in service since then. The records indicated that, at least three times in the period between the replacement of the fork and the accident, other TR maintenance that would have necessitated removal of the teeter bolts was accomplished on the helicopter. These events occurred in June 2017, and March and April 2018, at helicopter TT values of 12,643 hrs, 13,901 hrs, and 14,061 hrs, respectively.

Any removal of the hinge (teeter) bolts would enable detection of a loose, displaced, or detached teeter bearing. The available maintenance records for this period did not contain any references to any anomalies with, or repairs to, the teeter bearing installations, or any references to installation of new teeter bearings.

Records indicated that California Aero Components/Heli-Mart subcontracted the fork overhaul to another company called Heli-Tech. Heli-Tech was an FAA-certificated repair station. According to an MDHI representative, Heli-Tech was not on the MDHI-approved supplier list as a repair station; however, this did not preclude an owner/operator from using Heli-Tech for repairs, unless restricted by a contract between MDHI and the owner/operator.

Investigators contacted both HAS and Heli-Tech to obtain details about the fork overhaul. HAS responded that they did not have any details or substantiating documentation regarding the fork overhaul. The Heli-Tech representative stated that Heli-Tech adheres to the MDHI Component Overhaul Manual, and as prescribed by the manual, uses scrim cloth during the installation of the teeter bearings. The representative stated that due to the vintage of the overhaul, Heli-Tech no longer retained the relevant records to verify part and serial numbers, but that he was most likely the technician who performed the overhaul. The representative then stated that if the scrim cloth was absent, it was his opinion that either the fork had undergone some maintenance since the overhaul, or that it was unlikely that Heli-Tech had accomplished that overhaul. He also stated that any fork sold by Heli-Tech as "overhauled" will include installed teeter bearings. Heli-Tech did not track teeter bearing serial numbers of bearings they purchased or installed.

Invoices and other shipping information indicated at least two occasions where Heli-Mart sold teeter bearings directly to the operator. On August 22, 2017, two bearings were sold and shipped, and on February 8, 2018, three more bearings were sold and shipped. A cross-check of the serial numbers from the sold bearings and the accident bearings revealed that, at the time of the accident, one of the Heli-Mart provided bearings was installed on the inboard fork, and at least one was installed on the outboard fork. These findings were contrary to the operator's information that they had not installed any teeter bearings on the accident fork. The installation dates could not be determined.

The serial number from the other accident inner bearing did not match any of the bearings provided by

Heli-Mart, and the serial number for the outer bearing that was liberated in-flight could not be determined.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	HNL,10 ft msl	**Distance from Accident Site:**	13 Nautical Miles
Observation Time:	18:53 Local	**Direction from Accident Site:**	275°
Lowest Cloud Condition:	Few / 2500 ft AGL	**Visibility**	10 miles
Lowest Ceiling:	None	**Visibility (RVR):**	
Wind Speed/Gusts:	14 knots / 21 knots	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	20°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	29.92 inches Hg	**Temperature/Dew Point:**	28°C / 19°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Honolulu, HI (HNL)	**Type of Flight Plan Filed:**	Company VFR
Destination:	Honolulu, HI (HNL)	**Type of Clearance:**	VFR
Departure Time:	19:09 UTC	**Type of Airspace:**	Class E

Airport Information

Airport:	Honolulu International HNL	**Runway Surface Type:**	Grass/turf
Airport Elevation:	10 ft msl	**Runway Surface Condition:**	Dry;Rough;Vegetation
Runway Used:		**IFR Approach:**	None
Runway Length/Width:		**VFR Approach/Landing:**	Precautionary landing

Wreckage and Impact Information

Crew Injuries:	1 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	3 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	4 None	**Latitude, Longitude:**	21.273056,-157.706115(est)

On-Scene and Operator Facility Examination

The helicopter was examined about 3 weeks after the accident. The tail boom and several related components, including the TR transmission, had been removed and separated by the operator; otherwise, the airframe was intact. The tail boom had been unbolted from the fuselage at its normal attach point. The vertical and horizontal stabilizers had been removed and separated from one another. One of the four mounting lugs on the vertical stabilizer that was used to attach the horizontal stabilizer was fracture-separated.

The right side upper and lower bores on the tail boom mounting pads for the TR transmission were unobstructed, and the attach hardware was retained by the operator after disassembly. The left side upper and lower mounting pad bores retained fragments of the TR transmission attach hardware. The operator's director of maintenance advised investigators that the tail boom pad and TR transmission lug mating surfaces had been "cleaned" after the TR transmission was removed from the tail boom.

The TR input drive shaft remained attached to the TR transmission by the KAflex-brand flexible coupling and appeared undamaged. The KAflex coupling also appeared undamaged, and all its hardware remained securely installed. Manual rotation of the TR transmission input shaft resulted in rotation of the TR transmission output shaft, with normal (minimal) resistance. The pitch links on both the inboard and outboard TR hubs had been removed by the operator. One outboard pitch link appeared bent. The swashplate translated and rotated freely on the TR transmission output shaft.

The right side upper and lower mounting lugs on the TR transmission were fracture-separated from the TR transmission, and the left side upper and lower mounting lug holes exhibited some deformation. The right mounting bores in the tail boom were intact. Both left mounting bores in the tail boom contained fractured remnants of their TR transmission mounting bolts.

The TR fork assembly remained attached to the TR transmission. Both TR assemblies had been removed from their respective forks by the operator. One outboard teeter bearing had separated from the outboard fork but remained captive in the assembly. The other outboard teeter bearing was absent and was not recovered. The outboard TR assembly retained its TT strap pack and rotor blades during the accident, but the blades had been removed by the operator after recovery. The fork bolt had fractured, and a section remained inside the rotor hub. The bolt head section of the fork bolt was absent.

The inboard fork retained its two teeter bearings. The inboard TR assembly had retained its TT strap pack and rotor blades during the accident. One blade had been removed by the operator. The fork bolt nut had been removed and retained by the operator. The fork bolt appeared undamaged.

NTSB Materials Laboratory Examinations

The tail boom, TR transmission assembly, pitch control assembly, fork assembly, and hub assemblies were examined at the NTSB materials laboratory in Washington, DC.

Contrary to the MDHI MM guidance, all four of the tail boom lug faces that served as the mating surfaces for the TR transmission exhibited layers of primer and paint, even after reportedly being cleaned by the operator after initial disassembly.

Of the four bolts used to attach the TR transmission to the tail boom, two (right side) were intact, and two (left side) were fractured. Markings and measurements of the intact bolts were consistent with the correct hardware. The brackets holding the left side nut plates were removed in order to access the bolt fragments; the bolt fragments were both found disengaged from the nut plates. Both left side bolts were fractured in the grip portion of the shank. The bolt fragments displayed areas of thread damage where their thread peaks were sheared off, yielding a diameter reduction of about 0.01 inch. Sheared thread peaks were observed on the interior of the upper left nut plate. The lower left nut plate was not examined. Dimensional checks and thread counts were consistent with full engagement of the bolts in the nut plates.

The threads and portions of the grip areas of the fractured left-side bolts were covered with black greasy deposits, and slivers of fractured threads were observed intermixed with the deposits on the threads for the lower left bolt. A yellow-green coating consistent with primer was also noted on the threads. The presence of the primer was consistent with the Aerometals Instructions for Continued Airworthiness maintenance instructions for the tail boom.

Optical and scanning electron microscope (SEM) examination of the left side bolt fracture surfaces revealed features consistent with fatigue. The fatigue initiated from multiple surface origins located circumferentially around each bolt and covered a relatively small portion of the total cross-sectional area. These features were consistent with low-cycle fatigue with relatively high stress levels. Dimple features consistent with ductile overstress fracture were observed in the central portion of each bolt.

Measurements of the drag torque of the bolts into the right-side tail boom nut plates with wet primer applied (per the Aerometals installation instructions) yielded torque values within the allowable range. Due to their damaged condition, the drag torques of the left side nut plates were not measured.

The recovered outboard teeter bearing exhibited cracks in the elastomer and accumulations of fractured elastomer in some of its recesses. Remnants of adhesive were observed on portions of the mating surfaces of the bearing and the fork, and in some areas the adhesive material appeared to be discolored yellow, brown, and black. Fretting damage was noted on the seating surface of the bearing around approximately one-quarter of the circumference, with corresponding fretting damage on the fork seat. An arc-shaped inward deformation was observed on the side of the bearing, and the fretting damage was continuous across the deformation, consistent with the deformation occurring after the fretting damage.

The fork arm bearing seat for the missing outboard teeter bearing exhibited isolated areas of adhesive, with discolorations similar to those observed on the recovered outboard teeter bearing and seat. No evidence of fretting damage was observed on this bearing seat surface.

Both inboard bearings were removed using heat and pressure. Gray adhesive material remained attached to both the bearing and mating seat surfaces. Isolated areas of the adhesive appeared discolored. No fretting damage was observed. There was no evidence of any primer or scrim cloth on any of the four bearing or seat surface sets.

According to the MDHI specifications, the outboard teeter bolt material was nickel alloy 718. The fractured bolt was examined visually and via SEM. Approximately 75% of the fracture face was consistent with fatigue; the origin was at the bolt surface near the edge of a relatively smooth rubbed area consistent with contact damage associated with movement between the bolt and the mating surface. Fracture characteristics were consistent with those of the nickel alloy material specified by MDHI.

Organizational and Management Information

Magnum Helicopters was an Oahu-based helicopter air tour company. Magnum was a wholly owned subsidiary of Schuman Aviation Company, Ltd, which was also based on Oahu.

Hawaii Aviation Services (HAS) was also a wholly owned subsidiary of Schuman Aviation Company, Ltd, and was an FAA Part 145 certificated repair station. HAS was the primary maintenance provider for Magnum aircraft. According to an HAS representative, although there was no maintenance entry for the improperly installed teeter bearing, there was only one technician who was responsible for that maintenance task, and he is no longer employed by HAS; his departure was unrelated to the deficient maintenance or the accident.

The FAA Flight Standards District Office was the certificate management office for Schuman Aviation and HAS. As of the date of the accident, the FAA had one inspector assigned as the Principal Maintenance Inspector (PMI) for Schuman, and a different inspector assigned as the PMI for HAS. An FAA search of the HAS facility (after the maintenance error was identified) for other overhauled TR assemblies did not locate any overhauled TR assemblies.

Administrative Information

Investigator In Charge (IIC):	Huhn, Michael
Additional Participating Persons:	Edwin Kalilikane; FAA; Honolulu, HI John Hobby; Boeing Helicopter; Mesa, AZ Joan Gregoire; McDonnell Douglas Helicopter; Mesa, AZ
Original Publish Date:	May 27, 2021
Last Revision Date:	
Investigation Class:	Class 2
Note:	The NTSB did not travel to the scene of this accident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=98062