NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

December 13, 2013

Airworthiness Group Chairman's Factual Report

NTSB No: DCA12FA024

A. ACCIDENT

Operator:	AAR Airlift Corporation
Aircraft:	Bell 214ST, Registration Number N5748M
Location:	7 miles south of Camp Bastion, Helmund Province, Afghanistan
Date:	January 16, 2012
Time:	1045 local time[1] (0615 coordinated universal time)

B. AIRWORTHINESS GROUP

Group Chairman:	Chihoon Shin National Transportation Safety Board Washington, District of Columbia
Member:	Ronald Price National Transportation Safety Board Washington, District of Columbia
Member:	Harold Barrentine Bell Helicopter Textron Fort Worth, Texas
Member:	David Gridley General Electric Lynn, Massachusetts
Member:	Bob Drake Federal Aviation Administration Washington, District of Columbia
Member:	Tom Howell AAR Airlift Corporation Melbourne, Florida
Member:	Maj. Scott Frisius United States Transportation Command Scott Air Force Base, Illinois

[1] The local time in Afghanistan is Coordinated Universal Time (UTC) +4:30.

LIST OF ACRONYMS

AARS	attitude/altitude retention system
AD	Airworthiness Directive
AGB	accessory gearbox
AMC	Air Mobility Command
ATT	Aircraft Total Time
BHT	Bell Helicopter Textron
CFR	Code of Federal Regulations
DC	District of Columbia
ECU	electronic control unit
ESN	engine serial number
FAA	Federal Aviation Administration
FBW	fly-by-wire
FCF	functional check flight
FL	Florida
FSDO	Flight Safety District Office
GE	General Electric
GMM	general maintenance manual
HMU	hydromechanical unit
LDS	load demand spindle
NTSB	National Transportation Safety Board
PIC	pilot-in-command
S/N	serial number
SCAS	stability control and augmentation system
SIC	second-in-command
TSN	time since new
TX	Texas
USTRANSCOM	United States Transportation Command
UTC	coordinated universal time
VA	Virginia
VG	variable geometry

C. SUMMARY

On January 16, 2012 at 1045 local time, a Bell 214ST helicopter, registration number N5748M, operated by AAR Airlift Corporation crashed about 7 miles south of Camp Bastion, Helmund Province, Afghanistan. The accident helicopter, one of two helicopters on a 14 *Code of Federal Regulations* Part 135 flight under contract with the Air Mobility Command (AMC) of the United States Transportation Command (USTRANSCOM), departed Camp Bastion with no passengers on board. The three-member crew on board the accident helicopter consisted of the pilot-in-command (PIC), the second-in-command (SIC), and the crew chief. The helicopter impacted the ground on relatively flat terrain. All three crew members were fatally injured and the helicopter was destroyed by impact forces and subsequent fire. Weather was reported to be clear with unrestricted visibility.

Witness accounts from the crew of the second helicopter flying behind the accident helicopter reported both helicopters were at an altitude of about 800 to 1000 feet, climbing at a rate of about 300 feet per minute with an airspeed of about 120 knots, when the crew saw the accident helicopter roll sharply to the right in conjunction with a steep, nose-down pitch, during which the tailboom was observed to begin separating from the helicopter. The helicopter continued its descent with a nose-down pitch until ground impact. There were no reported mayday or distress calls.

Under the provisions of Annex 13 to the Convention on International Civil Aviation, the National Transportation Safety Board (NTSB) accepted full delegation of the accident investigation from the Ministry of Transport and Civil Aviation of the Islamic Republic of Afghanistan. The NTSB did not launch to perform an on-site investigation. The ground impact area and debris field were examined and photographed by the US military and AAR Airlift's Director of Ground Support Operations in Afghanistan. The wreckage was then collected and transported to the NTSB Training Center in Ashburn, Virginia (VA) for examination.

On June 27 – 29, 2012, members of the Airworthiness Group convened at the NTSB Training Center to examine the wreckage. The examination found that only one of the two collective lever arms was recovered from the accident site. Furthermore, the areas on the main transmission and main rotor mast to which the missing collective lever arm was installed did not exhibit significant damage similar to the damage found in the areas where the recovered collective lever arm was attached at impact. Several components were removed from the wreckage and retained by the NTSB for further examination in the NTSB laboratory in Washington, District of Columbia (DC). During the week of October 29, 2012, members of the Airworthiness Group convened at Bell Helicopter Textron (BHT) facilities in Fort Worth, Texas (TX) for a detailed examination of the hydraulic and electrical actuators from the accident helicopter flight control system, which found no evidence consistent with abnormal operation. On September 9, 2013, members of the Airworthiness Group convened at BHT to discuss with BHT engineering the information needed to run a math model to simulate the helicopter's response to a severe reduction in main rotor collective pitch. Preliminary results from the simulation predicted the helicopter would respond with a severe right roll and a nose-down pitch following a failure of the collective flight control system. As of this report, additional simulations are still in work. On September 30, 2013, members of the Airworthiness Group convened at the NTSB Training Center to perform an additional examination of the tailboom wreckage, which confirmed overload fractures on the four tailboom attachment fittings.

The review into the collective flight control system maintenance records revealed that the collective torque shaft support bracket had been replaced the day before the accident flight. The support bracket installation was found within the wreckage with no evidence consistent with an erroneous

installation of the replacement support bracket. However, the maintenance records revealed neither discrepancies related to the collective flight control system that led to the replacement of the support bracket nor the troubleshooting performed to determine the support bracket needed replacement.

D. DETAILS OF THE INVESTIGATION

1.0 HELICOPTER INFORMATION

1.1 HELICOPTER DESCRIPTION

The Bell 214ST helicopter has a two-bladed, semi-rigid, under-slung main rotor system that provides helicopter lift and thrust, and a two-bladed, semi-rigid, tail rotor system that provides main rotor anti-torque and directional control (**Figure 1**). The helicopter is equipped with two General Electric (GE) CT7-2A turboshaft engines that provide power to the main and tail rotor systems via a geared transmission system and drive shafts. The helicopter's flight controls for cyclic, collective, and anti-torque/directional control are hydraulically assisted. The automatic flight controls consist of a stability control and augmentation system (SCAS), attitude/altitude retention system (AARS), and a fly-by-wire (FBW) elevator system. The helicopter can be configured for a possible total seating capacity of 20 persons, with a pilot and co-pilot seat in the crew compartment and 18 seats in the passenger compartment. At the time of the accident, N5748M was configured with a total of 9 seats in the passenger compartment.

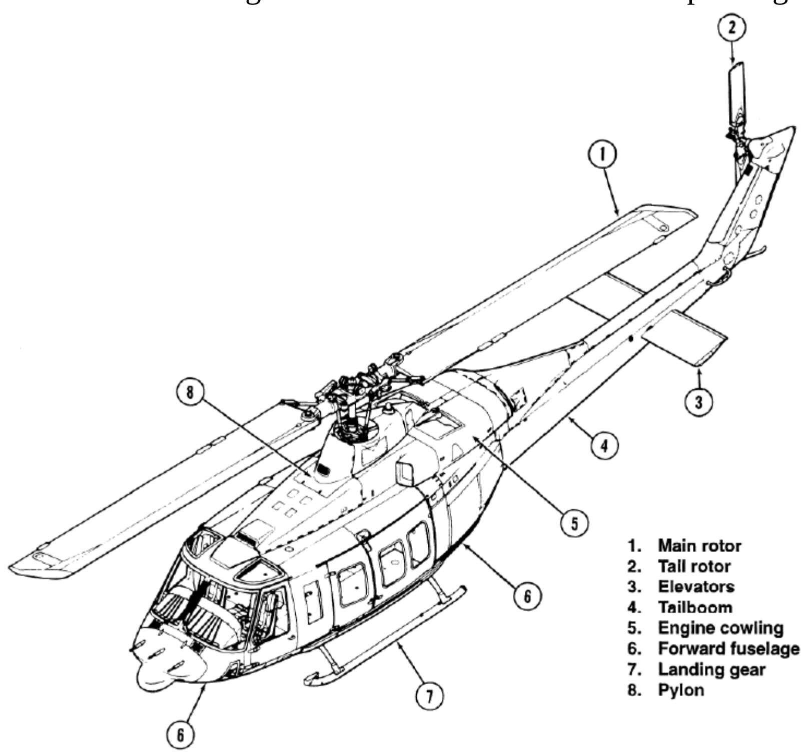

Figure 1. Bell 214ST (typical configuration) **[image courtesy of BHT]**

1.2 HELICOPTER HISTORY

The accident helicopter, serial number (S/N) 28102, was built in 1984 under FAA Type Certificate H10SW and was approved for Title 14 *CFR* Part 91 and Part 135 operations. Records showed the helicopter had accumulated an aircraft total time (ATT) of 12,346.2 flight hours as of January 15, 2012, the day prior to the accident.

2.0 IN-SITU HELICOPTER EXAMINATION

Detailed information and photographs of the accident site were provided to the NTSB by the US military and AAR Airlift Corporation's Director of Ground Support Operations in Afghanistan. The accident site consisted of a primary impact area and a scattered debris field. The debris field was measured by a laser range finder to be about 1,575 feet north-south by 656 feet east-west. The primary impact area consisted of the main fuselage. The forward end of the tailboom was found separated from the fuselage about 49 feet north of the primary impact area and the aft end of the tailboom (containing the vertical fin) was found about 279 feet north of the primary impact area. The main debris field was located in a southerly direction from the primary impact area at an undefined distance; it comprised of various parts including an engine cowling, door, Plexiglas, and the 'white'[2] main rotor blade. The 'red' main rotor blade was found about 426 feet south-west of the primary impact area. **Photo 1** shows an aerial view of the accident site. The primary impact area was reported to have been fully consumed by the post-impact fire. The wreckage was collected and shipped to the NTSB Training Center for further examination.

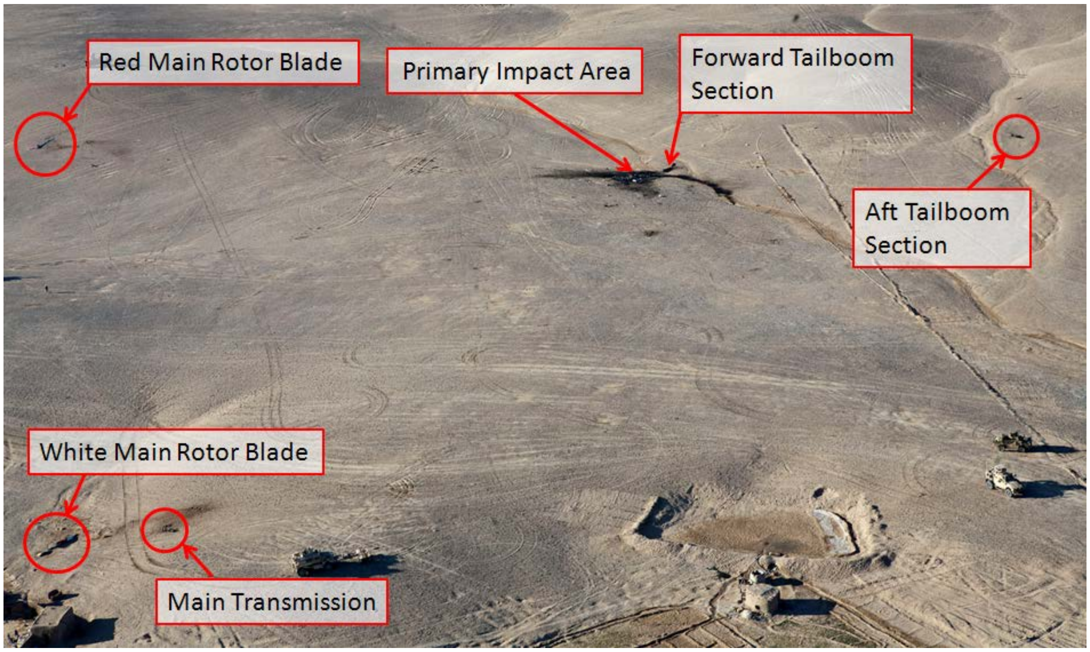

Photo 1. Aerial view of the accident site. **[image courtesy of USTRANSCOM]**

3.0 DETAILED EXAMINATION OF THE WRECKAGE AT THE NTSB TRAINING CENTER

The Airworthiness Group convened at the NTSB Training Center in Ashburn, VA from June 27 – 29, 2012 in order to examine the wreckage collected from the accident site.

3.1 MAIN ROTOR SYSTEM

3.1.1 SYSTEM DESCRIPTION

The main rotor blades are comprised of a primarily fiberglass spar with a titanium leading edge abrasion strip. The blade core is composed of a Nomex honeycomb covered by a fiberglass skin. Each blade has a stainless steel cap at the tip end of the blade. Each

[2] The main rotor blades were labeled 'white' and 'red' to differentiate between the two blades.

blade attaches to a blade grip and spindle assembly on the hub end. The pitch horn attaches to the blade grip and rotates the blade to change its angle of attack. The drag brace, attached to the blade grip and to the inboard trailing end of the blade, prevents rotation of the blade about the blade grip due to lead and lag forces.

The main rotor hub, comprised of a yoke and trunnion assembly, is attached to and driven by the main transmission's main rotor mast via a splined connection (**Figure 2**). The hub is secured to the main rotor mast via a mast nut. The hub provides rotating drive to the main rotor blades during normal operation and also allows both blades to flap in unison (but opposing direction) via its teetering hinge.

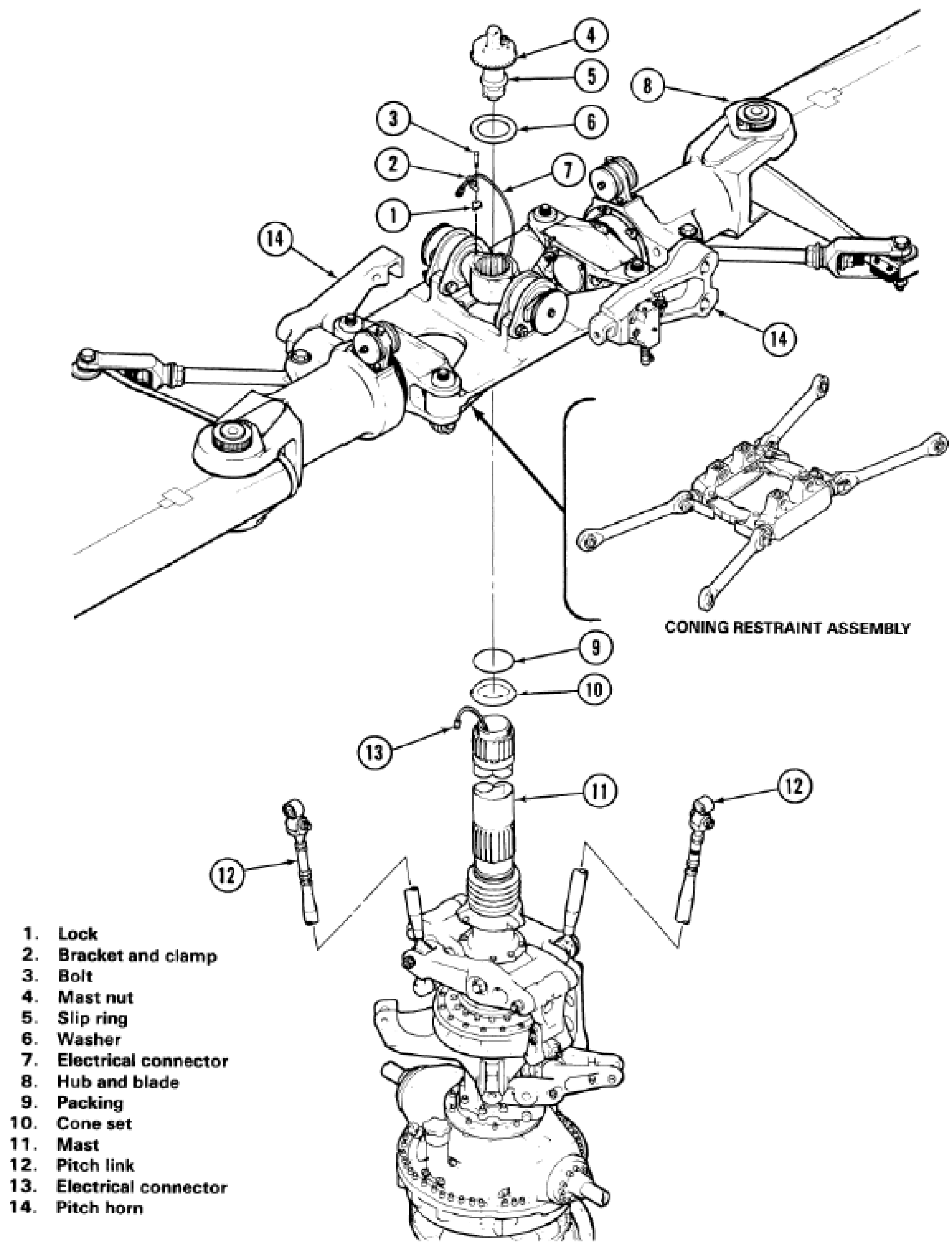

Figure 2. Main rotor installation **[image courtesy of BHT]**

Inputs from the cyclic stick in the cockpit are transmitted to the stationary swashplate via a system of control tubes, bellcranks, and two hydraulic actuators. The two cyclic hydraulic actuators' output pistons tilt the stationary swashplate in the desired orientation, which actuates each individual rotating scissor link and its corresponding pitch link and pitch horn, resulting in an individual change to the pitch of each blade. Inputs from the collective stick in the cockpit are transmitted to the collective sleeve via a system of control tubes, bellcranks, a single collective hydraulic actuator, and the collective lever. The up-and-down actuation of the collective sleeve results in a collective actuation of the rotating scissors and corresponding pitch link and pitch horn, resulting in a collective change to the pitch of both blades.

3.1.2 MAIN ROTOR BLADES

Both of the main rotor blades were recovered from the accident site. Both blades were received with permanent marker labeling on their respective pitch horns, with one blade labeled "white' and the second blade labeled "red'. Both main rotor blades were substantially damaged, but their respective pitch horns, drag braces, and grip and spindle assemblies remained installed with damage consistent with scuffing from ground impact (**Photos 2 and 3**). The bearing and clevis ends of both pitch change links remained attached to the pitch horns with all attachment hardware intact. The pitch change links were fractured at the upper end of the tube assembly. Both main rotor blade spindles remained attached to their respective yoke flanges. All four yoke flanges were fractured, with the fractured ends were slightly bent upward. Examination of the yoke fracture surfaces revealed features consistent with overstress failure.

The 'white' main rotor blade had its tip cap still installed. The blade contained multiple fractures in its honeycomb core and fiberglass skin throughout the span of the blade consistent with impact forces. The blade had evidence of blue and black paint transfer marks[3] in the chordwise direction, from the leading edge to the trailing edge, about 24 inches in width in the spanwise direction (**Photo 4**). Impact damage was seen on the leading edge of the blade about 12 inches from the spanwise measurement reference point[4]. A small section of the underside of the leading edge abrasion strip was missing at the impact location (**Photo 5**); a section of the leading edge abrasion strip of similar size and shape to the aforementioned missing section was found lodged in a fractured section of the elevator spar (**Photo 6**). Both coning restraint links remained attached to the blade spindle but fractured, with fracture surfaces exhibiting features consistent with overstress failure.

[3] The accident helicopter's tailboom was painted in a similar blue color and the tail rotor driveshafts installed in the tailboom were painted in a similar black color.

[4] All of the spanwise measurements for both blades described in this section are measured from the point of intersection between the blade tip cap and the leading edge abrasion strip, and will be referred to as the spanwise measurement reference point.

Photo2. The red main rotor blade. Arrows indicate yoke flange fractures.

Photo3. The white main rotor blade. Arrows indicate yoke flange fractures.

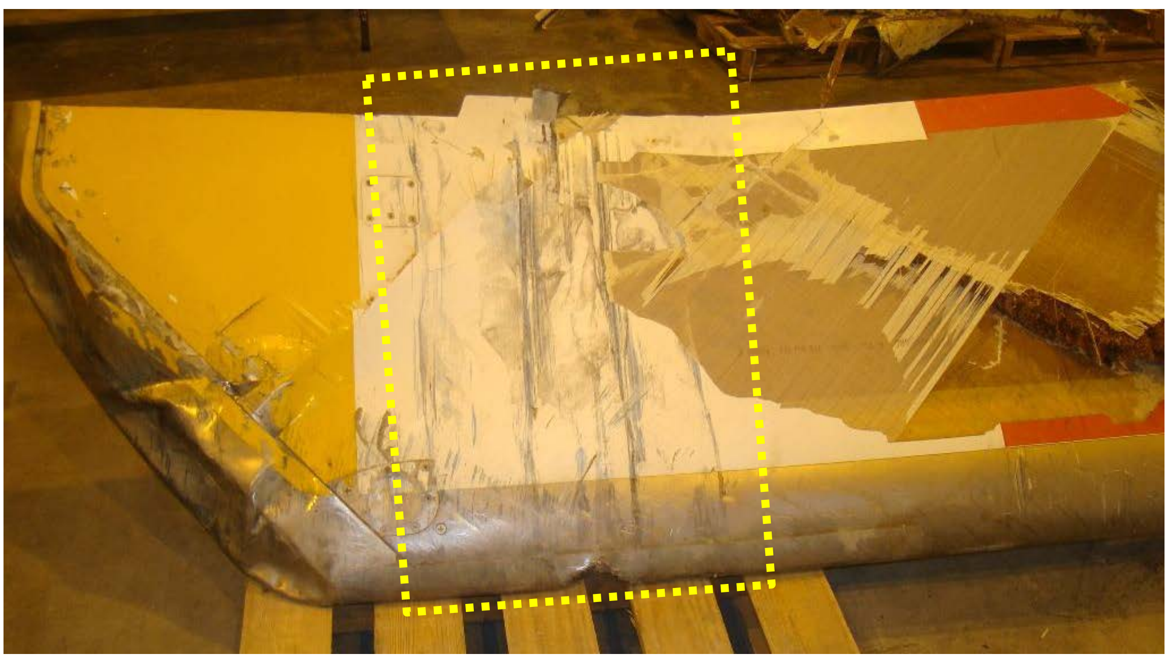

Photo 4. Blue and black paint transfer marks on the top surface of the white main rotor blade.

Photo 5. The white main rotor blade's leading edge abrasion strip with missing piece.

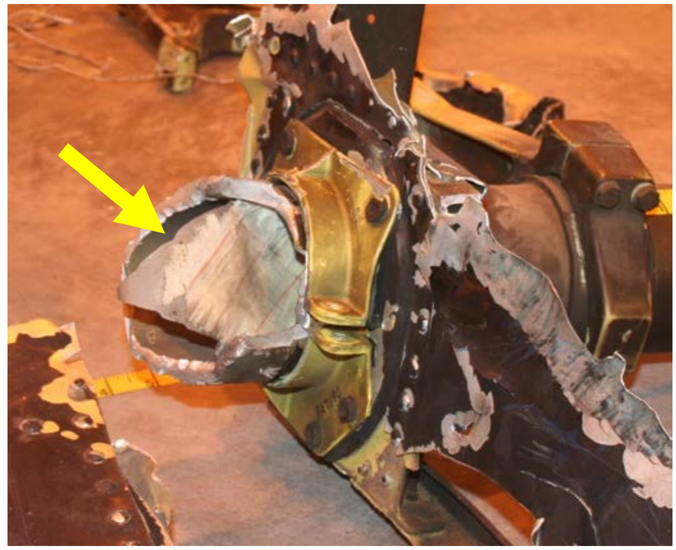

Photo 6. Leading edge abrasion strip piece found in the tailboom elevator spar (see arrow).

The 'red' main rotor blade tip cap was not installed on the blade, but the tip cap was recovered from the accident site and was observed to be substantially deformed. The tip weight remained inside the blade. Similar to the 'white' blade, the 'red' blade contained multiple fractures in its honeycomb core and fiberglass skin throughout the span of the blade. Furthermore, the 'red' blade also exhibited blue and black paint transfer marks at about 84 inches from the spanwise measurement reference point. Impact damage similar to the 'white' blade was observed at the blade leading edge approximately 24 inches from the spanwise measurement reference point. There was also a high concentration of maroon paint transfer marks that started at about 36 inches from the spanwise measurement reference point and ended at about 72 inches from the reference point. The helicopter battery cover, painted in maroon, was recovered from the accident site and was observed to be deformed in the shape of a main rotor blade leading edge (**Photo 7**). Only one coning restraint link remained attached to the blade spindle; examination of its fracture surfaces revealed signatures consistent with overstress failure.

Photo 7. Deformed helicopter battery cover (placed over the 'red' main rotor blade leading edge).

3.1.3 MAIN ROTOR HUB, MAIN ROTOR MAST, AND ROTATING CONTROLS

On the visible portions of the main rotor mast, evidence of two areas with impact damage was found 180° opposite of each other and aligned with the flapping direction of main rotor hub; the impact damage was matched to impact damage seen on the inner surface of the teetering yoke (**Photos 8 and 9**). The teeter stops were not recovered with the yoke. The impact damage on the main rotor mast contained characteristics consistent with mast bumping.[5] The remaining visible portions of the main rotor mast extending up to the main rotor hub did not exhibit unusual damage aside from those consistent with ground impact forces. The trunnion assembly and the mast nut were found installed and intact.

The bellcrank that connects the stationary swashplate link to the stationary swashplate remained installed on the main transmission case, but the connecting links were fractured. The fractured pieces of the stationary swashplate link were recovered from the accident site. All examined fracture surfaces exhibited signatures consistent with overstress failure.

[5] Mast bumping is a phenomenon that occurs on two-bladed semi-rigid rotor systems when the rotor system exceeds the teetering limit and strikes the mast of the helicopter, usually with sufficient force to cause mast deformation and potentially mast failure.

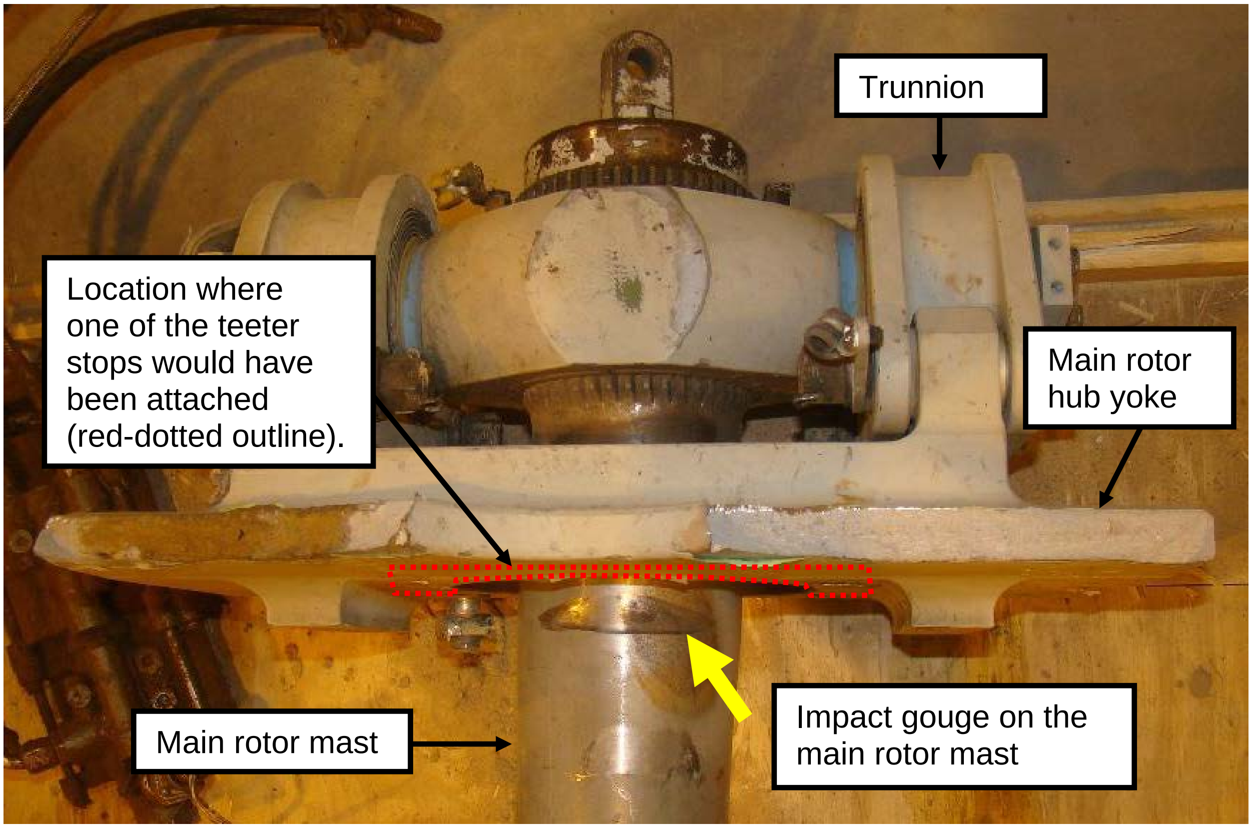

Photo 8. Impact gouge on the main rotor mast.

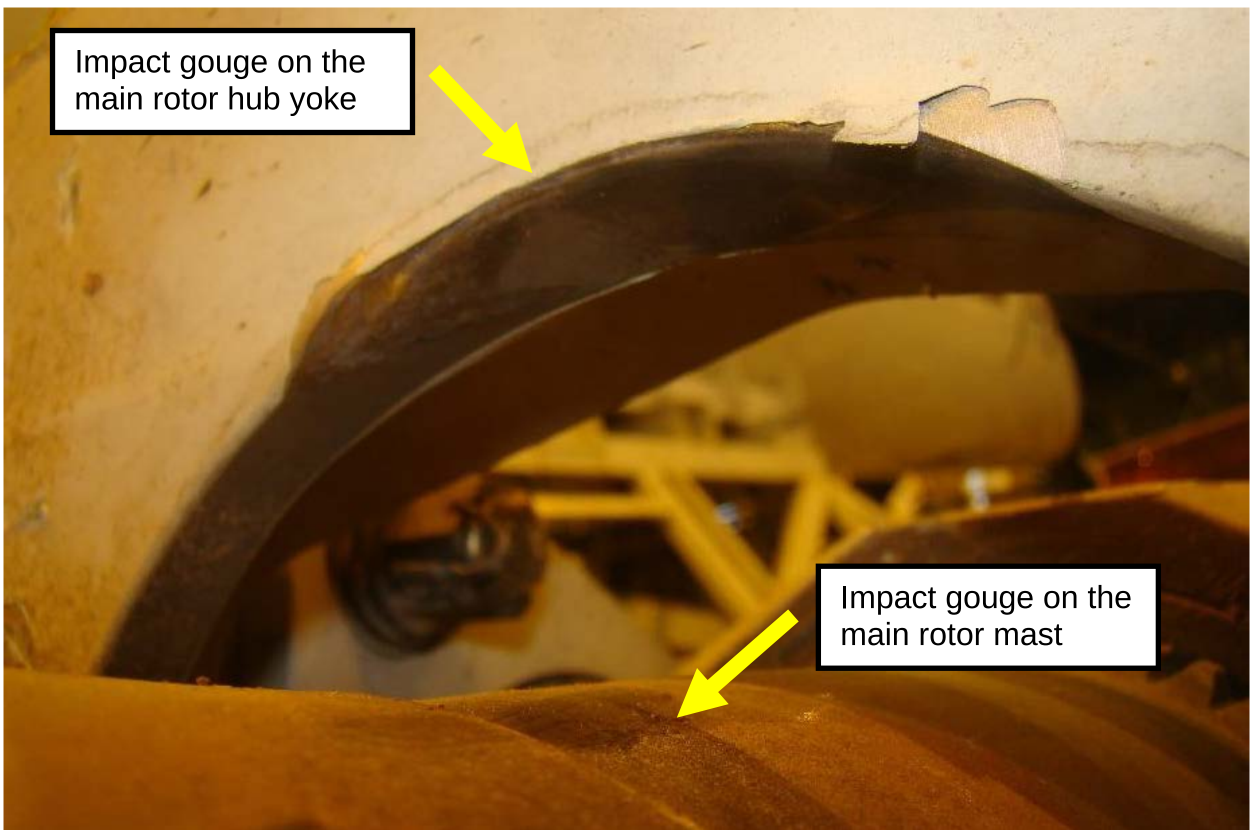

Photo 9. Corresponding impact gouges on the main rotor hub yoke (upper arrow). Impact gouge on the main rotor mast is also visible (lower arrow).

The stationary and rotating swashplates both remained installed on the main rotor mast. The upper rod end from the output piston of both cyclic hydraulic actuators remained installed on the stationary swashplate with their attaching hardware intact (**Photo 10**). Both rotating scissors assemblies and their drive links remained installed on the collective hub assembly. The rod ends and the entire length of the control tubes of both pitch change links remained attached to their respective rotating scissor link. Damage observed on the aforementioned parts was consistent with ground impact forces.

The swashplate support assembly remained in place with the recovered main transmission assembly, but seven of the eight nut, washer, and stud assemblies that attach the swashplate support assembly to the main transmission housing were missing. Remnants of grease were evident on and around the collective lever attachment points on both the idler link and the visible part of the collective sleeve seen through the swashplate support assembly window.[6] The collective lever assembly was not attached to the idler link or the collective sleeve (**Photo 11**). Only one of the two collective lever arms was found within the recovered wreckage. The collective lever assembly will be discussed further in depth in the next section of this report.

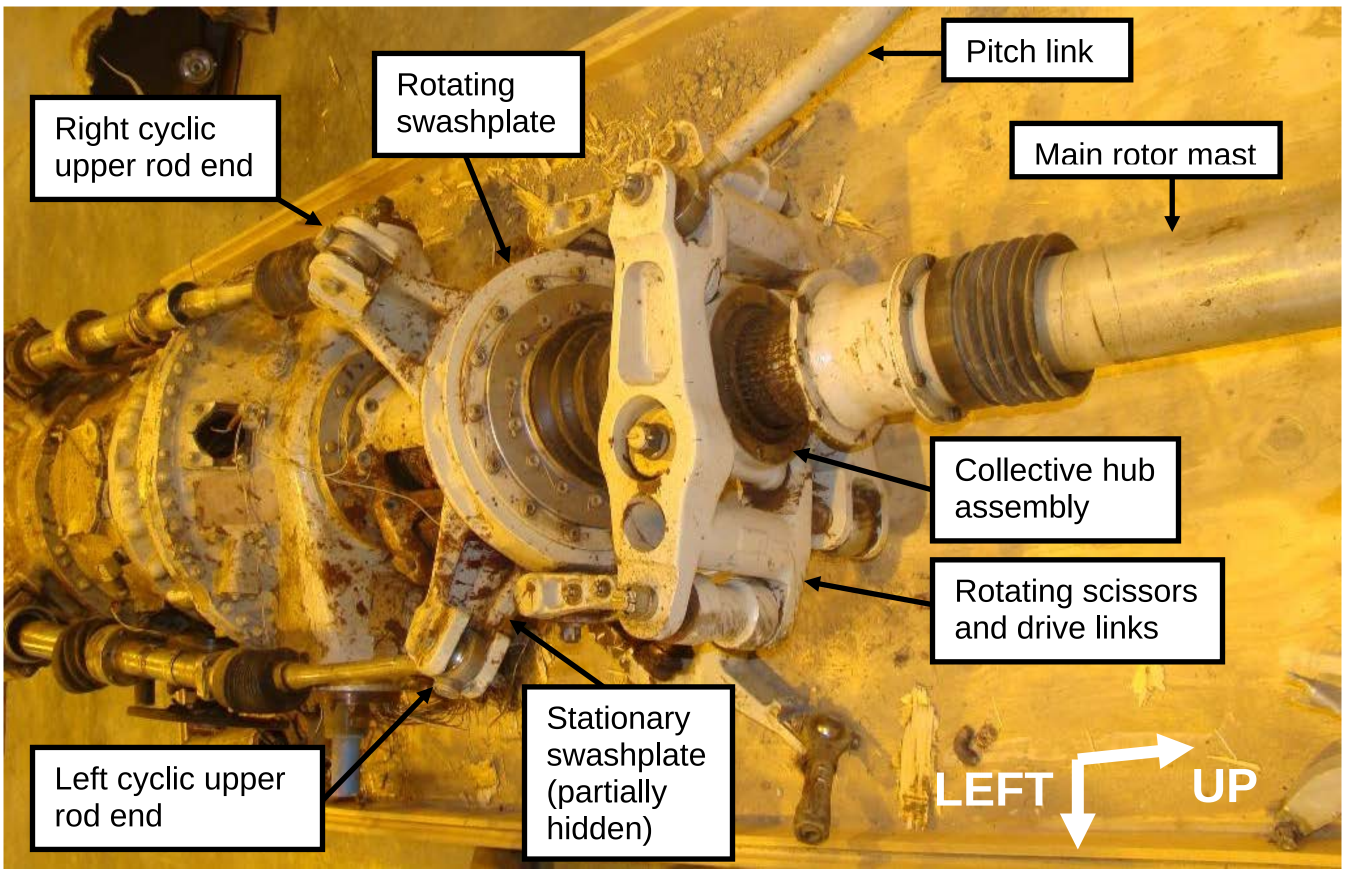

Photo 10. Upper end of the main transmission with rotating flight controls installed.

[6] The collective lever assembly is attached to the idler link and to the collective sleeve via a pinned connection, and uses the idler link as a pivot point for leverage when it actuates the collective sleeve up and down within the swashplate support assembly.

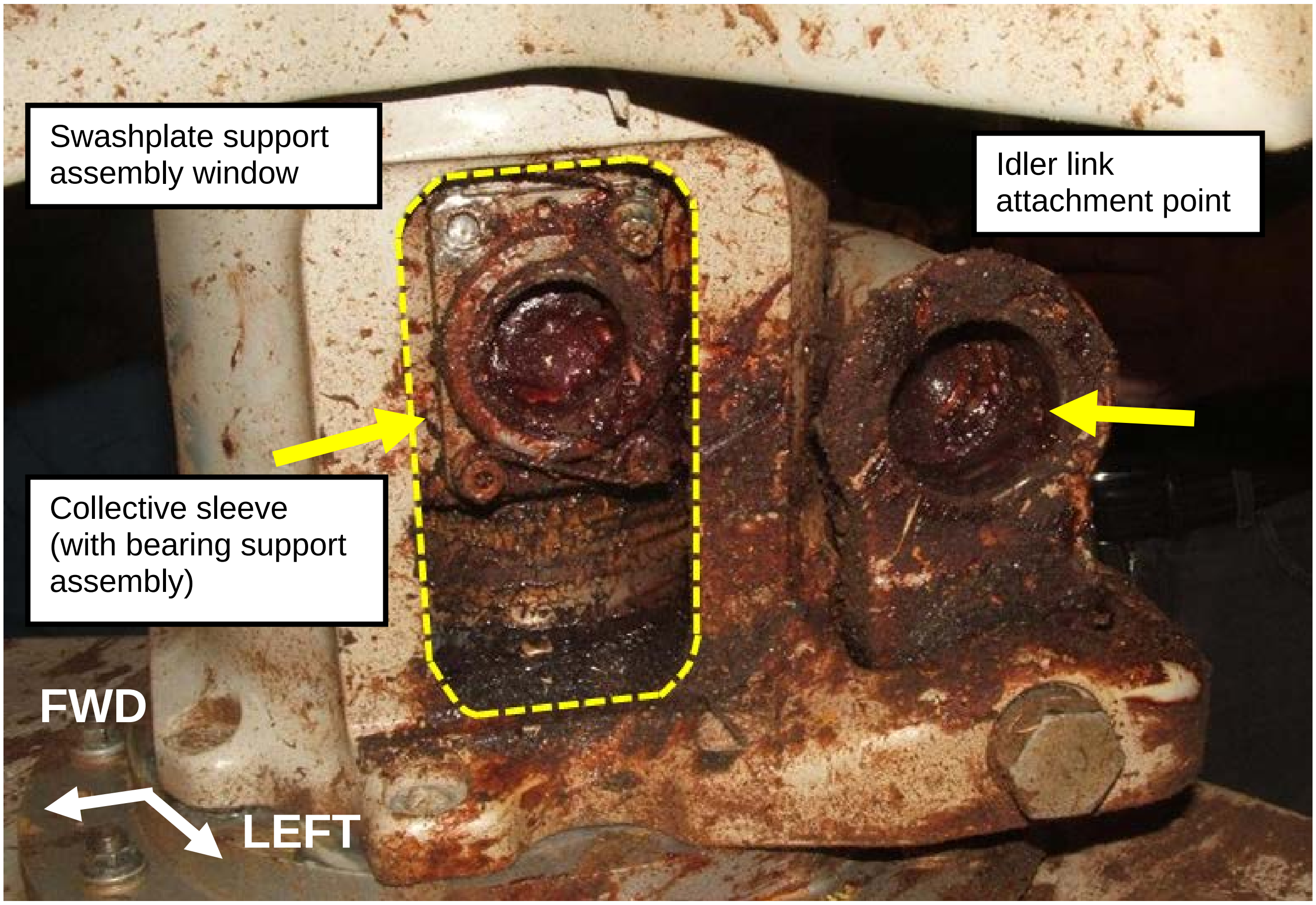

Photo 11. The collective sleeve (left arrow) and idler link (right arrow) attachment points for the collective lever (not seen). The swashplate support assembly window is marked by dashed lines.

The idler link was found to have two impact marks on the left and right sides of its outboard-facing edges in similar locations (**Photos 12 and 13 – yellow arrows**). The impact mark on the left side of the idler link was observed to be smaller than that of the right. According to BHT engineering, the impact marks on the idler link were consistent with an over-travel of the collective lever arm in the direction of an upward movement of the collective sleeve. The impact mark on the idler link's right side was matched to damage found on the recovered collective lever arm; thus the only recovered collective lever arm was identified as the right collective lever arm. The idler link bearings were not found installed within the link and were not recovered with the wreckage. On the swashplate support assembly, impact marks were seen on the upper edge of both sides of the window (**Photos 14 and 15**). These impact marks matched damage seen on the upper two of the four bolts used to secure the bearing assemblies on both sides of the collective sleeve; the damaged bolt heads exhibited a downward bend. On the left side bearing assembly, the upper left bolt head was discovered to have sheared off completely. According to BHT engineering, the impact marks observed on the upper edge of the swashplate support assembly window is consistent with an over-travel of the collective sleeve in the upward direction. Both left and right bearing assemblies on collective sleeve contained their respective bearings, with the right bearing assembly exhibiting significant deformation and damage while the left bearing assembly exhibited little damage.

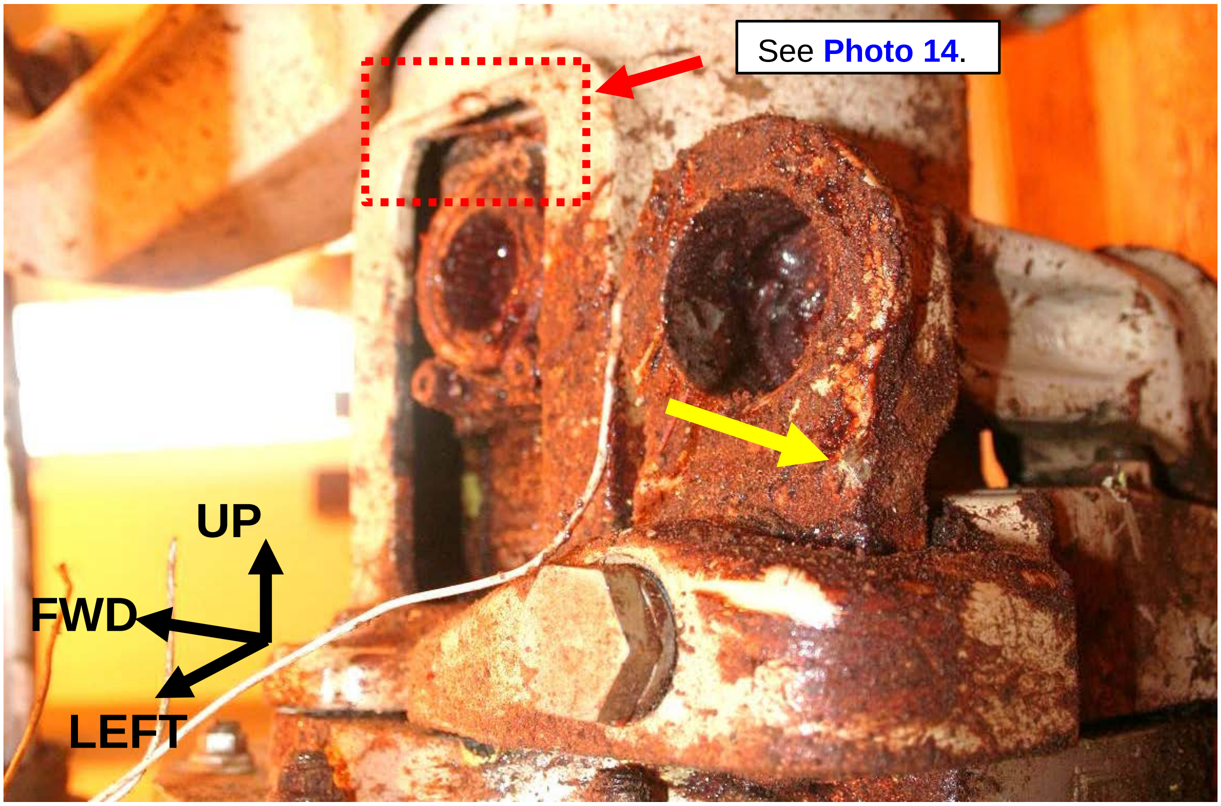

Photo 12. Impact mark on the left side of idler link (yellow arrow).

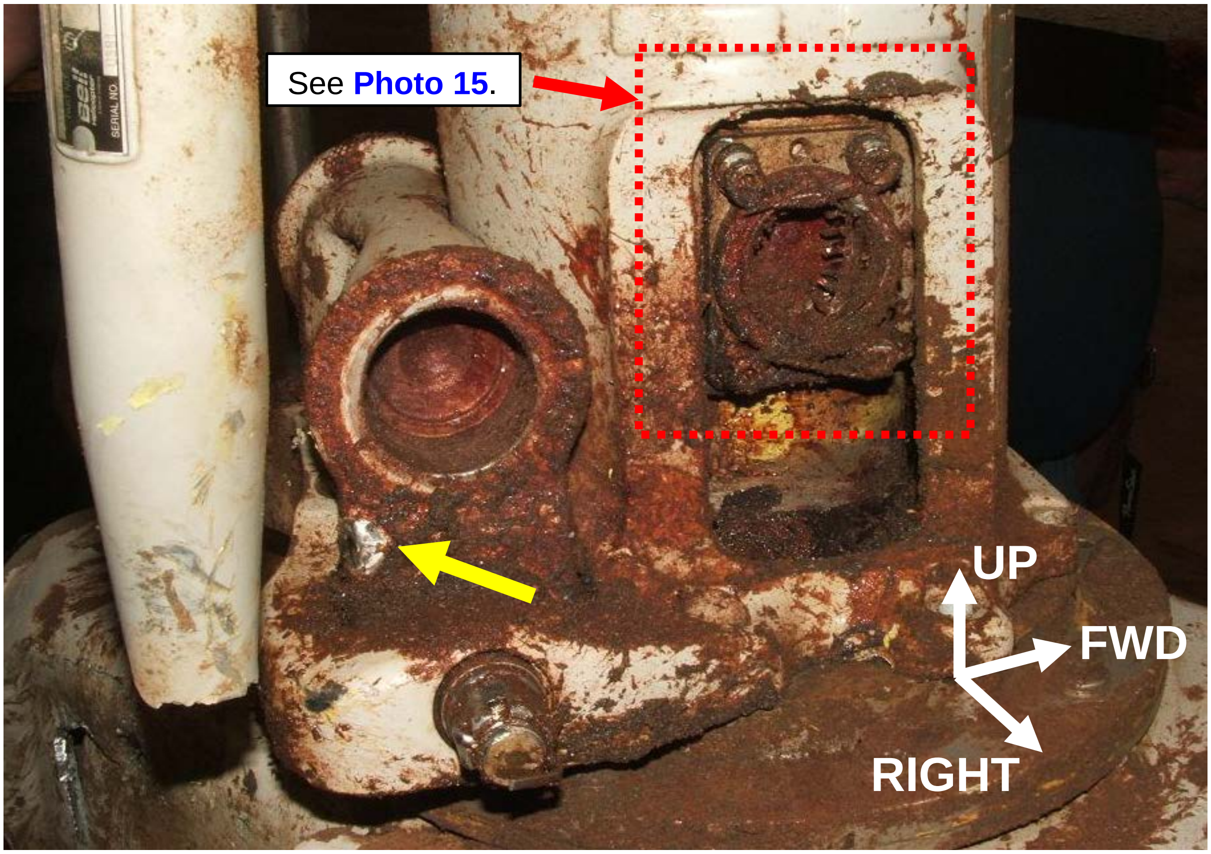

Photo 13. Impact mark on right side of idler link (yellow arrow).

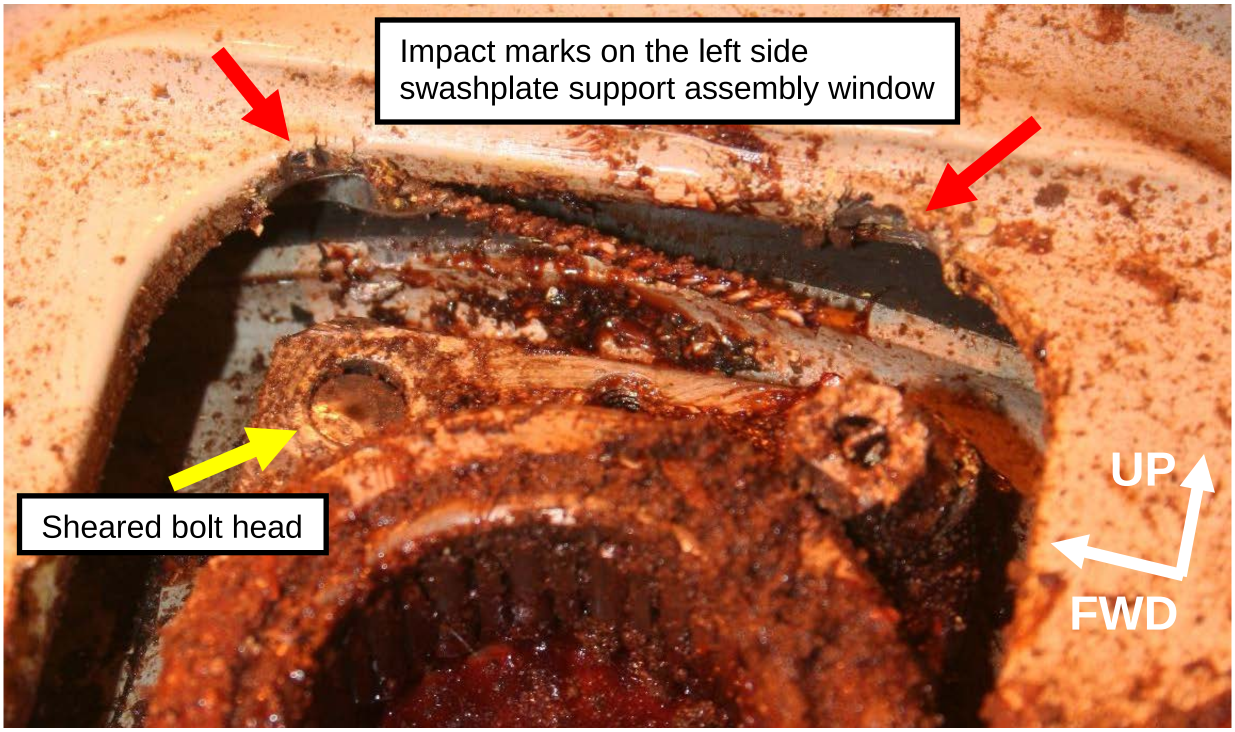

Photo 14. Impact marks (upper two arrows) and sheared bolt head (lower left arrow) on the left side of the swashplate support assembly window. A portion of the undamaged bearing is visible.

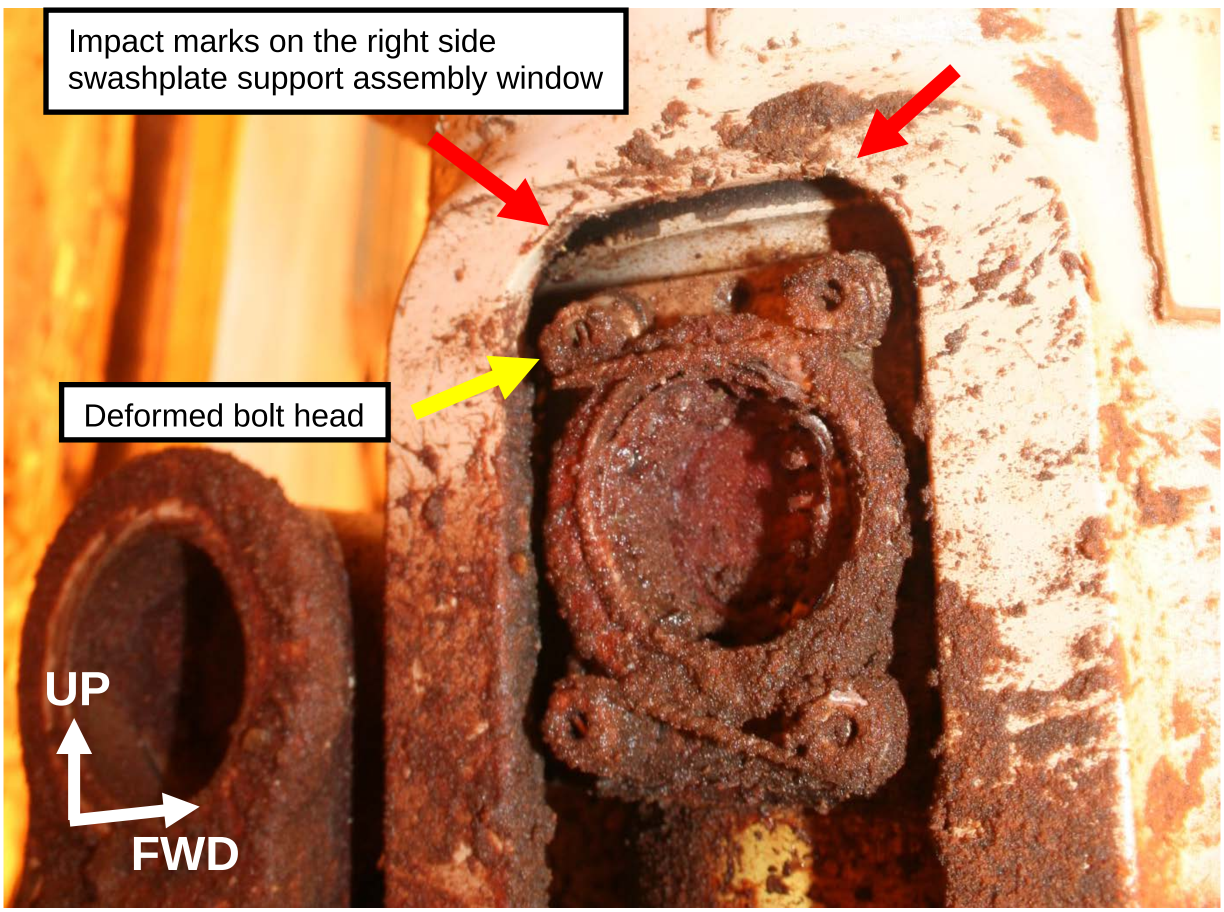

Photo 15. Impact marks (upper two arrows) of the bolts on the right side of the swashplate support assembly window. The damaged and deformed bearing is also visible.

3.1.4 COLLECTIVE LEVER

Figure 1 shows the collective lever and idler link installation to the swashplate support assembly. The collective lever assembly consists of two collective lever arms (**Figure 1, Index 1**) secured together with two sets of bolts, washers, and nuts (**Figure 1, Indices 2 thru 7**). Each lever arm contains two pins: one pin connects to the collective sleeve (**Figure 1, highlighted in yellow**) and a second pin connects to the idler link (**Figure 1, Index 13**). Bearings in both the collective sleeve and the idler link provide rotational support for the pinned connection, with the pins acting as the bearings' inner race. The collective hydraulic actuator output piston's upper rod end assembly is connected to the aft-outboard end of the collective lever assembly via a bolted connection (**Figure 2**). A collective lever installation from an exemplar Bell 214ST is seen in **Photo 16.**

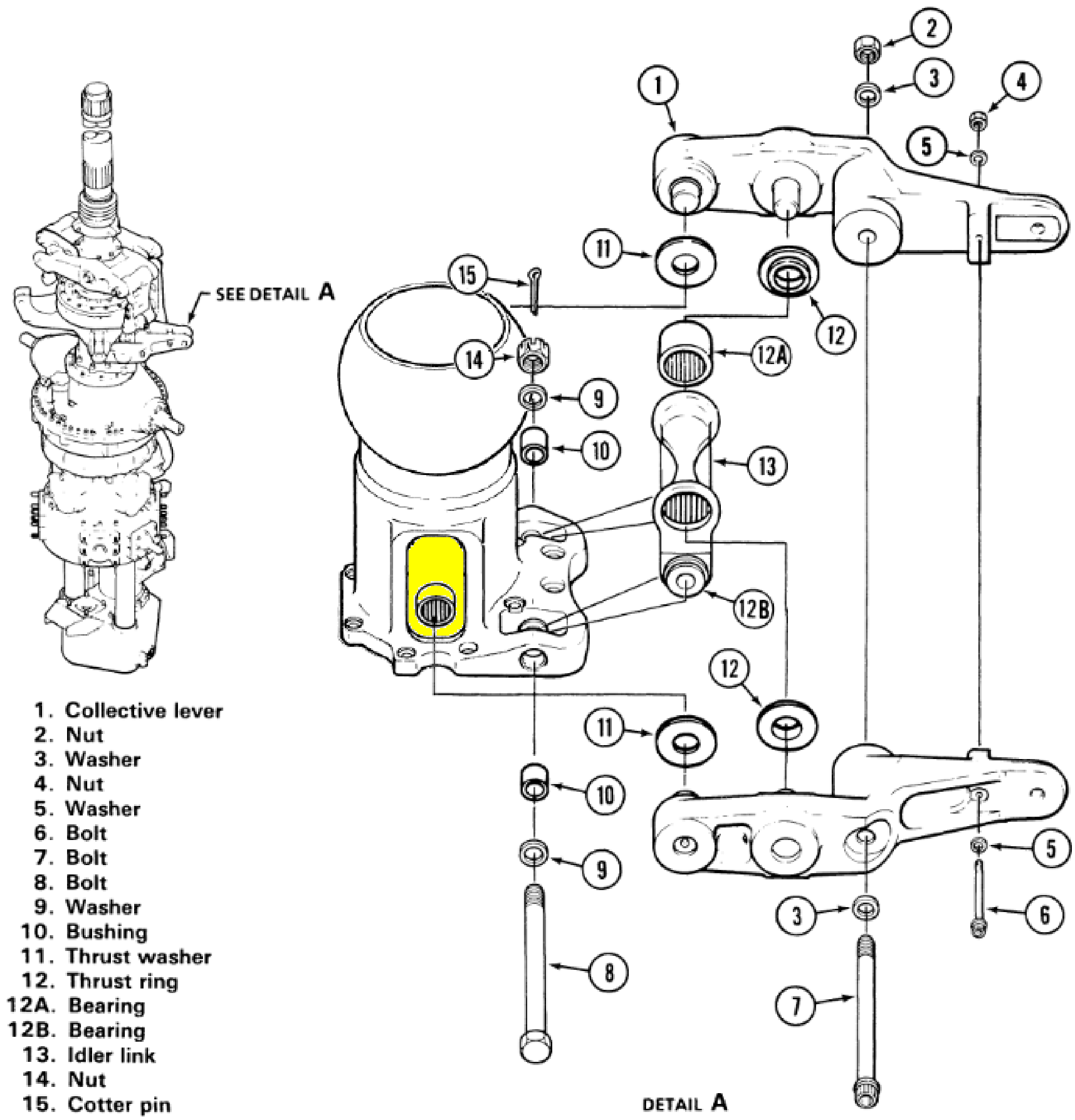

Figure 3. Collective lever installation. **[image courtesy of BHT]**

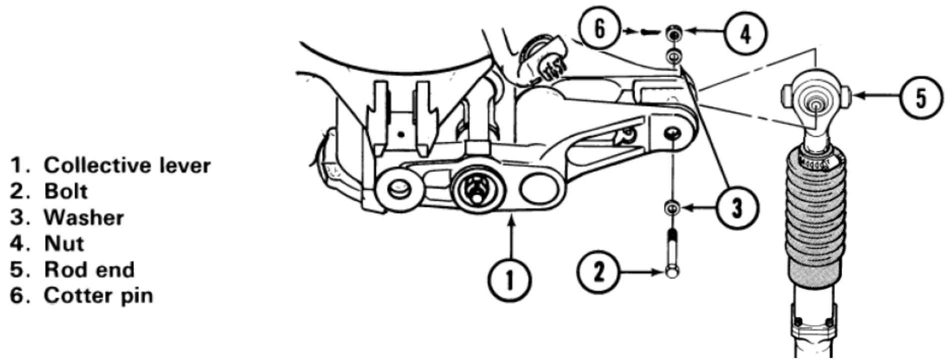

Figure 4. Collective hydraulic actuator output piston rod end installation. **[image courtesy of BHT]**

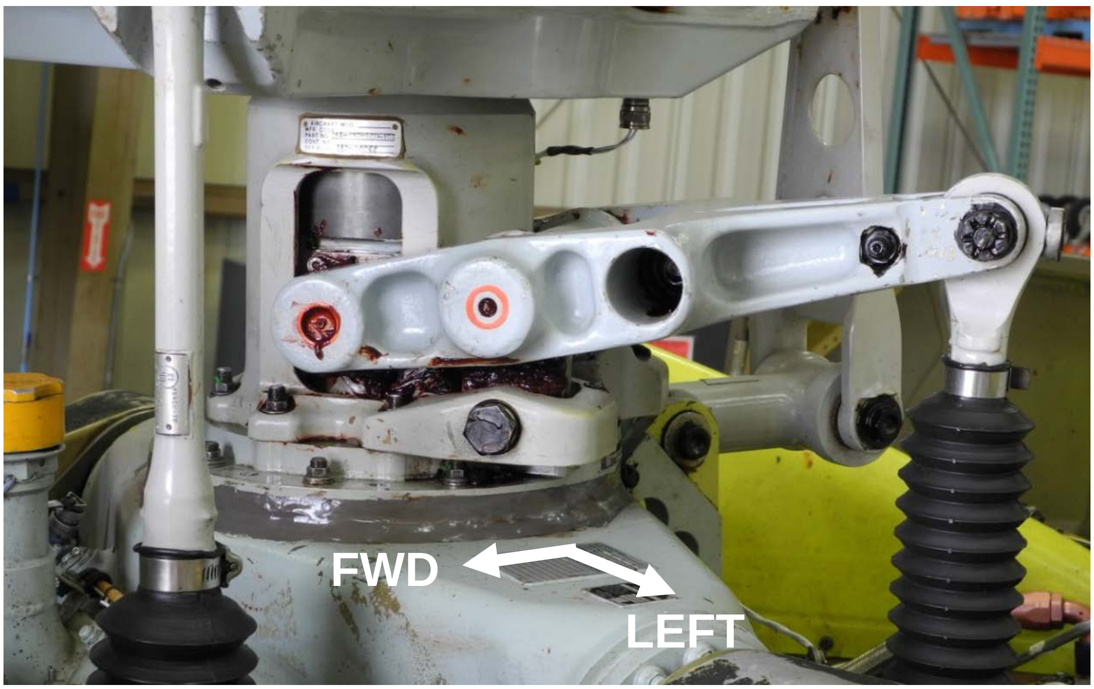

Photo 16. A collective lever installation from an exemplar Bell 214ST.

Photographs from the accident site showed the collective lever assembly was not attached when the wreckage was recovered and that only one collective lever arm was recovered and photographed at the accident site (**Photo 17**). The recovered collective lever arm was determined to be the right-side collective lever arm based on an impact mark matched to that of an impact mark on the right-side of the idler link (**Photo 18**). The left collective lever arm and the bolts and washers that secure the two lever arms together (**Figure 3, Indices 2 through 7**) were not recovered. The two mounting pins and the hydraulic actuator's upper rod end remained attached to the right collective lever arm. The bolt securing the upper rod end to the recovered lever arm (**Figure 4, Index 2**) had fractured; only the threaded end of the bolt, the castellated nut, the nut-side washer, and cotter pin (**Figure 4, Indices 3, 4, and 6**) remained installed.

The right collective lever arm, idler link, and collective sleeve bearing assemblies were retained by the NTSB for further examination at the NTSB materials laboratory in Washington, DC. The lab examination of the two bolt holes for the bolts that secure the two lever arms together found evidence of circumferential wear consistent with rubbing by the adjacent washer when the collective lever arms are joined, but found no indications of hole enlargement or longitudinal wear marks on the inside of bolt hole bores. The damage on the left side of the idler link was characterized as severe material smearing that mirrored damage found on the recovered collective lever arm. The fracture surfaces of the fractured rod end bolt exhibited signatures consistent with overstress failure. The left collective sleeve bearing possessed all of its rollers and was able to spin freely without binding. The right collective sleeve bearing cage was deformed and fractured, with 12 of 19 bearing roller elements missing. For complete details of the examination, see NTSB Materials Laboratory Report 13-031, dated July 17, 2013.

Photo 17. The collective lever arm in a photo taken at the accident site (left image [image courtesy of USTRANSCOM]) and the collective lever arm from the recovered wreckage (right image).

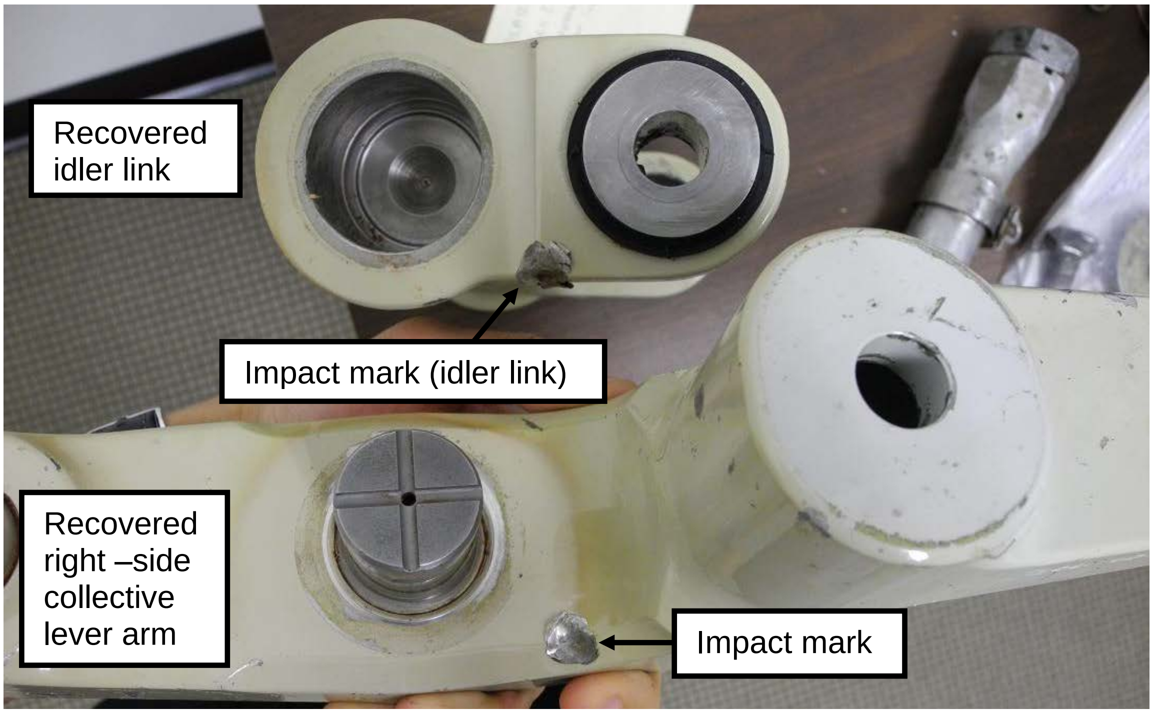

Photo 18. Impact marks matched between the right-side of the idler link and the received collective lever arm (both parts have been cleaned).

3.2 FLIGHT CONTROL SYSTEMS

3.2.1 SYSTEM DESCRIPTION

The main rotor flight controls consists of a system of control tubes, bell cranks, and hydraulic actuators that transfers cyclic and collective control stick inputs from the cockpit to the appropriate main rotor rotating controls. Control stick inputs are directly transferred to the SCAS assembly that is linked to the mixer, which serves as the mechanical interconnect to the hydraulic actuators.

The tail rotor directional and anti-torque control system consists of a system of control tubes, bell cranks, and a hydraulic actuator to transfer rudder pedals inputs from the cockpit to the tail rotor rotating controls. The tail rotor rotating controls collectively change the pitch of the tail rotor blades, thereby increasing or decreasing the amount of thrust (i.e. anti-torque reaction to counter main rotor torque) produced by the tail rotor system.

The tailboom FBW elevator system consists of a left and right elevator control surface attached to a common spar extending through the tailboom and two FBW electrical actuators located inside the tailboom to control the movement of the elevators.

3.2.2 CYCLIC AND COLLECTIVE CONTROL SYSTEMS

The right cyclic hydraulic actuator output piston's upper rod end assembly remained attached to the stationary swashplate. The output piston was continuous from the upper rod end down through its bearing housing assembly, but the lower output piston was bent. The recovered right cyclic hydraulic actuator unit was not attached to its respective output piston (**Photo 19**). The servo tube assembly, which attached the right cyclic hydraulic actuator to the right cyclic bellcrank, was fractured. A fractured rod end was found attached to the right hydraulic actuator and the rest of the servo tube assembly containing a portion of the threaded rod end remained attached to the right cyclic bellcrank. The observed fracture surfaces exhibited signatures consistent with overstress failure. Portions of the isolation tube and the tube assembly which connects to the mixing levers were found connected to the right cyclic bellcrank assembly. However, the bellcrank weight was not recovered. All connecting hardware remained installed on all recovered rod ends.

The left cyclic hydraulic actuator output piston's upper rod end assembly remained attached to the stationary swashplate. The output piston was continuous from the upper rod end down through its bearing housing assembly, but the lower output piston was bent. The recovered left cyclic hydraulic actuator unit was not attached to its respective output piston (**Photo 19**). The servo tube assembly, which attaches the left cyclic hydraulic actuator to the left cyclic bellcrank, was fractured. A fractured rod end was found attached to the left hydraulic actuator and the rest of the servo tube assembly was found connected to one lobe of the left cyclic bellcrank. However, the remainder of the left cyclic bellcrank assembly was not recovered. The observed fracture surfaces exhibited signatures consistent with overstress failure. All connecting hardware remained installed on all recovered rod ends.

The collective hydraulic actuator output piston's upper rod end assembly remained attached to the recovered right collective lever arm. The remainder of the output piston was continuous from the separated upper rod end down through its bearing housing assembly, but the lower and upper output pistons were bent. The recovered collective hydraulic actuator unit was not attached to its respective output piston (**Photo 19**). The collective torque tube assembly (also known as the collective lower bellcrank) was recovered in the wreckage. The majority of the control tube that connects the torque tube assembly to the collective hydraulic actuator remained attached to the torque tube assembly (**Photo 20**). The clevis end to the control tube that inputs load to the torque tube assembly and the attaching hardware for the engine load demand spindle (LDS) remained attached to the torque tube assembly. The isolation tube and retainer that connects the torque shaft to the main transmission sump case were also recovered in the wreckage (**Photo 20**). The lower bolt hole of the retainer was observed to be slightly elongated. The sump case end of the isolation tube had fractured and separated; observed fracture surfaces exhibited signatures consistent with overstress failure. The sump case mounting hardware remained intact (**Photo 21**). The torque shaft and the support bracket remained installed to its respective structural bulkhead (**Photo 22**). Both the torque shaft and support bracket and their respective attachment hardware exhibited evidence of fire damage consistent with exposure to the post-impact fire. The support bracket's attachment point to the torque shaft was bent upward with fractures seen in several locations. These fracture surfaces exhibited signatures consistent with overstress failure. The lower bolt hole of the support bracket was slightly elongated, mirroring that of the retainer's lower bolt hole.

The right cyclic, left cyclic, and collective hydraulic actuators and associated output piston were sent to BHT facilities in Fort Worth, TX for further examination. The findings from the examination at BHT will be discussed in section 5.1 of this report.

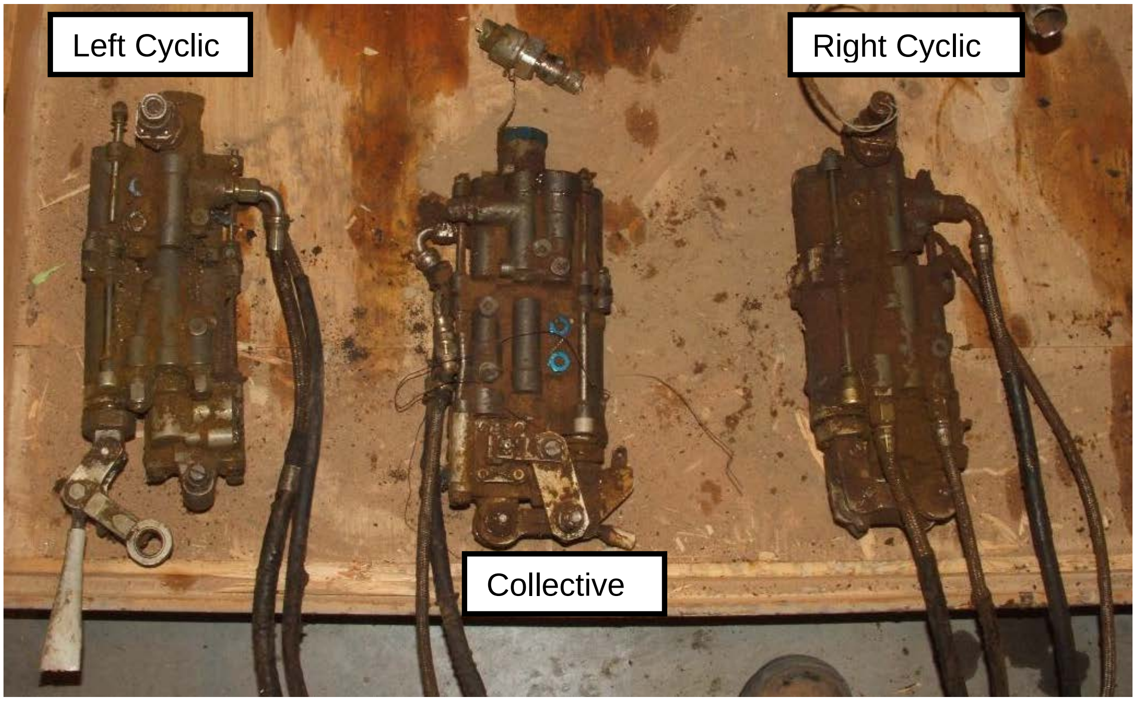

Photo 19. The left cyclic (left), collective (center), and right cyclic (right) hydraulic actuator units.

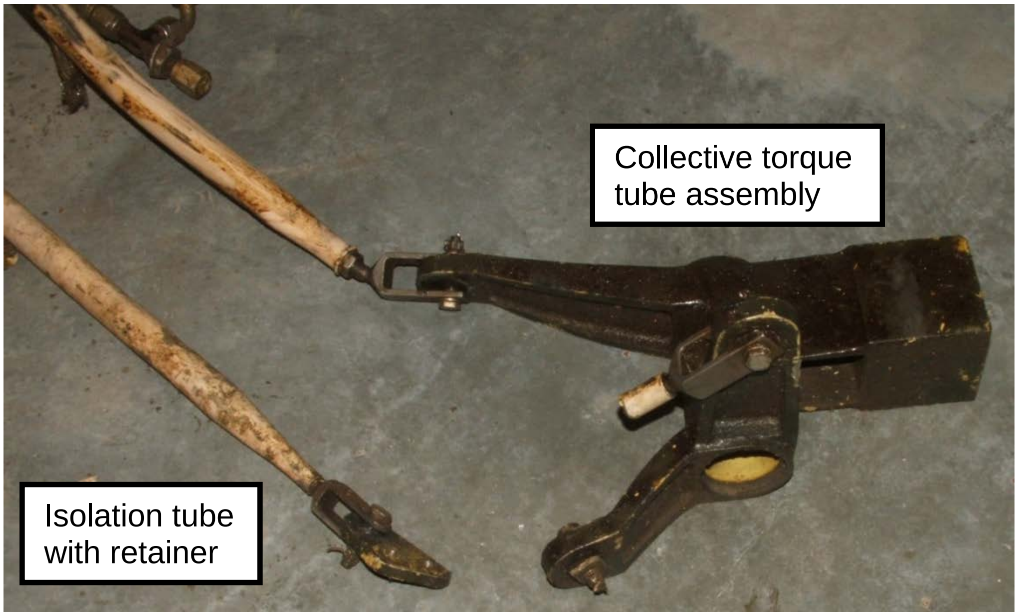

Photo 20. Collective torque tube assembly (right) and isolation tube with retainer (lower left).

Photo 21. Isolation tube mount and clevis connection on the main transmission sump case.

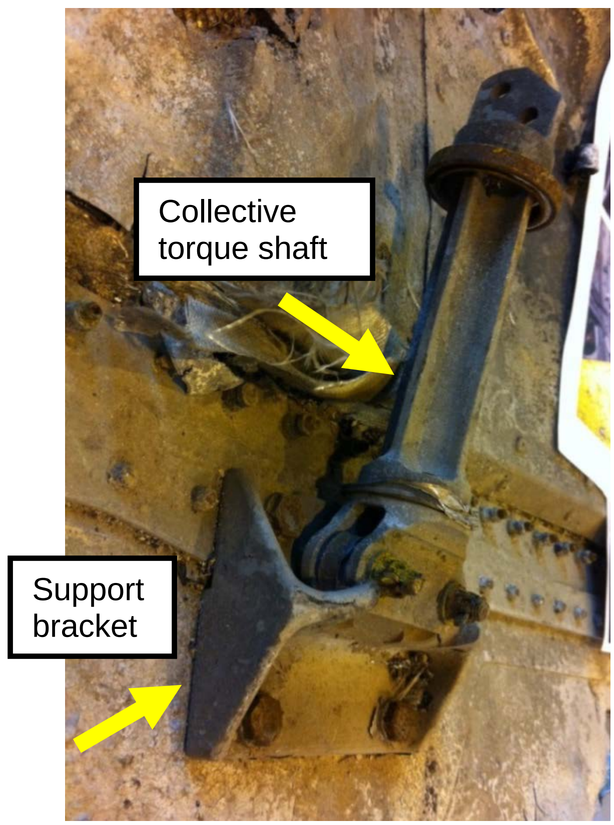

Photo 22. The collective torque shaft (upper arrow) and support bracket (lower arrow).

The SCAS pitch and roll actuator assemblies were recovered in the wreckage. It could not be determined which assembly was for pitch and which assembly was for roll. One SCAS assembly was mostly intact as recovered: the connecting rod between the drive and centering assembly and the walking beam was bent but intact with all attachment hardware in place (**Photo 23**). The clevis connection for the SCAS assembly's output control tube was found installed on the walking beam with the associated attachment hardware in place (**Photo 24**). The clevis connection for the SCAS assembly's input control tube was found attached to the SCAS idler (**Photo 24**). The other SCAS assembly was incomplete as recovered: the connecting rod between the drive and centering assembly and the walking beam was bent but intact with all attachment hardware in place (**Photo 25**). The clevis connection for the SCAS assembly's output control tube was attached to the walking beam with the associated attachment hardware in place (**Photo 26**). However, the idler had fractured and the section of the idler which was connected to the input control tube was not recovered. All fracture surfaces examined on both SCAS assemblies showed signatures of overstress failures with no evidence of fatigue fractures.

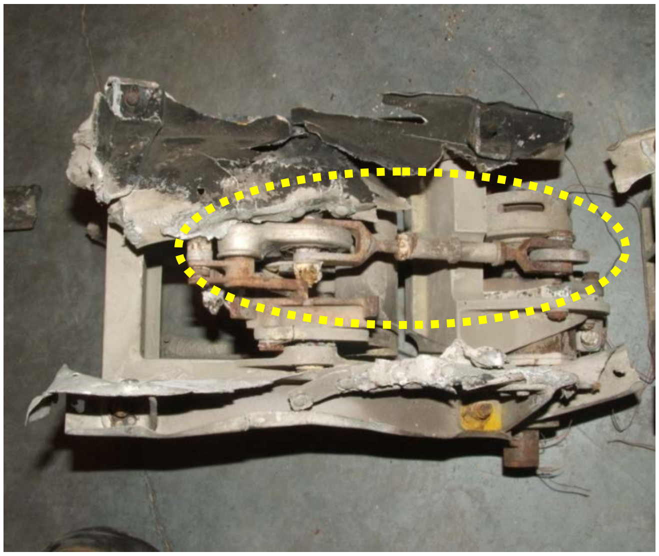

Photo 23. The connecting rod between the walking beam and the drive and centering assembly on the mostly intact SCAS assembly.

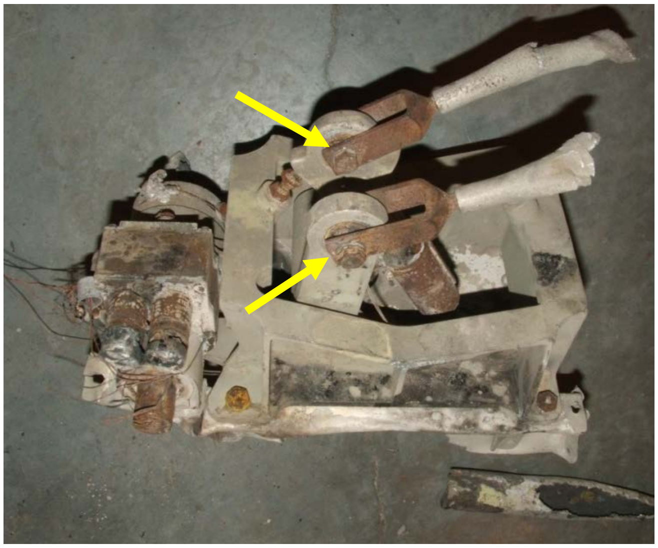

Photo 24. The clevis connections on the idler (lower arrow) and the walking beam (upper arrow) from the mostly intact SCAS assembly.

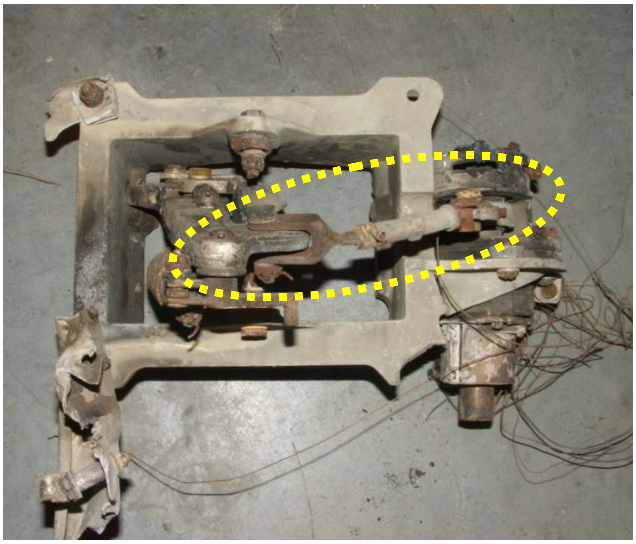

Photo 25. The connecting rod between the walking beam and the drive and centering assembly on the incomplete SCAS assembly.

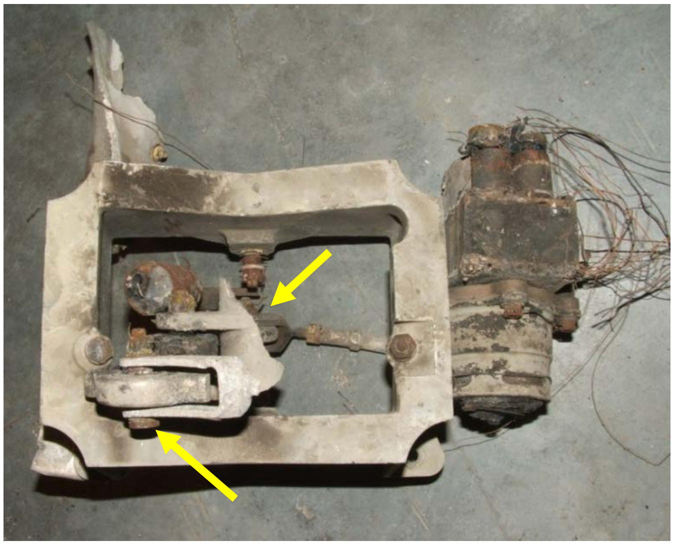

Photo 26. The clevis connection on the walking beam (lower arrow) from the incomplete SCAS assembly. The idler was observed to be fractured (upper arrow).

The mixing lever assembly components were not recovered. Five severed clevis connections and several pieces of a jackshaft were recovered within the wreckage but could not be matched to their respective assemblies. Due to impact damage and post-impact fire damage to the tube assemblies, continuity of the flight controls forward of the cyclic bellcranks and the collective torque tube assembly could not be established.

3.2.3 TAIL ROTOR DIRECTIONAL AND ANTI-TORQUE CONTROL SYSTEM

Continuity of the control tubes that provide tail rotor anti-torque and directional control could not be established due to breaks in the system and a loss of components due to exposure to the post-impact fire. The tail rotor pitch control system at the upper end of the vertical fin remained intact (**Photo 28**). This section of the pitch control system showed no evidence of binding and corresponding tail rotor pitch changes were manually performed using the pitch change links. The tail rotor pitch control hydraulic actuator was recovered intact but found loose in the wreckage debris. The hydraulic actuator's input and output rod ends and associated attachment hardware were attached and intact.

Photo 28. Tail rotor rotating flight controls.

3.2.4 TAILBOOM ELEVATORS

Both elevator flight control surfaces, both elevator electrical actuators, both elevator pitch horns, and the elevator spar were recovered from the accident site (**Photo 29**). The elevator spar had fractured at two locations, approximately 7 inches outboard to the left and right of the left elevator horn. A piece of the 'white' main rotor blade leading edge abrasion strip was found lodged in the left-side fracture of the elevator spar (**Photo 6**); the left elevator pitch horn and clamp was still attached to this spar section. The right elevator pitch horn was recovered in the wreckage debris and contained a portion of the rod end from the fractured elevator electrical actuator. All examined fracture surfaces exhibited signatures consistent with overstress failure. A section of the right elevator spar support with a stop fitting was retained for further examination at the NTSB materials laboratory in Washington, DC. The lab examination found evidence consistent with impact forces. For complete details of the lab findings, see NTSB Materials Laboratory Report 13-031, dated July 17, 2013.

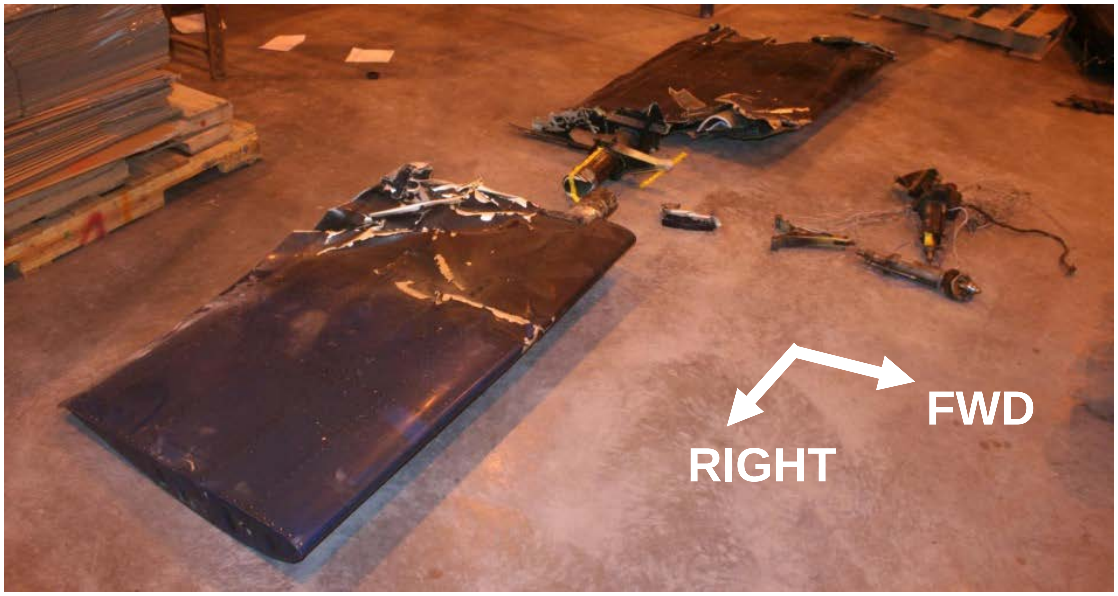

Photo 29. Recovered pieces of the elevator system.

The right elevator's inboard aft corner was significantly bent upward and outboard in a near-45° angle with impact damage consistent with a main rotor blade contact. The remainder of the right elevator's surfaces remained wholly intact. The majority of the left elevator's inboard and outboard ends were separated at almost a 45° angle with signatures consistent with main rotor blade contact. All examined fracture surfaces exhibited features consistent with overstress failures with no evidence of fatigue.

The left elevator electrical actuator was recovered mostly intact with only a fractured rod end (**Photo 30**). The right elevator electrical actuator was fractured and missing its control unit (linear transducer), servomotor, tailboom support mounting flanges, and elevator horn-side rod end. The left and right elevator electrical actuators were sent to BHT for further examination. The findings of this examination are located in section 5.2 of this report.

Photo 30. Left (top) and right (bottom) elevator electrical actuators.

3.3 TRANSMISSION SYSTEMS

3.3.1 SYSTEM DESCRIPTION

The two engines provide power to the combining gearbox, which in turn drives the main transmission. The combining gearbox contains two overrunning clutches, one for each engine power output shaft, as a means to prevent the main transmission from driving the engine. The combining gearbox also drives one of the two main hydraulic pumps as well as the utility hydraulic pump. The main transmission is roof-mounted via nodal beam support assemblies near the aft end of the main fuselage and contains a two-stage planetary gear system to reduce the main driveshaft input speed in order to drive the main rotor head. The main transmission also drives the tail rotor drive system as well as the second main hydraulic pump.

The tail rotor drive system is comprised of the tail rotor driveshafts, the intermediate gearbox, and the tail rotor gearbox. Tail rotor driveshafts no. 1 thru no. 5 are installed along the tailboom and connect the tail rotor output quill from the main transmission to the intermediate gearbox. Tail rotor driveshaft no. 6 is installed along the vertical fin between the intermediate and tail gearboxes. The intermediate gearbox is installed at the junction between the tailboom and the vertical fin and provides a change in the angle of drive between the two structures. The tail rotor gearbox, installed at the upper-aft end of the vertical fin, changes the angle of drive and also provides final drive for the tail rotor head. The cambered tail rotor blades are comprised of a stainless steel spar, which also forms the leading edge strip, and a core composed of an aluminum honeycomb covered by a stainless steel skin.

3.3.2 MAIN TRANSMISSION AND COMBINING GEARBOX

The main transmission assembly was recovered mostly whole from the transmission assembly's lower pylon restraint case up to the main rotor head. The tail rotor drive case, sump case, and both oil transfer tubes were not attached to the main transmission assembly (**Photo 31**). The lower pylon restraint case had both right and left transmission stops and all three hydraulic actuator output piston bearing housing assemblies[7] still attached. The main transmission's main bevel gear case had a circumferential fracture adjacent to the attaching point of the ring gear case to the main bevel gear case. The rotor brake quill assembly and the spiral bevel input pinion assembly remained installed in the main bevel gear case. The oil filler tube assembly had completely fractured from the top case. All observed fracture surfaces on the aforementioned components exhibited signatures consistent with overstress failure.

Both left and right transmission nodal beam support assemblies were recovered from the accident site. A portion of the transmission pylon was still attached to each nodal beam support, with the fracture surfaces on the remnant transmission pylon exhibiting signatures consistent with overstress failure. The spherical bearing in the left nodal beam in which the spindle is installed was observed to be biased in the aft direction, with a gouge seen in the bearing support in the aft direction (**Photo 32**). The

[7] The three output piston bearing housing assemblies that are mounted to the main transmission case are for the two cyclic hydraulic actuators and one collective hydraulic actuator.

right nodal beam spherical bearing still contained a fractured portion of the transmission mounting spindle (**Photo 33**). Examination of the right transmission mounting spindle still installed on the main transmission revealed the fracture surface to mirror that of the piece found in the right nodal beam (**Photo 34**). Both fracture surfaces exhibited signatures consistent with overstress failure. The retaining hardware for the right spindle was found in place in the right nodal beam. The left transmission mounting spindle remained installed and intact on the main transmission (**Photo 35**). The retaining hardware for the left spindle was located in the wreckage and retained by the NTSB for further examination at the NTSB materials laboratory in Washington, DC. Lab examination found the damage to the hardware was consistent with the bolt being pulled outward while the threads were still engaged. For complete details of the lab findings, see NTSB Materials Laboratory Report 13-031, dated July 17, 2013.

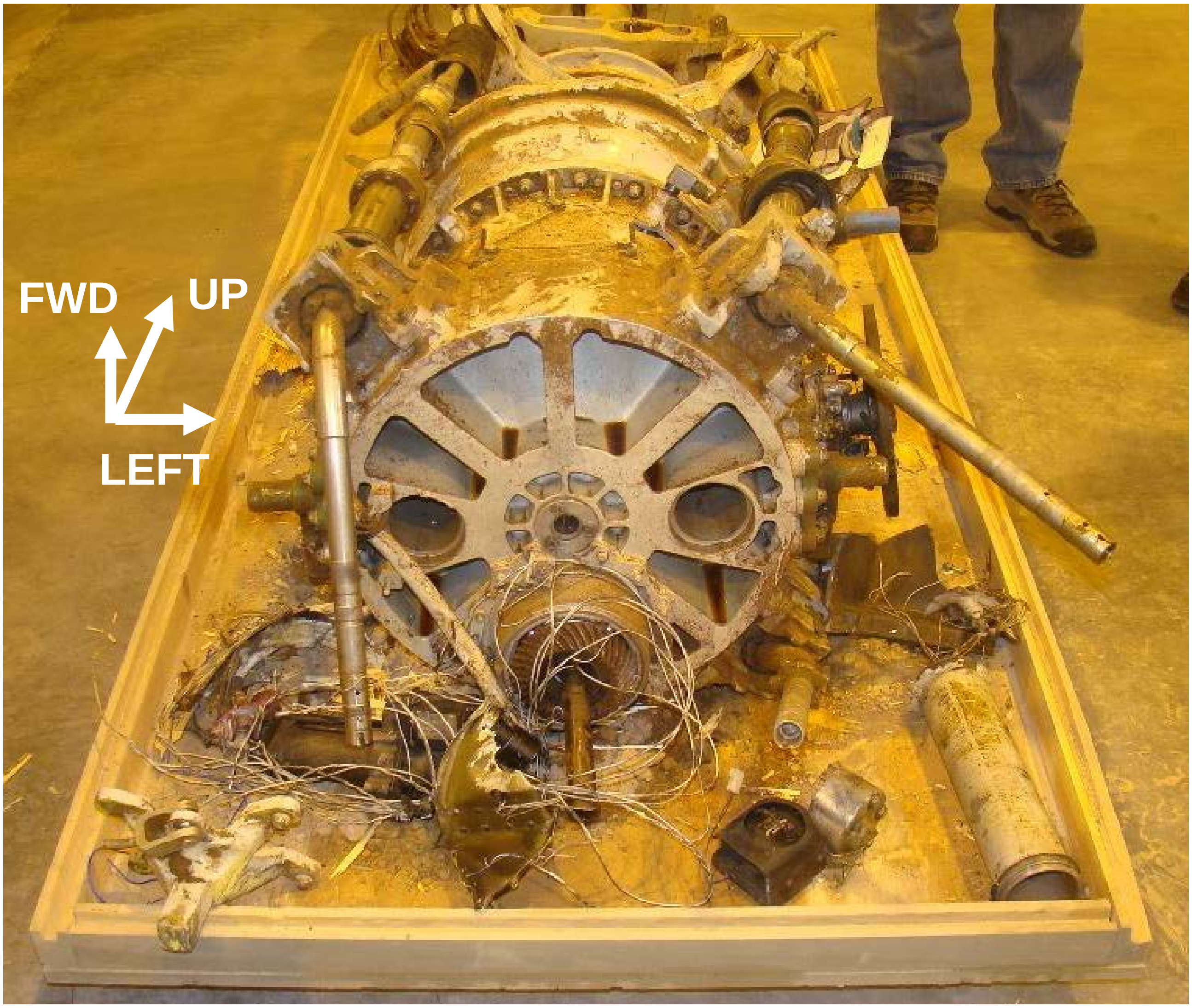

Photo 31. The recovered main transmission assembly looking upward from the lower pylon restraint case.

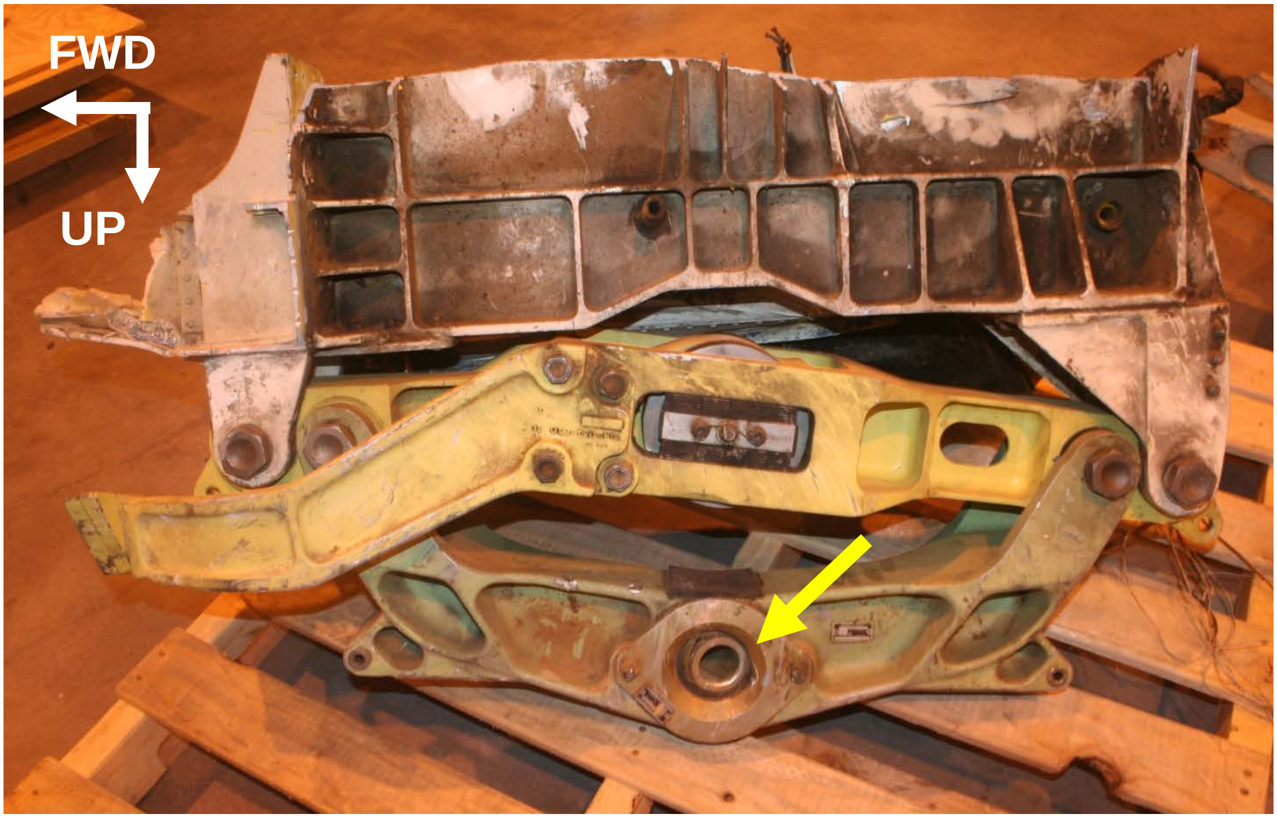

Photo 32. Left nodal beam support assembly for the main transmission. The arrow points to the spherical bearing with the aft-ward bias as recovered.

Photo 33. Right nodal beam support assembly for the main transmission. The arrow points to the fractured portion of the transmission mounting spindle found within the spherical bearing.

Photo 34. Right transmission mounting spindle.

Photo 35. Left transmission mounting spindle.

3.3.3 TAIL ROTOR SYSTEM

The intermediate and tail rotor gearboxes were found intact and still attached on the severed aft tailboom and vertical fin section. Continuity of drive was established through both the intermediate and tail rotor gearboxes. Continuity of tail rotor drive could not be established forward of the intermediate gearbox due to breaks in the drive system in the tailboom. However, all flexible couplings between driveshafts in the tailboom section were recovered. The flexible coupling that remained attached to the intermediate gearbox input flange exhibited a slight serpentine deformation with the coupling laminates opening up between bolted connections (**Photo 36**). A separated tail rotor driveshaft section exhibited curling in the shape of the main rotor blade leading edge (**Photo 37**). All examined fracture surfaces exhibited signatures consistent with overstress failure.

The majority of the tail rotor hub and blades remained intact and attached to the tail rotor gearbox (**Photo 38**). Blade no. 1[8] was bent about its chord approximately 10 inches from where the blade attaches to the plate assembly. Blade no. 2 was partially fractured along the chordwise direction approximately 10 inches from where the blade attaches to the plate assembly. The fracture extended forward approximately 11 inches from the trailing edge.

[8] The tail rotor blades were not previously labeled like the main rotor blades. The Airworthiness Group labeled the blades during the examination for the purposes of this investigation.

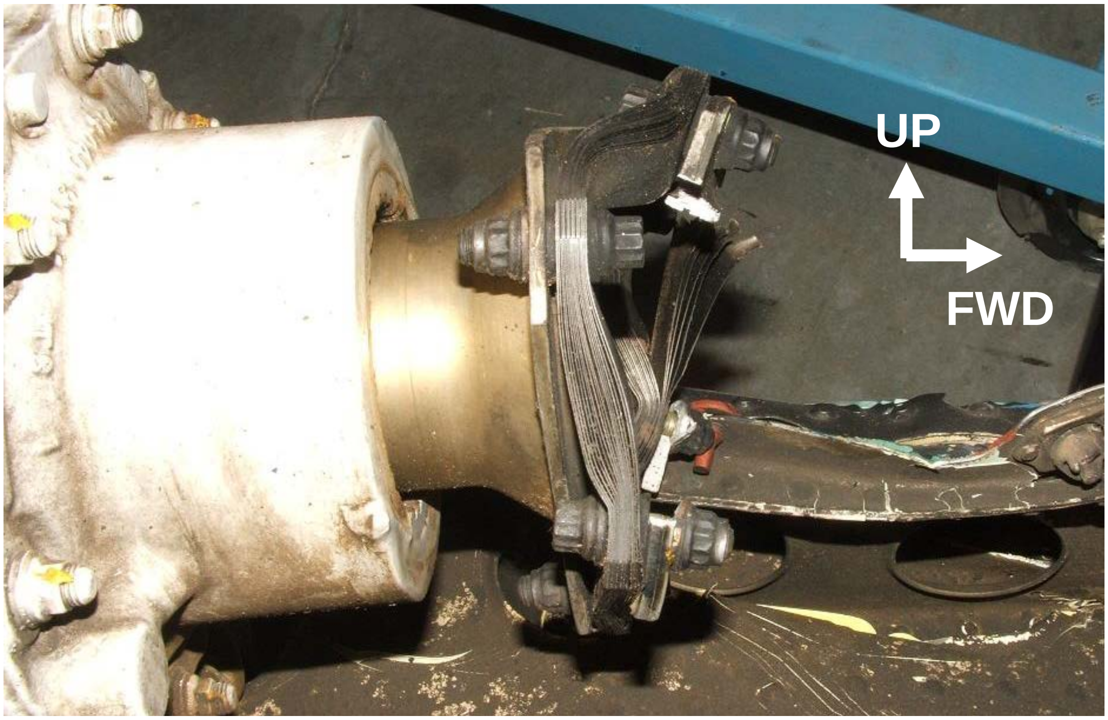

Photo 36. Intermediate gearbox flexible coupling.

Photo 37. A severed section of tail rotor drive shaft.

Photo 38. Tail rotor gearbox with tail rotor blades installed.

3.4 AIRFRAME AND STRUCTURES

3.4.1 DESCRIPTION

The primary structure of the helicopter consists of the main fuselage and the tailboom. The main fuselage is comprised of the cockpit, the passenger cabin, the baggage compartments, transmission and engine mounting compartments, and the fuel tank. The tailboom supports the tail rotor drive system, the elevators, and the vertical fin. The tailboom is attached to the main fuselage via four attachment fittings (also known as "bathtub fittings") located on the upper-left, upper-right, lower-left, and lower-right corners of the tailboom cross-section. The accident helicopter had skid landing gears installed to its main fuselage.

3.4.2 COCKPIT AND CABIN

The vast majority of the main fuselage was substantially damaged or destroyed during impact and due to exposure to the post-impact fire. Many pieces of resolidified molten aluminum were found within the recovered wreckage. Broken pieces of fairings in a variety of sizes, fragmented Plexiglas from windows, plastic interior cabin panels, and fragments of the main fuselage airframe and sections of the landing skids were found within the recovered wreckage.

3.4.3 TAILBOOM AND VERTICAL FIN

A large forward section of the tailboom, beginning at the interface with the main fuselage and measuring approximately 15 feet long by 4 feet wide, was recovered from the accident site (**Photo 39**). Beginning from the forward end, the first 4 feet of this tailboom section was a complete barrel section comprised of the left, right, upper, and lower skin panels, where the left and right skin panels were crushed flat onto one another. The remaining 11 feet of this tailboom section was comprised only of the right and upper skin panels and was crushed. Sections of the tail rotor drive system, the tail rotor flight control linkages, and the elevator mounting points were found within this tailboom section. The helicopter's registration number, "N5748M", was seen painted on the right skin panel on this tailboom section. A skin panel matching the left side of this tailboom section was recovered; it measured approximately 8 feet long by 3 feet wide. This skin panel had the marking "48M" and had forward-to-aft scuff marks and scratches in a 45° direction. Examination of the various fracture surfaces on both the tailboom and the matching skin panel revealed no evidence of fatigue fractures, but contained features consistent with overstress failure and crushing consistent with ground impact forces. Additional information of the tailboom can be found in section 7.0 of this report.

The aft end of the tailboom, containing the vertical fin, was recovered with the intermediate gearbox, the no. 6 tail driveshaft, the tail rotor gearbox, and the tail rotor assembly still installed. The left skin panel adjacent to the fractured area exhibited patches of transferred red paint and the fracture exhibited a left-to-right directionality and characteristics consistent with a main rotor blade strike (**Photo 40**). Examination of the fracture surfaces revealed signatures consistent with overstress failure.

Photo 39. The recovered forward tailboom section (left-side outer skin is visible).

Photo 40. Forward section of the severed tailboom and vertical fin.

3.5 ENGINES

3.5.1 DESCRIPTION

The GE CT7-2A turboshaft engine contains a 6-stage compressor (5-stage axial, 1-stage centrifugal), an annular combustor, a 2-stage gas generator turbine, and a 2-stage power turbine. Torque is transferred through a power output shaft from each engine to the combining gearbox.

3.5.2 EXAMINATION

The engine installed in the no. 1 (left) position, engine serial number (ESN) 343085, had accumulated 9,442 hours time since new (TSN). The engine installed in the no. 2 (right) position, ESN 343053, had accumulated 5,503 hours TSN.

Both engines were recovered from the accident site and had sustained severe fire damage, particularly to the mainframe, electronic control unit (ECU), and accessory gearbox (AGB), all of which are located on the forward end of the engine (**Photo 41**). The no. 1 engine exhibited significant impact damage to the swirl frame at the front of the engine and the turbine casing and exhaust frame at the aft of the engine. Both engines had separated where the mainframe aft flange mates with the compressor casting forward flange, allowing visual inspection of the compressor. Additionally, some of the blisks[9] were found loose in the wreckage debris. The blades of both engines' stage 1 blisks exhibited damage in the form of large nicks, cuts, and tip bending in the direction opposite of normal rotation. The blades of both engines' stage 2 blisks were all separated at their root; these blades were not recovered from the accident site. The majority of the remaining blades of both engines' stage 3 and 4 blisks were bent over in the direction opposite of normal rotation. Many of the remaining compressor stator vanes in both engines were observed to be bent over in the direction of normal rotation. Of the stage 4 power turbine blades that were visible in both engines, all observed blades were separated at the blade root; these blades were not recovered from the accident site. The hydromechanical [fuel control] unit (HMU) of each engine had separated from the AGB, and the variable geometry (VG) actuation system that connects the HMU to the variable compressor stator vanes was destroyed.

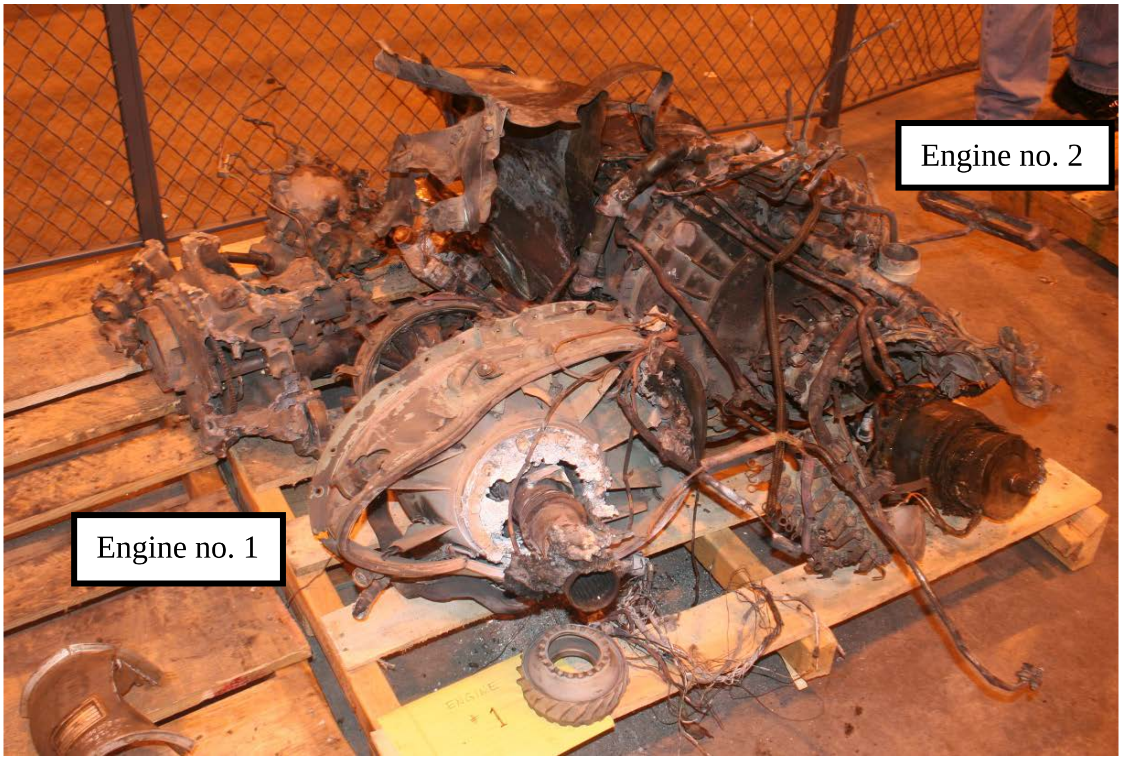

Photo 41. Components from both engines recovered from the accident site.

[9] A blisk is a one-piece bladed disk.

4.0 MAINTENANCE RECORDS

The operator provided the Airworthiness Group Chairman with maintenance records that showed that unscheduled and non-routine maintenance actions were performed the day prior to the accident on January 15, 2012. The unscheduled work consisted of replacement of the pilot-side door upper latch assembly (work order no. 113986, task no. 3) and replacement of the collective flight control system's torque shaft support bracket (work order no. 113986, task no. 4); see **Photo 22** for the collective system's support bracket found in the recovered wreckage. The non-routine work record stated collective system's torque shaft support bracket was replaced due to wear beyond limits of the support bracket bearings; however, there was no information as to the circumstances that led to the discovery of the worn support bracket bearings. The parts control tag for the replacement support bracket stated the part was new; however, the parts control tag stated that it was installed on aircraft registration number N3897N instead of the accident helicopter. The non-routine work record stated that the helicopter was released for functional check flight (FCF) purposes due to the replacement of the support bracket, but noted that no flight control adjustments were made. Attachment 1 contains the non-routine work record and associated task cards for the maintenance actions performed on January 15, 2012. Attachment 2 contains the parts control tag for the replacement collective torque shaft support bracket installed on January 15, 2012. The non-routine work record and the parts control tag for the replacement collective system's support bracket referenced flight logbook sheet no. 023378. Flight logbook sheet no. 023378 contained no entries related to the collective system's support bracket. Attachment 3 contains flight logbook sheet no. 023378.

Section 3-01 of the AAR Airlift General Maintenance Manual (GMM), dated June 21, 2011, provided procedures for documenting unscheduled, non-routine work. The procedure stated that any discovered discrepancies may be recorded on the maintenance task card, the flight logbook, or a non-routine work record. Additionally, the discovered discrepancy should be either manually written or entered into the maintenance computer system. Attachment 4 contains the AAR Airlift GMM procedures for documenting unscheduled, non-routine work. The operator uses WinAir Enterprise software for their maintenance tracking system. According to the operator, maintenance task no. 3 and no. 4 for work order no. 113986, consisting of the collective torque shaft support bracket replacement and the collective torque shaft support bracket replacement, respectively, were not labeled as completed within the WinAir system since all maintenance records, including the maintenance computer system task cards, were under lockdown immediately after the accident occurred. While these two maintenance tasks were left as incomplete within the maintenance computer system, the corrective actions for the two tasks were signed as completed in a non-routine work record (see item no. 1 and no. 2 in Attachment 1).

Other unscheduled work performed prior to the accident included the replacement of the transmission oil pressure indicator on January 7, 2012 (work order no. 113986, task no. 1) and the replacement of the left elevator spar support bearing on January 9, 2012 (work order no. 113986, task no. 2). Attachment 5 contains the work order no. 113986 task cards no. 1 and 2. Flight logbook sheet no. 0233720 and no. 023372 contains entries related to work order no. 113986 task no. 1 and 2, respectively. Attachment 6 contains flight logbook sheet no. 023370 and no. 023372. Scheduled work performed on January 9, 2012 consisted of a 25-hour/7-day airframe inspection (A inspection), a 25-hour lubrication, a 25-hour left and right engine inspection (B inspection), and complying with Airworthiness Directives (AD) 87-11-06 and 99-04-13. The flight times accumulated following the maintenance actions performed on January 7, 2012 and January 9, 2012 until the accident flight were 23.0 hours and 17.8 hours, respectively.

According to the operator's maintenance records, the tailboom was installed on February 20, 2007 at ATT 10,455.5 flight hours and was last removed for a 12 month/1,000 hour inspection on March 11, 2011 at ATT 11,538.2 flight hours. The collective lever assembly was last replaced, as part of its next higher assembly, on June 15, 2011 at ATT 11,807 flight hours. Because it was replaced as part of its next higher assembly, the operator stated the collective lever was not disassembled and the two collective lever arms remained installed (i.e. the attaching hardware securing the two collective lever arms were not removed) during the last replacement.

The helicopter's last recorded weight and balance occurred on April 5, 2010 with a net weight of 10,445.1 pounds. Attachment 7 contains a copy of the helicopter's last recorded weight and balance.

5.0 ACTUATOR EXAMINATION AT BHT

The right cyclic, left cyclic, and collective hydraulic actuators and the left and right elevator electrical actuator were sent to BHT facilities in Fort Worth, TX for further examination. During the week of October 29, 2012, BHT performed the examination and teardown of the actuators with oversight from the FAA Rotorcraft Directorate.

5.1 HYDRAULIC SYSTEMS

Disassembly of the right cyclic hydraulic actuator manifold revealed no discrepancies of its internal components. Examination and disassembly of the output piston revealed a bearing housing retainer mount with multiple fractures, with the fracture surfaces exhibiting signatures consistent with overstress failure. The working surfaces of the lower and upper output pistons exhibited wear typically seen due to time in service. Examination of the remainder of the damage observed on the output piston and actuator was consistent with impact damage.

Disassembly of the left cyclic hydraulic actuator manifold revealed the servo spools had fractured with signatures consistent with overstress failure; the remainder of the internal components revealed no discrepancies. Examination and disassembly of the output piston revealed the lower outer cylinder had fractured, with the fracture surfaces exhibiting signatures consistent with overstress failure. The working surfaces of the lower and upper output pistons exhibited wear typically seen due to time in service. Examination of the remainder of the damage observed on the output piston and actuator was consistent with impact damage.

Disassembly of the collective hydraulic actuator manifold revealed no discrepancies of its internal components. A fracture was observed on the bearing housing retainer mount, with the fracture surfaces exhibiting signatures consistent with overstress failure. The lower piston was bent about 14.7 inches from the bearing housing. The upper piston exhibited a fracture about 1.2 inches from the upper rod end's lower jam nut; the fracture surface revealed signatures consistent with overstress failure. Examination of the remainder of the damage observed on the output piston and actuator was consistent with impact damage.

5.2 ELEVATOR ELECTRICAL ACTUATORS

For the left elevator electrical actuator, measurements were taken of the position of the ball screw shaft and the shaft from the transducer. A review of the measurements by BHT engineering concluded the elevator actuator appeared to be at about mid-stroke, putting the elevators at about mid-travel. The left elevator electrical actuator ball screw assembly and the gear and motor shaft remained engaged. With the motor removed, the gear was moved manually and the ball screw assembly responded appropriately. The servomotor could not be functionally tested due to an open wiring circuit. Three of the wires were observed to be sticking out from their insulation, with one wire exhibiting a break and only being held together by its insulation. The linear transducer was tested but one of its wires exhibited no continuity. The discontinuous wire was cut down to restore wire continuity. Subsequent testing of the linear transducer revealed the transducer had an appropriate voltage versus position curve as the shaft from the transducer was moved through its travel range. No abrupt drop in voltage reading was observed in the testing of the linear transducer.

The fracture surfaces of the right elevator electrical actuator exhibited signatures consistent with overstress failure. The right elevator electrical actuator's ball screw assembly was no longer held in place and could be moved inside its housing. The right elevator electrical actuator was sent to BHT facilities in Fort Worth, TX for further examination, but no additional information could be gathered from the recovered components.

6.0 MATH MODEL SIMULATION OF A SUDDEN AND SEVERE COLLECTIVE PITCH REDUCTION

On September 9, 2013, the Airworthiness Group convened at BHT to discuss the findings of the investigation. Based on the finding that one half of the collective lever arm was never recovered and of the asymmetric damage found on the idler link and collective sleeve bearings, the Airworthiness Group Chairman requested BHT to run a math model simulation for a Bell 214ST to predict the helicopter's response to a scenario analogous to a severe and sudden reduction of collective pitch. Preliminary results of a math model simulating a failure of the collective control system resulted in helicopter responding with a severe right roll and nose-down pitch. Furthermore, the main rotor hub contacted the teeter stops immediately after failure of the collective control system and the main rotor blade tips deflected downward and nearly lost clearance with the tailboom.[10] At the time of this report, BHT is working on additional simulations.

7.0 TAILBOOM EXAMINATION

Members of the Airworthiness Group convened at the NTSB Training Center on September 30, 2013 to re-examine the tailboom wreckage. The focus of the examination was to verify the damage to the tailboom attachment fittings. Of the four tailboom attachment fittings, three (upper-right, lower-left, and lower-right) remained attached to the tailboom and were fractured forward of the attachment point (**Photo 42**). The three attachment fittings still contained their respective attaching hardware. The fourth

[10] A loss of clearance between the main rotor blade tips and the tailboom would result in the main rotor blades contacting the tailboom.

(upper-left) attachment fitting had fractured aft of the attachment point. All examined fitting fracture surfaces exhibited features consistent with failure from overstress.

Photo 42. Three of the four tailboom attachment fittings with attaching hardware present (yellow arrows) and the fractured fourth attachment point (red circle).

Submitted By:
Chihoon Shin
Aerospace Engineer – Helicopters