



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

April 26, 2017

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: DCA16FA199

A. ACCIDENT

Operator: Bell Helicopter Textron Incorporated
Aircraft: Bell Helicopter 525, Registration N525TA
Location: Italy, Texas
Date: July 6, 2016
Time: 1148 central daylight time

B. AIRWORTHINESS GROUP

| | |
|-----------------|--|
| Group Chairman: | Chihoon Shin National Transportation Safety Board Washington, District of Columbia |
| Member: | Greg Borsari National Transportation Safety Board Washington, District of Columbia |
| Member: | Josh Lindberg National Transportation Safety Board Dallas, Texas |
| Member: | Michael Hemann Federal Aviation Administration Fort Worth, Texas |
| Member: | Gary Howe Bell Helicopter Hurst, Texas |
| Member: | Josh O'Neil Bell Helicopter Hurst, Texas |
| Member: | David Gridley GE Aviation Lynn, Massachusetts |

LIST OF ACRONYMS

| | |
|-------|-------------------------------------|
| AGB | accessory gearbox |
| AHRS | attitude heading reference system |
| ALF | aft looking forward |
| ASIP | aircraft system interim procedure |
| ATP | acceptance test procedure |
| ATT | aircraft total time |
| CDT | central daylight time |
| CF | centrifugal force |
| CFR | Code of Federal Regulations |
| CG | center of gravity |
| CLAWs | control laws |
| EEO | experimental engineering order |
| FAA | Federal Aviation Administration |
| FCC | flight control computer |
| GE | General Electric |
| IGB | intermediate gearbox |
| lbs | pounds |
| LH | left-hand |
| LIVE | Liquid Inertia Vibration Eliminator |
| PCL | pitch change link |
| RGB | reduction gearbox |
| RH | right-hand |
| RSTA | rotor station |
| S/N | serial number |
| STA | fuselage station |
| TRDS | tail rotor drive shaft |
| TRGB | tail rotor gearbox |
| TX | Texas |
| VMC | visual meteorological conditions |

C. SUMMARY

On July 6, 2016, about 1148 central daylight time (CDT), an experimental Bell Helicopter 525 helicopter, N525TA, broke up in flight and impacted terrain near Italy, Texas (TX). The two pilots on board were fatally injured. The majority of the helicopter was destroyed by the ground impact and postcrash fire. The flight originated from the Arlington Municipal Airport in Arlington, TX, as a developmental flight test and was conducted under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91. Visual meteorological (VMC) prevailed at the time of the accident.

On July 6, 2016, a National Transportation Safety Board (NTSB) Central Region investigator and investigators from Bell Helicopter and the Federal Aviation Administration (FAA) convened at the accident site for initial documentation of the wreckage. From July 7-8, 2016, the Airworthiness Group convened at the accident site for documentation of the wreckage. The wreckage was recovered on July 9, 2016 and stored in a secured hangar at Bell Helicopter facilities in Arlington, TX. On July 10, 2016, members of the Airworthiness Group convened at Bell Helicopter facilities in Arlington, TX to layout the recovered wreckage and perform additional wreckage documentation. The wreckage distribution was consistent with an inflight breakup. Damage signatures observed on the airframe and main rotor system were consistent with main rotor blade contact with the tail boom and the nose cone.

From August 3-5, 2016, representatives from the NTSB, Bell Helicopter, and the FAA performed bench testing of three of the four recovered tail rotor dampers. The bench testing revealed no anomalous findings for the three tail rotor dampers.

D. DETAILS OF THE INVESTIGATION

1.0 HELICOPTER INFORMATION

1.1 HELICOPTER DESCRIPTION

The Bell Helicopter 525 has a five-bladed main rotor that provides helicopter lift and thrust. A four-bladed, canted tail rotor provides thrust to counteract main rotor torque effect, control helicopter yaw, and provide lift (due to the canted-nature of the tail rotor). The helicopter was equipped with two General Electric (GE) CT7-2F1 turboshaft engines mounted aft of the main transmission and one Honeywell RE100BR auxiliary power unit (APU) mounted between the two engines at the aft end of the engine deck. The helicopter was equipped with a triply-redundant fly-by-wire flight control system with a triplex hydraulic system. Additionally, the helicopter was equipped with retractable tricycle landing gear.

The terms “left”, “right”, “up” and “down” are used when in the frame of reference of looking forward from the aft end of the helicopter, i.e. aft looking forward (ALF). All locations and directions will be viewed from ALF unless otherwise specified.

1.2 HELICOPTER HISTORY

The accident helicopter, serial number (S/N) 62001, was manufactured in 2015, received its registration certificate on April 13, 2015, and its most recent experimental airworthiness certificate on April 25, 2016. The helicopter accumulated an aircraft total time (ATT) of about 200 flight hours at the time of the accident. According to helicopter records, engine S/Ns 436011 and 436013 were installed on the helicopter and each accumulated about 285 hours at the time of the

accident. The helicopter was estimated to weigh about 19,975 pounds at the time of the accident and was configured for a heavy forward center of gravity (CG) specifically for the flight test.

2.0 WRECKAGE DOCUMENTATION AT THE ACCIDENT SITE AND AFTER RECOVERY

On July 7-8, 2016, members of the Airworthiness Group convened at the accident location to document the wreckage. The wreckage was distributed into two distinct areas (**Figure 1**). The first distinct area was the main wreckage site, comprising an impact crater, remnants of the main fuselage, cockpit, main transmission and main rotor hub, two of the five main rotor blades, the forward portion of the tail boom, and both engines. There was evidence of a postcrash fire at the main wreckage site. The wreckage debris path at the main wreckage site, about 200 feet in length, was oriented about 315 degrees magnetic (**Figure 2**). The second distinct area (the secondary wreckage site), about 1,300 feet southeast of the main wreckage site, comprised the aft portion of the tail boom. The aft portion of the tail boom contained the tail rotor drive system, intermediate gearbox (IGB), tail rotor gearbox (TRGB), and tail rotor. Three of the five main rotor blades were found separate from the main and secondary wreckage sites (**Figure 3**). Various pieces of forward cowlings, cockpit frames, and cabin doors were found in a debris path between the main and secondary wreckage sites. Additionally, lightweight debris, such as insulation and main rotor blade skin pieces, was found scattered to the northeast of the debris path between the main and secondary wreckage sites¹, with the furthest piece being found about 1,520 feet away from the debris path between the main and secondary wreckage sites.



Figure 1. The location of the main wreckage site, secondary wreckage site, and selected items from the wreckage debris field.

¹ The debris path between the main and secondary wreckage sites is a straight line drawn between the main wreckage site and secondary wreckage site.

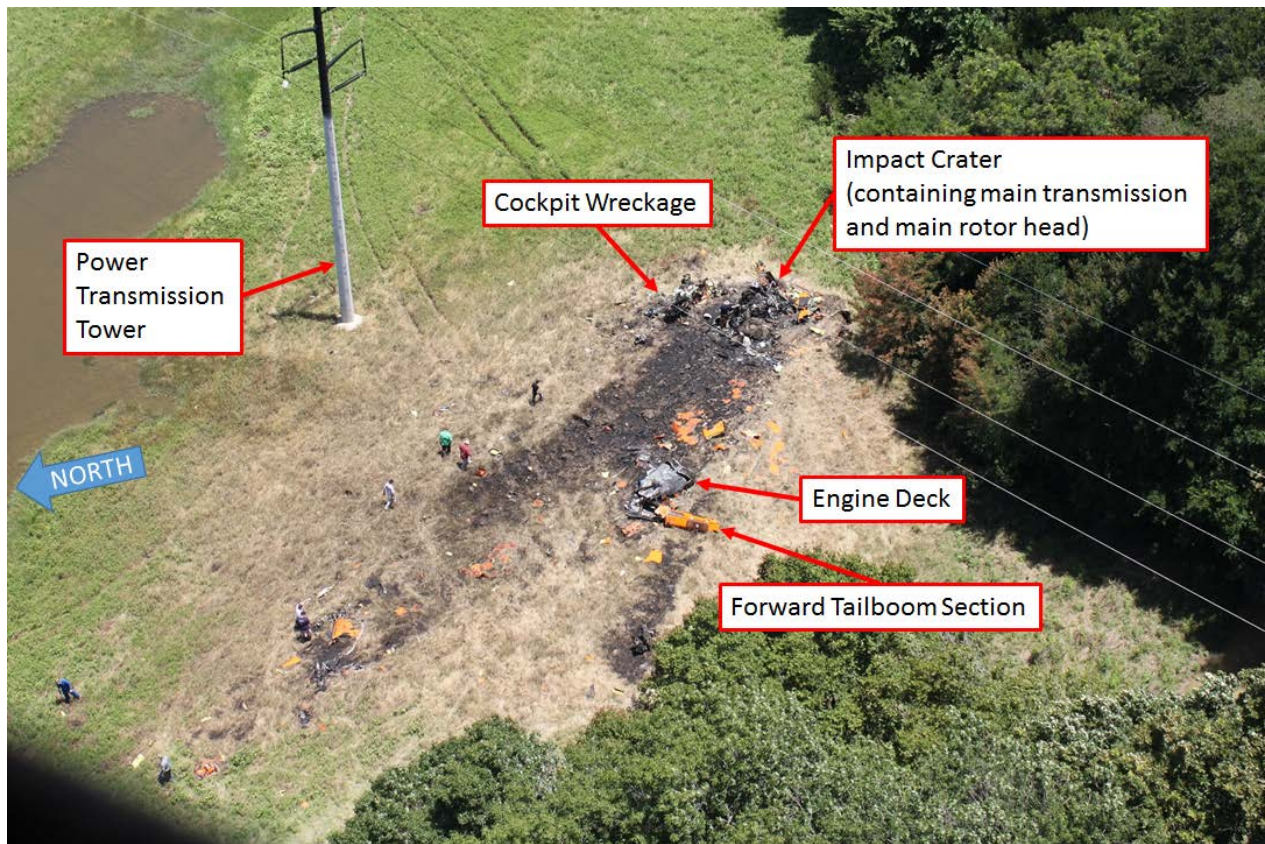


Figure 2. Aerial view of the main wreckage site.



Figure 3. The location of main rotor blade sections.

A power transmission tower, about 80 feet to the north of the impact crater, did not exhibit evidence of impact with the accident helicopter. No evidence of broken power lines was observed. However, the upper portion of the power transmission tower exhibited evidence of soot deposits from the postcrash fire.

The wreckage was recovered on July 9, 2016 and stored in a secured hangar at Bell Helicopter facilities in Arlington, TX. On July 10, 2016, members of the Airworthiness Group convened at Bell Helicopter facilities in Arlington, TX to examine the recovered wreckage.

2.1 STRUCTURES

The helicopter structure is primarily composed of the main fuselage, tail boom with horizontal and vertical stabilizers, and retractable tricycle landing gear. The main fuselage is constructed primarily of aluminum and composites. The tail boom, horizontal stabilizer, and vertical stabilizer are constructed primarily of composites. N525TA was painted in a solid orange paint scheme, with its registration number, black in color, on its tail boom.

2.1.1 MAIN WRECKAGE SITE

The main fuselage was highly fragmented and was observed in or near an impact crater at the main wreckage site. The majority of the main fuselage pieces exhibited evidence of thermal damage from exposure to the postcrash fire. Orange-colored ballast plates were observed scattered along the debris path. The engine deck, containing both engines but not the auxiliary power unit, was observed further down the debris path, about 82 feet away from the impact crater. The right pylon and right landing gear were found at the southeastern edge of the impact crater. The nose landing gear was found on the northeastern edge of the impact crater. The left landing gear was found further down the debris path, about 94 feet away from the impact crater. The cockpit wreckage was observed adjacent to the impact crater and did not receive significant thermal damage. The left pilot seat frame remained installed on the left seat track. The right pilot seat frame was found near the cockpit wreckage. The right seat track remained installed in the cockpit wreckage. Various avionics and instrumentation boxes were found in the cockpit wreckage and in the debris path. Fractured display panels were also observed within the cockpit wreckage.

The forward portion of the tail boom was found adjacent to the engine deck and resting on its left side. The forward portion of the tail boom exhibited an angled fracture line at its aft end consistent with main rotor blade contact. The tail boom attachment points to the main fuselage exhibited fractures near the upper left corner and lower right corner.

The nose cone was recovered in the debris field between the main and secondary wreckage sites. The nosecone exhibited an angled cut line from the upper-right side to the lower-left side consistent with main rotor blade contact.

2.1.2 SECONDARY WRECKAGE SITE

The aft portion of the tail boom was found resting partially inverted, with the tail rotor head and one tail rotor blade fully embedded into the ground (**Figure 4**). The aft portion of the tail boom exhibited an angled cut line at its forward end consistent with main rotor blade contact (**Figure 5**). On the top surface of the tail boom, the cut line was located

about fuselage station (STA) 480.² At the bottom surface of the tail boom, the cut line was located about STA 542.5.



Figure 4. The aft portion of the tail boom.



Figure 5. Angled cut line at the forward end of the aft section of the tail boom. (photo courtesy of GE Aviation)

The left horizontal stabilizer was fractured at the root end of its spar and was found resting against the “orange” tail rotor blade. The right horizontal stabilizer was fractured several inches outboard of the root end and its outboard end was embedded in the IGB cowling. The vertical stabilizer remained attached to the tail boom and exhibited crushing damage in the area of the TRGB cowling. A cabin door and a cockpit door were found about 300 feet to the west and southwest of the tail boom, respectively.

² The nose of the helicopter is located at STA 55, the main rotor axis of rotation is at the hub is about STA 282, and tail rotor axis of rotation is about STA 673. All STA values are in inches.

2.2 MAIN ROTOR DRIVE SYSTEM

Each engine provides power to its respective engine reduction gearbox (RGB). The RGB reduces the engine output speed to the main transmission. The main transmission contains two freewheeling clutches, left-hand (LH) and right-hand (RH), which transfers power from each engine RGB to its respective input pinion. During autorotation, the freewheeling clutches disengage the engines from the main transmission, allowing the main rotor to freely rotate. The main transmission drives the main rotor and two accessory gearboxes (AGB). The AGBs are mounted forward of the main transmission and are each driven by the main transmission via an AGB drive shaft. Components driven by the AGB include a hydraulic pump, a blower (radiator fan), and two generators. The main transmission housing is mounted to two pylon beams (left and right). The forward and aft ends of each pylon beam are connected to the airframe mount via Liquid Inertia Vibration Eliminator (LIVE)³ mounts which provide damping for oscillatory vibrations.

2.2.1 MAIN TRANSMISSION

The main transmission was separated from both pylon beams and was found in the impact crater. The main transmission outer surfaces exhibited thermal damage. A portion of the housing had fractured and separated, exposing the right input bevel and spur gear. The transmission sump case was fractured from the housing and found northwest of the impact crater in the debris path. The left and right pylon beams were found in the impact crater with a portion of the transmission housing mounts attached. Longitudinal portions of airframe structure remained attached to both pylon beams. On the left pylon beam, both forward and aft LIVE and airframe mounts remained attached to both the pylon beam and airframe structure. On the right pylon beam, the forward LIVE and airframe mounts remained attached to both the pylon beam and airframe structure. The lower portion of the aft LIVE mount remained attached to its airframe mount, the latter of which remained attached to airframe structure.

2.2.2 INPUT DRIVESHAFTS AND REDUCTION GEARBOXES

The LH input driveshaft's forward diaphragm coupling remained attached to the main transmission. The forward diaphragm coupling had circumferentially fractured at the forward diaphragm thin wall. The left input driveshaft remained attached to the LH RGB at the aft diaphragm coupling. The LH RGB was found loose, northwest of the impact crater in the debris path. A portion of the LH RGB housing had fractured on its aft side, exposing its internal gearing. The outer surfaces of the housing exhibited a light coat of soot but did not exhibit significant thermal damage.

The RH input driveshaft remained installed to the main transmission via the forward diaphragm coupling. Its aft diaphragm coupling had circumferentially fractured at the forward diaphragm thin wall. The remainder of the aft diaphragm coupling remained installed on the RH RGB. The RH RGB remained attached to the RH engine and did not exhibit significant thermal damage.

³ LIVE is a registered trademark.

2.2.3 ACCESSORY GEARBOXES

The majority of both AGBs were not found on scene. A hydraulic pump and heat exchanger was found in the debris path and exhibited damage due to impact and exposure to the postcrash fire.

2.3 MAIN ROTOR SYSTEM

The main rotor is a five-bladed, fully articulated system that utilizes elastomeric bearings to accommodate blade feathering, flapping, and lead-lag motions. A fluid-elastic damper moderates blade lead-lag motion. The main rotor head comprises a titanium hub, also known as a yoke, to which each main rotor blade is connected via a grip assembly. The hub accommodates a droop-stop ring and the drive hub for the rotating swashplate drive arm. The grip assembly comprises a centrifugal force (CF) elastomeric bearing, installed between the composite grip's C-channel and the hub, an aluminum pitch horn/damper attachment fitting, a droop-stop, and a flap limiter (or up-stop). The pitch horn/damper attachment fitting accommodates connections for the adjustable pitch change link (PCL) and the lead-lag damper. Each main rotor blade is connected to its respective grip assembly via three blade retention bolts. The five main rotor blades are identified by colored stickers, presented in the order of advancing rotation (when seated in the pilot seat and observing the blades pass from right to left): 'blue', 'orange', 'red', 'green', and 'white'. The blade airfoil, including its spar and afterbody, is constructed primarily of composites with a stainless steel leading edge abrasion strip. The main rotor blade upper skin is painted in an alternating white and red high visibility color scheme while the lower skin is painted solid black. A 10-inch wide portion of the tip end is painted yellow.

The rod ends of each lead-lag damper are connected in two places: the hub-side of the damper is connected to attachment lugs on the hub and the blade-side of the damper is connected to attachment lugs on the pitch horn/damper attachment fitting. The upper rod ends of the PCLs are connected to attachment lugs on the pitch horn/damper attachment fitting. The lower rod ends of the PCLs are connected to the rotating swashplate. A tilt ball facilitates tilting of the swashplate for cyclic inputs and an up-and-down movement of the tilt ball along the collective sleeve for collective inputs. Three triplex main rotor hydraulic actuators (LH-forward, LH-aft, and RH actuators) are connected at their upper ends to the stationary swashplate and receive inputs from the flight control computers (FCC). The lower ends of the three main rotor hydraulic actuators are attached to fittings mounted on the transmission pylon beams.

2.3.1 MAIN ROTOR HUB AND CONTROLS

The main rotor hub remained attached to the main rotor shaft, also known as the main rotor mast. The swashplate assembly, the tilt ball, and collective sleeve remained installed. The drive hub's drive lever attachment fitting was fractured, with remnant pieces of the attaching boss and the attachment hardware still installed on the drive lever. The drive lever remained attached to the drive link, the latter of which remained attached to the rotating swashplate.⁴ The anti-drive link, anti-drive lever, and the anti-drive attachment fitting were found loose in the debris field as an assembly.⁵ The anti-drive link bolt was retained within the stationary swashplate attachment lug but the bolt shank exhibited

⁴ The assembly comprising the drive link and drive lever is also known as the rotating scissors assembly.

⁵ The assembly comprising the anti-drive link and anti-drive lever is also known as the stationary scissors assembly.

bending in the direction opposite normal main rotor rotation. The lower two mounting bolt holes of the anti-drive attachment fitting exhibited elongation and the upper two mounting bolt holes contained remnant bolt shanks.

2.3.2 'BLUE' MAIN ROTOR BLADE

The inboard end of the blade was found at the main wreckage site and exhibited evidence of thermal damage. The root end of the blade airfoil remained attached to its respective grip assembly via three blade retention bolts. The inboard blade retention bolt head fractured from the bolt shank and the two outboard blade retention bolt heads remained whole. The grip was observed to be loosely wrapped around its hub attachment point. Loose carbon fiber, consistent with blade construction material, was observed wrapped around the main rotor head, main rotor shaft, and main transmission. A 12-foot long outboard section of blade, from about rotor station⁶ (RSTA) 189 to the blade tip, found about 410 feet east-northeast of the accident site, was identified as originating from the 'blue' main rotor blade. The spar and abrasion strip exhibited multiple fractures along its span. The afterbody was mostly separated and missing from this blade section, but the blade tip weight package remained installed.

The inboard surface of the outboard lug for the PCL attachment exhibited contact marks consistent with the PCL rod end. The upper rod end of the PCL was fractured at its threads and exhibited bending in the outboard direction. The lower rod end of the PCL remained attached to the rotating swashplate but was fractured at its threads. The PCL link body was not recovered. The blade-side damper rod end lugs were fractured from its fitting. The damper remained attached to the hub but was fractured at its blade-side thread housing. The CF bearing remained attached to the hub but the elastomeric bearing was thermally degraded, with remnant steel laminates and the inboard bearing cap retained in the hub area. The 'blue' droop stop was found separated from the grip and its outboard end was bent upward. The droop stop's ring contact surface exhibited a polished appearance on its trailing side, but did not exhibit evidence of significant imprints.

2.3.3 'ORANGE' MAIN ROTOR BLADE

A 14-foot long inboard section of blade, comprising the blade airfoil, pitch horn/damper attachment fitting, and the upper and lower portions of the grip (still attached to the blade airfoil via three blade retention bolts), was found about 1,140 feet southeast of the main wreckage site. This blade section's inboard end was embedded in the ground and its outboard end was embedded in tree branches. The lower grip fractured adjacent to the grip C-channel; the upper grip fractured near the root end of the blade airfoil. The upper and lower portions of the grip fractures exhibited a broomstrawed appearance. The outboard section (remainder) of the blade was found as a single piece on an earthen dam, about 2,880 feet southeast of the main wreckage site. The blade tip weight package remained installed.

Yellowish-orange paint transfer marks was observed on the leading edge surfaces in the area of RSTA 204, where the blade fractured into its two distinct [inboard and

⁶On the Bell 525, RSTA 0 for the main rotor is located at its axis of rotation. The main rotor blade tip end is located at RSTA 327. The longitudinal centerlines of the two outboard blade retention bolts are located at RSTA 34. All RSTA values are in inches.

outboard] pieces (Figure 6). The yellow-colored paint transfer was similar in color to the yellow-colored primer found on portions of the airframe. The spar exhibited a significant impact mark and a broomstrawed appearance at RSTA 204. Additional orange paint transfer marks were observed on the leading edge surfaces along various RSTAs of the inboard section. Gouge marks into the lower blade surface were observed between RSTA 64 and 74, with the gouge increasing in depth toward the trailing edge. Damage to the blade afterbody was observed between RSTA 153-204. Outboard of RSTA 204, on the outboard section of the blade, no significant damage was observed.

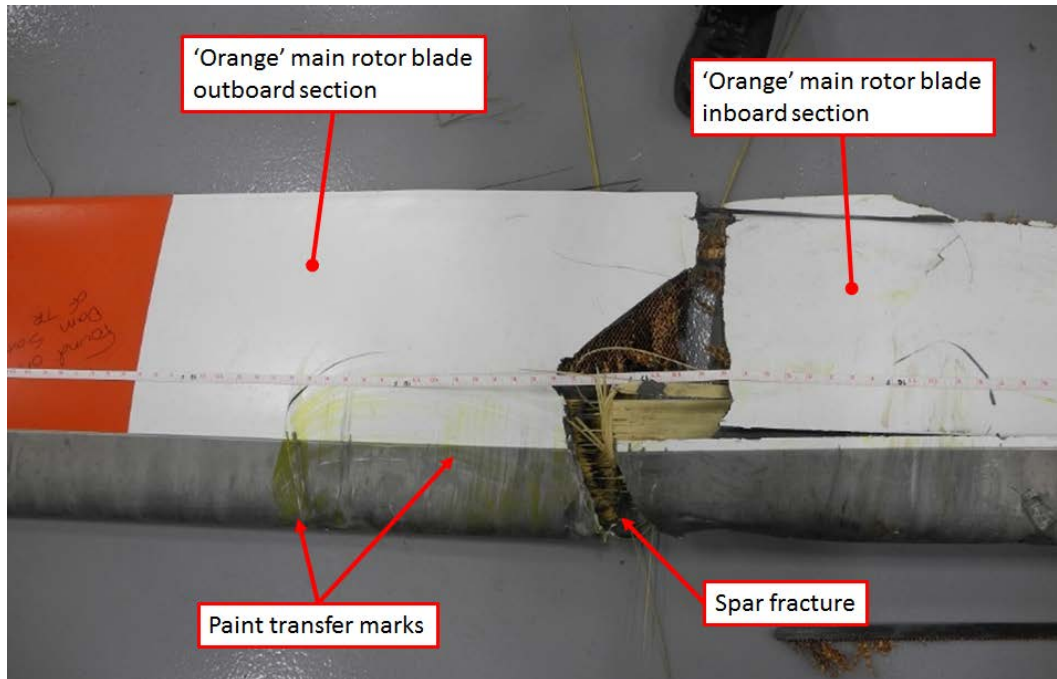


Figure 6. Damage signatures observed near RSTA 204 on the 'orange' main rotor blade.

Impact marks, consistent with contact with the blade-side damper rod end nut, were observed on the top and bottom damper attachment lugs. The damper threaded rod end was bent in the direction of the blade flapping downward. The blade-side of the damper body was fractured in overload, and the remainder of the damper remained attached to the hub. The outboard lug of the PCL attachment exhibited impact marks consistent with contact with the PCL upper rod end. The PCL upper rod end was fractured at its threads. The PCL lower rod end, link body, and upper rod end nut remained attached to the rotating swashplate. The PCL lower rod end threaded shank was bent slightly in the direction of main rotor rotation. The droop stop and droop stop bolt were not attached to the grip. The CF bearing assembly was whole and remained attached to the hub.

2.3.4 'RED' MAIN ROTOR BLADE

The 'red' main rotor blade, comprising the entire blade airfoil, pitch horn/damper attachment fitting, and grip, was found embedded in a tree about 1,400 feet southeast of the main wreckage site (Figure 7). The blade airfoil remained attached to the grip via three blade retention bolts. The grip fractured near the lower end of the C-channel. The interior surface of the upper portion of the grip was fractured adjacent to the pitch horn/damper attachment fitting. The sheared droop stop attachment bolt shank was observed within the grip, but the droop stop was not attached. The blade tip weight package remained installed.

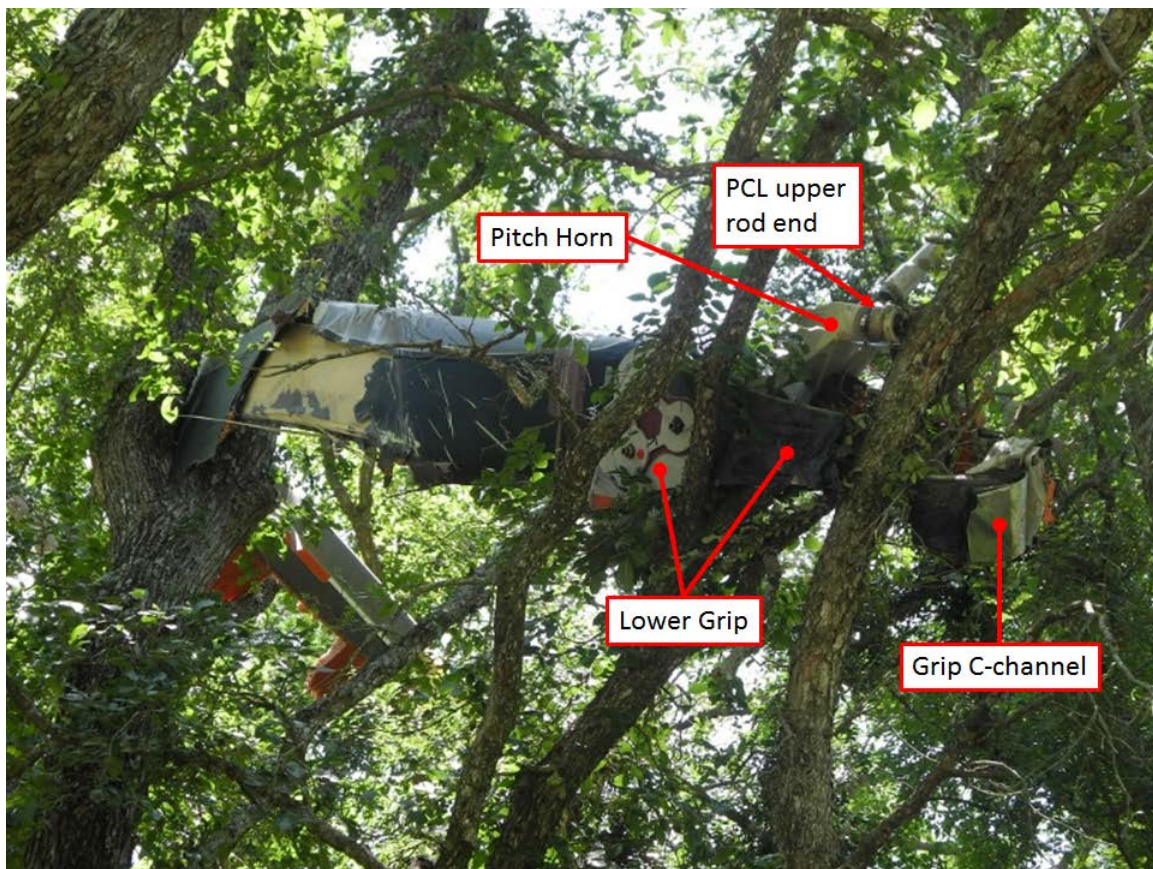


Figure 7. 'Red' main rotor blade embedded in a tree.

Impact marks on the leading edge were observed between RSTA 67-94. The spar exhibited a fracture at RSTA 80. A chordwise gouge was observed on the lower surface of the blade around RSTA 111-113. Between RSTA 202-253, the leading edge abrasion strip was missing and the spar exhibited a broomstrawed appearance. The spar exhibited a significant impact mark and a broomstrawed appearance at RSTA 204. The leading edge abrasion strip was bent upward at RSTA 253. Major portions of the afterbody were missing between RSTA 133-270. The blade tip remained intact. Instrumentation gauges remained bonded along the span of the blade airfoil.

The inboard PCL attachment lug on the pitch horn exhibited a fracture across the lug. Material was missing from the leading edge side of the PCL attachment lug to the PCL attaching hardware bore, but the PCL upper rod end remained attached to the pitch horn. The PCL upper rod end threads were bent inboard and the link body was fractured in overload about mid-length. The PCL lower rod end remained attached to the rotating swashplate but was fractured at the rod end threads. The damper was found loose in the wreckage near the impact crater. A portion of the damper housing and hub-side rod end remained attached to the hub. The blade-side rod end of the damper remained attached to the pitch horn/damper attachment fitting and was fractured in overload at its thread housing. The blade-side damper attachment lugs exhibited impact marks consistent with contact with the blade-side rod end nut, with deeper impressions on the upper lug. The CF bearing attachment remained on the hub, but the elastomeric bearing was missing and was not recovered.

2.3.5 'GREEN' MAIN ROTOR BLADE

An inboard section of the blade, comprising a roughly 2-foot section of the blade airfoil, the upper and lower grips, and the pitch horn/damper attachment fitting was recovered adjacent to the main transmission at the main wreckage site. This inboard section of blade exhibited significant thermal damage. The upper and lower grips were fractured near the C-channel and the droop stop remained partially attached to the lower grip.

A 9-foot long outboard section of the blade, from about RSTA 216 to the blade tip, was found in a tree canopy about 1,325 feet southeast of the main wreckage site. At RSTA 216, the spar exhibited a broomstrawed appearance and the blade afterbody was missing. The leading edge abrasion strip was missing from RSTA 216-246. The upper skin of the blade and core material were missing from RSTA 216-282. Instrumentation gauges remained bonded at the outboard end. The blade tip exhibited no significant damage and the blade tip weight package remained installed. A significant portion of the blade could not be reconstructed due to thermal damage.

The damper remained attached to the pitch horn/damper attachment fitting and exhibited soot deposits on its outer housing. The hub-side damper rod end was fractured from the damper but remained attached to the hub. The PCL upper rod end remained attached to the pitch horn and thread imprints were observed on the upper edges of the PCL attaching lug. The PCL upper rod end was fractured immediately below the thread nut and the threads exhibited a slight bend in the inboard direction. The PCL lower rod end with a portion of the link body remained attached to the rotating swashplate. The remainder of the link body was found loose near the impact crater. The CF bearing remained installed on the hub and the elastomeric bearing remained whole. The inboard CF bearing cap was separated but was retained in the hub.

2.3.6 'WHITE' MAIN ROTOR BLADE

The 'white' main rotor blade, comprising the entire blade airfoil, upper and lower grips, and pitch horn/damper attachment fitting, was found on the ground about 350 feet southeast of the main wreckage site. The upper grip was fractured near the blade root end and the lower grip was fractured near the C-channel. Both upper and lower grip fractures exhibited a broomstrawed appearance with a downward directionality. The droop stop was not attached to the grip. The blade airfoil remained attached via three blade retention bolts. The inboard blade retention bolt head fractured from the bolt shank and the two outboard blade retention bolt heads remained whole. The blade leading edge abrasion strip exhibited impact marks at RSTAs 102, 149, 204, 228-247, and 294. The majority of the impact marks exhibited orange paint transfer, while yellow paint transfer was observed on the impact mark at RSTA 204. Orange paint transfer was also observed at RSTA 316. The lower skin separated from the core between RSTA 102-236, with afterbody separation observed between RSTA 228-305. The blade tip weight package remained installed.

The damper remained attached to the hub but was fractured at its blade-side damper thread housing. The blade-side damper rod end remained attached to its attaching lugs. The blade-side damper rod end remained attached to the pitch horn/damper attachment fitting and exhibited witness marks consistent with contact with the lower attachment lug. The

PCL upper rod end remained attached to the pitch horn but was fractured at its threads; the threads exhibited bending deformation in the outboard direction. Witness marks were observed between the PCL upper rod end's outboard surface and the inner surface of the outboard pitch horn lug. The lower rod end of the PCL, the link body, and the upper rod end nut remained attached to the rotating swashplate. The lower rod end threaded shank was bent slightly in the direction of main rotor rotation. The CF bearing remained attached to the hub but the elastomeric bearing was thermally degraded, with remnant steel laminates retained in the hub area.

2.3.7 ADDITIONAL MAIN ROTOR BLADE FINDINGS

A partial inboard section of droop stop was found in the debris field, but could not be identified to a main rotor blade color. The droop stop's ring contact surface exhibited a polished appearance on its trailing side and caked dirt on the lower side, but the contact surface did not exhibit evidence of significant imprints. Various pieces of main rotor blade skin and core material were recovered in the debris field but could not be positively matched to a main rotor blade color.

2.4 TAIL ROTOR DRIVE SYSTEM

The tail gearbox output drive flange, driven by the RH input pinion in the main transmission, is connected to the rotor brake disk and the tail rotor output diaphragm coupling. Four tail rotor drive shafts (TRDS), the No. 1 TRDS identified as the forward-most drive shaft, transmits drive from the tail rotor output coupling to the IGB. The No. 5 TRDS, installed on the vertical fin, transmits drive from the IGB to the TRGB. On N525TA, the No. 1 TRDS comprised an aluminum shaft tube while the Nos. 2 thru 5 TRDS comprised a carbon fiber shaft tube. On the Nos. 1 thru 4 TRDS, a hanger bearing was located between each drive shaft and a disk pack [flexible] coupling (comprising 18 laminates) was installed between each drive shaft ends and between the No. 4 TRDS and the IGB input flange. The hanger bearings are installed on support mounts that are installed on the tail boom structure. Diaphragm couplings were utilized to connect the No. 5 TRDS to both the IGB and the TRGB. The IGB and TRGB are both mounted to the vertical fin.

2.4.1 TAIL ROTOR DRIVE SHAFTS

The tail gearbox output drive flange and its idler gear were found separated from the main transmission but with a portion of its housing. The rotor brake disk, rotor brake calipers, and the tail rotor output diaphragm coupling remained attached. The rotor brake calipers were not engaged. The forward end of the No. 1 TRDS remained attached to the tail rotor output diaphragm coupling, but the shaft tube was circumferentially fractured immediately aft of the drive shaft attachment flange. The fracture exhibited signatures consistent with overload. The remainder of the No. 1 TRDS was not recovered in the wreckage.

The forward portion of the No. 2 TRDS, comprising the majority of the length of the No. 2 TRDS, was found within the engine deck but exhibited thermal damage. The aft end of the forward portion of the No. 2 TRDS, near the location of the aft edge of the APU exhaust, exhibited an angular fracture. Subsequent handling of the forward portion of the

No. 2 TRDS during recovery led to significant separation of the carbon fibers.⁷ The aft portion of the No. 2 TRDS was found within the tail boom at the secondary wreckage site. The aft portion of the No. 2 TRDS, comprising the shaft tube attachment to the aft flange adapter, remained attached to the No. 3 TRDS. The hanger bearing support between the Nos. 2 and 3 TRDS remained attached to the hanger bearing and the hanger bearing support mount, but the support mount was separated from the tail boom structure.

The No. 3 TRDS was found within the tail boom at the secondary wreckage site. No significant damage was apparent along the length of the shaft tube. The aft flange adapter was fractured circumferentially, immediately forward of the flange's attachment to the disk pack coupling. The aft flange adapter remained attached to the disk pack coupling, which remained attached to the hanger bearing and the No. 4 TRDS forward flange adapter. The disk pack coupling exhibited slight opening between its laminates and the disk pack coupling exhibited curving. The hanger bearing support mount remained attached to the tailboom structure.

The No. 4 TRDS remained intact with no apparent damage along the length of the shaft tube. The No. 4 TRDS remained installed to the IGB at its aft end, with no evidence of damage observe on the disk pack coupling. One slight opening was observed between the laminates of the disk pack coupling.

The forward end of the No. 5 TRDS was fractured near its flange adapter, but the forward flange adapter remained attached to the diaphragm coupling, oil cooler blower, and the IGB output flange. The aft end of the No. 5 TRDS was fractured near its flange adapter, but the aft flange remained attached to the aft diaphragm coupling and TRGB input flange.

2.4.2 INTERMEDIATE GEARBOX

The IGB remained installed on the vertical fin structure. The exterior of the IGB did not exhibit anomalous damage. Manual rotation of the No. 4 TRDS resulted in a corresponding movement of the No. 5 TRDS forward flange adapter.

2.4.3 TAIL ROTOR GEARBOX

The TGB remained installed on the vertical fin structure. The exterior of the TGB had dirt on its housing, but no anomalous damage was observed.

2.5 TAIL ROTOR

The tail rotor is a four-bladed, fully articulated system that utilizes elastomeric bearings to accommodate blade feathering, flapping and lead-lag motions. A fluid-elastic damper moderates blade lead-lag motion. A non-adjustable PCL controls blade feathering. The tail rotor head comprises a titanium hub to which each tail rotor blade is connected via a grip. A CF elastomeric bearing is installed on the grip and is attached to the hub. Each grip contains a pitch horn to which a PCL inboard rod end is connected. Damper fittings, at each blade location, are attached to the

⁷ When exposed to very high temperatures, the epoxy resin that is used during construction of carbon fiber components can melt while the carbon fiber, which has a higher temperature tolerance, will stay intact. The resultant loss of epoxy resin can lead to the separation of carbon fiber filaments.

hub and accommodates the hub-side damper elastomeric rod end. Each tail rotor blade is connected to its respective grip via two blade retention bolts. The four main rotor blades are identified by colored stickers, presented in the order of advancing rotation: 'blue', 'orange', 'red', and 'green'. The blade airfoil is constructed primarily of composites with a stainless steel leading edge abrasion strip. Both sides of the tail rotor blade are painted white with chordwise stripes painted black for high visibility; the inboard-most stripe is painted orange.

Each PCL outboard rod end is connected to the crosshead whose movement (along the tail rotor axis of rotation) results in collective pitch adjustments to the tail rotor blades. Crosshead movement is controlled via a control tube that routes through the TRGB and is connected to the tail rotor hydraulic actuator.

2.5.1 TAIL ROTOR HEAD

The tail rotor head remained attached to the TRGB (**Figure 8**). The hub exhibited no evidence of cracks or fractures. Its outer surfaces exhibited scuffing and caked dirt. All four damper attachment fittings, dampers, CF bearings, and grips were present. The crosshead and slider remained installed. All attaching hardware was secured and did not exhibit evidence of looseness.



Figure 8. The recovered tail rotor head with all four tail rotor blades attached. (Photo courtesy of Bell Helicopter)

2.5.2 TAIL ROTOR BLADES

The 'blue' tail rotor blade leading edge was partially embedded into the ground. The blade airfoil remained attached to its grip via two attachment bolts. A small puncture was observed on the outboard surface, located about mid-span and mid-chord of the airfoil. The remainder of the blade airfoil exhibited no evidence of significant damage. The damper

remained attached at both ends. The CF elastomeric bearing was separated from its inboard bearing housing but remained attached to the blade and hub. The PCL remained attached at both ends. Both inboard and outboard flap stops were intact.

The 'orange' tail rotor blade leading edge tip was found embedded into the bottom-left edge of the tail cone. The blade airfoil remained attached to its grip via two attachment bolts. The 'orange' tail rotor blade tip end afterbody exhibited a mid-chord fracture extending about 10 inches inboard, with orange instrumentation wiring observed within the fracture opening. The trailing side of the blade airfoil root end exhibited damage due to contact with the hub-side outboard flap stop. The remainder of the blade airfoil was intact and exhibited no evidence of significant damage. The grip exhibited witness marks on its inboard surface and adjacent to the CF bearing. The damper remained attached at both ends. The CF bearing was separated from its inboard bearing housing but remained attached to the blade and hub. The PCL remained attached at both ends. Both inboard and outboard flap stops were present but the outboard hub-side droop stop attaching bolt shank was fractured in overload and the nut was missing. The hub-side outboard flap stop exhibited an impact mark on its advancing side. The blade-side outboard flap stop exhibited an impact mark on its trailing side.

The 'red' tail rotor blade trailing edge was partially embedded into the ground. The blade airfoil exhibited no evidence of significant damage and remained attached to its grip via two attachment bolts. Instrumentation gauges remained bonded along various locations of the blade span. The damper remained attached at both ends, but the damper body had separated at its elastomeric bushing. The elastomeric bushing exhibited signatures consistent with cohesive overload failure of the elastomer. The CF bearing was separated from its inboard bearing housing but remained attached to the blade and hub. The PCL remained attached at both ends. Both inboard and outboard flap stops were intact.

The 'green' tail rotor blade was wholly embedded into the ground. Removal of the tail rotor revealed the blade airfoil had partially folded over immediately outboard of the grip attachment, which resulted in opening of the inboard trailing edge, exposing the blade interior. The outer surfaces of the blade and portions of the exposed interior had remnant caked dirt. The blade airfoil remained attached to its grip via two attachment bolts. Instrumentation gauges remained bonded along various locations of the blade span. The damper was attached at both ends. The CF bearing remained installed between the grip and hub. When the blade was moved in the flapping direction by hand, a corresponding movement of the CF bearing's elastomers was observed. The PCL remained attached at both ends. The flap stop on the inboard side had fractured and separated, but the flap stop on the outboard side remained intact.

2.6 MAIN AND TAIL ROTOR FLIGHT CONTROLS

The pilot and co-pilot cyclic and collective controls are pedestal-mounted sidesticks. Both cyclic and collective sidesticks, as well as the pilot and co-pilot pedal controls, are mechanically linked via lateral push-pull tubes. These lateral push-pull tubes are also connected to trim actuators: a pitch and roll trim actuator for the cyclic, a collective trim actuator for the collective, and a yaw trim actuator for the pedals. The pilot and co-pilot pedal controls activate the helicopter landing gear braking system by rotating the top end of the pedals forward. Control inputs from the pilot and the attitude heading reference system (AHRS) are transmitted to the three flight control

computers (FCC) and to the flight control laws (CLAWs) resulting in a command to each main rotor hydraulic actuator and the tail rotor hydraulic actuator.

2.6.1 MAIN ROTOR FLIGHT CONTROLS

Fractured pieces of the cyclic and collective sidesticks were observed within the cockpit wreckage. The lateral push-pull tubes were retained in the cockpit wreckage but exhibited fractures consistent with overload. Both pitch and roll trim actuators remained attached to the airframe. Both pitch and roll trim actuator arms were able to be moved by hand and exhibit no evidence of binding. The collective trim actuator mounting flanges were fractured and the actuator was separated from the airframe. The collective trim actuator arm was moved by hand and exhibited no evidence of binding, but its movement exhibited very low friction consistent with a fracture of its internal shear pin.⁸

The spherical bearings for the upper rod ends of both the LH-forward and LH-aft main rotor hydraulic actuators remained attached to the stationary swashplate. The lower portion of both attachment lugs (on the stationary swashplate) for the RH main rotor hydraulic actuator were fractured. The LH-aft main rotor hydraulic actuator remained attached to the left pylon beam. The LH-forward and RH main rotor hydraulic actuators were not observed in the recovered wreckage.

2.6.2 TAIL ROTOR FLIGHT CONTROLS

The pedal controls were not observable within the cockpit wreckage. The yaw trim actuator mounting flanges were fractured and the actuator was separated from the airframe. The yaw trim actuator arm and housing were fractured, exposing the interior of the actuator. The tail rotor hydraulic actuator remained attached to the TRGB and exhibited no evidence of anomalous damage. The interface between the actuator's three cylinders and base plate showed no evidence of fretting.

2.7 POWERPLANTS

Both engines remained installed on the engine deck and exhibited thermal distress from exposure to the postcrash fire (**Figure 9**). The APU was not observed on the engine deck and was not recovered. Both inlet barrier filters remained with the engine deck but were separated from their normally installed location. Both engine fairings remained installed to the engine deck but exhibited thermal damage. All engine casings remained attached to each other with no evidence of anomalous damage. The stage 1 and 2 vanes of both engines appeared to be in the closed position. For both engines, the anti-icing valve actuator rod was in the fully retracted position and the fuel metering unit actuator rod was in the fully extended position. For both engines, manual rotation of the engine core was attempted but unsuccessful. No evidence of the case crushing against the rotors was observed in the areas viewable via borescope. For both engines, the stage 4 power turbine blade sets did not exhibit evidence of damage.

⁸ In the event of a trim actuator jam, the pilot can apply increased control force and fracture the internal shear pin within the jammed trim actuator. The result is a mechanical severance of the trim actuator from its respective control stick.



Figure 9. The recovered engine deck.

3.0 TAIL ROTOR DAMPER BENCH TEST

From August 3-5, 2016, representatives from NTSB, FAA, and Bell Helicopter convened at Bell Helicopter facilities in Hurst, TX to bench test the tail rotor dampers (removed from the tail rotor wreckage) for evidence of anomalous response behavior. Only three tail rotor dampers were able to be bench tested: ‘orange’ (S/N LK0002); ‘blue’ (S/N LK0004); and ‘green’ (S/N LK0008). The ‘red’ tail rotor damper was separated into two halves and could not be bench tested. The bench testing plan comprised three steps: 1) a static bench test, 2) a dynamic bench test using acceptance test procedure (ATP) conditions, and 3) a dynamic bench test replicating the conditions of the accident flight. The static bench test measured the dampers’ force response based on a given tension or compression displacement. If the spring rate measured from the static bench test was within acceptable values, the damper was deemed suitable for dynamic bench testing. Conversely, if a damper did not produce acceptable values during static bench testing, then dynamic bench testing would not be performed on that damper. The dynamic bench test measured the dampers’ stiffness and damping over time. The results from the dynamic testing of the accident tail rotor dampers were compared to those of newly manufactured dampers which had undergone similar bench testing.

During the static bench test, displacement in both tension and compression resulted in acceptable values for all three accident tail rotor dampers tested. Dynamic testing of all three accident dampers did not reveal evidence of anomalous response behavior. **Figure 10** shows the stiffness and damping result comparison between the accident and exemplar dampers from the dynamic bench test using ATP conditions. **Figure 11** shows the stiffness comparison between the accident and exemplar dampers from the dynamic bench test replicating the conditions of the accident flight. **Figure 12** shows the damping comparison between the accident and exemplar dampers from the dynamic bench test replicating the conditions of the accident flight.

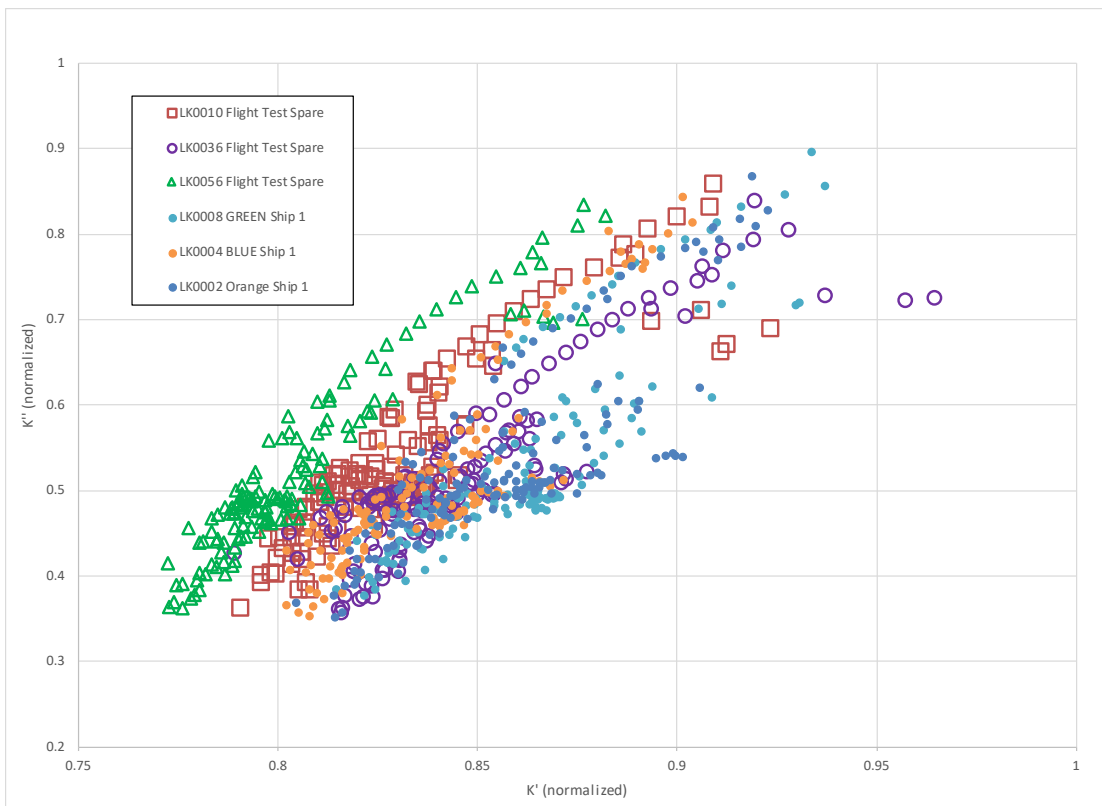


Figure 10. Comparison of the stiffness and damping results between accident and exemplar tail rotor dampers using ATP conditions.

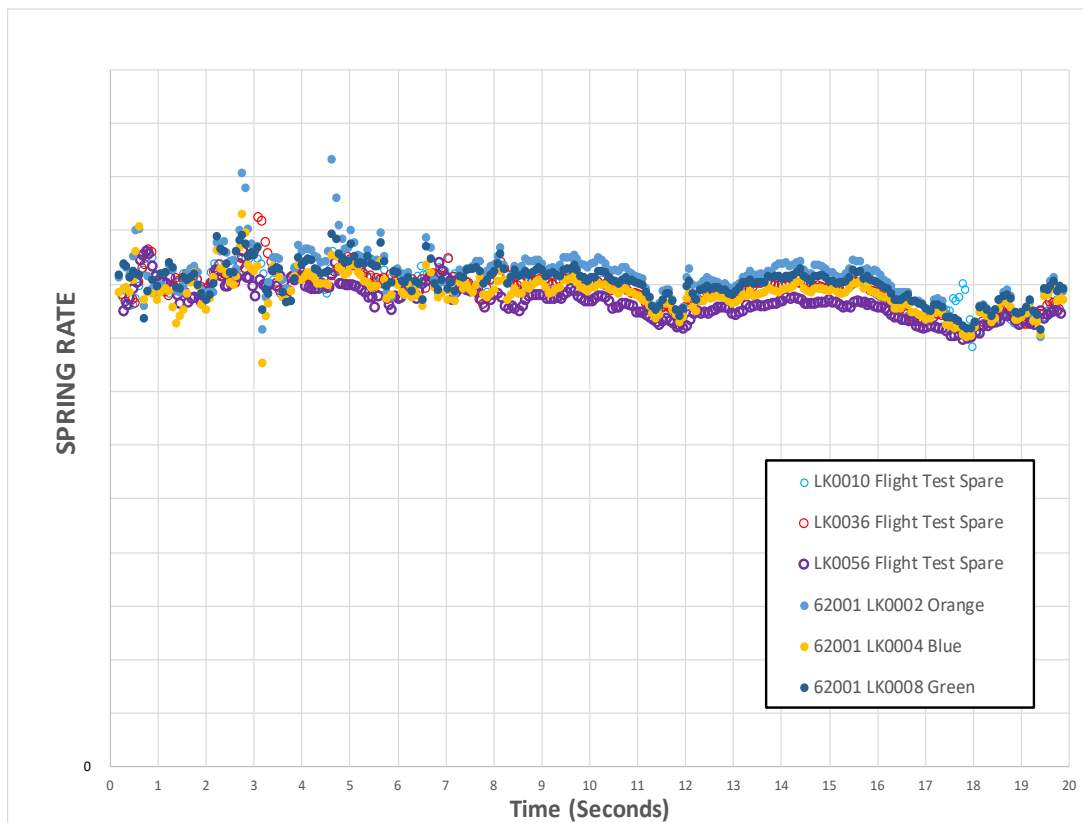


Figure 11. Comparison of the stiffness results between accident and exemplar tail rotor dampers using simulated accident flight conditions.

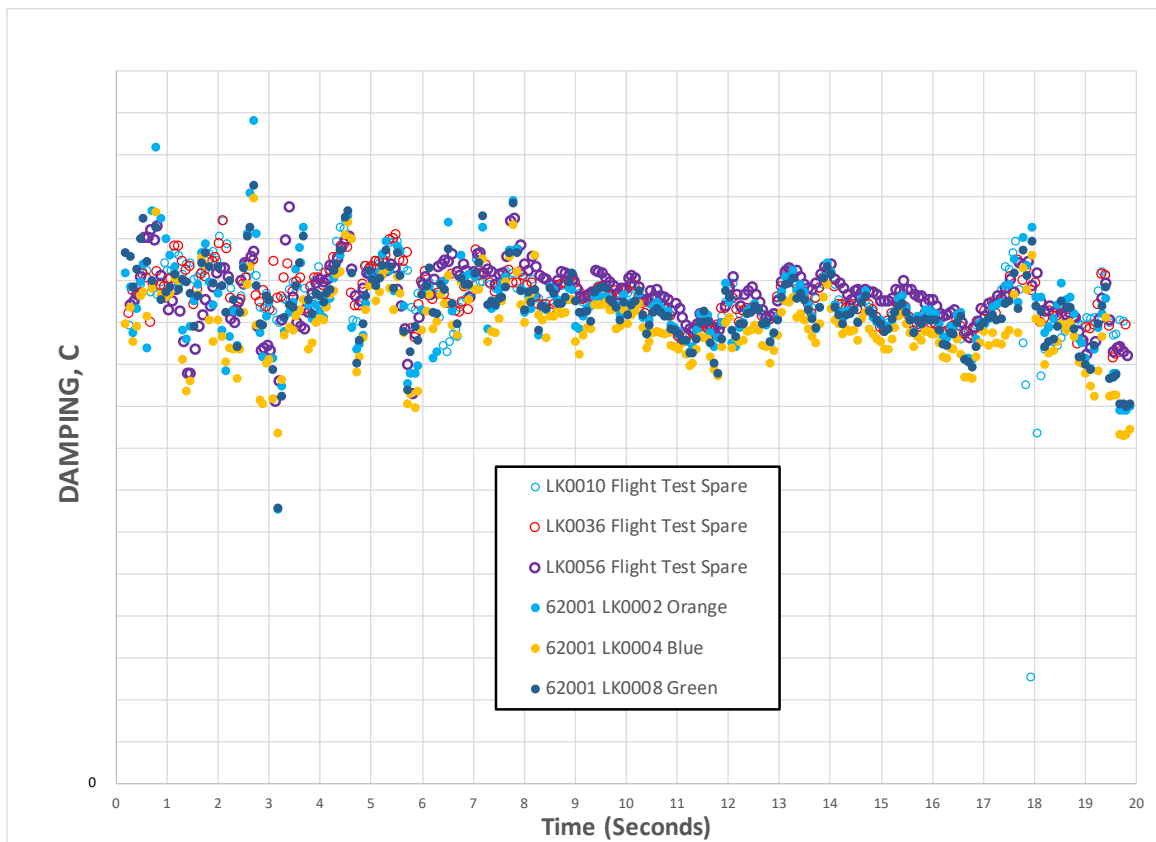


Figure 12. Comparison of the damping results between accident and exemplar tail rotor dampers using simulated accident flight conditions.

4.0 MAINTENANCE HISTORY

During the course of experimental ground and flight testing, discrepancies and anomalies (also known as “squawks”) that were discovered on the helicopter were recorded, prioritized, and tracked. Aircraft systems interim procedures (ASIP) provided instructions for periodic or on-condition inspection and/or maintenance. Inspection tasks, including those required by ASIPs and experimental engineering orders (EEO), were logged into a database with comments including inspection results. A pre-flight briefing sheet included sections that reviewed squawks, recent maintenance actions performed (including configuration changes), and recent inspections performed along with the inspection results.

Recent maintenance performed on the accident helicopter prior to the accident flight included:

- A non-destructive inspection and tap test of all four tail rotor blades. No damage was noted.
- A detailed visual inspection of the tail rotor hub. No damage was noted.
- A torque check of the pylon beam attaching hardware. No movement of the attaching hardware was noted.
- A recurrent inspection of airframe longerons required by an ASIP. No anomalous findings reported.

Chihoon Shin
Aerospace Engineer – Helicopters