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

February 13, 2022

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: DCA20LA100

A. ACCIDENT

Operator: Construction Helicopters, Inc.
Aircraft: Sikorsky S-61N, registration N908CH
Location: Camp Dwyer, Afghanistan
Date: April 20, 2020
Time: 0800 local time

B. GROUP

Group Chairman: Chihoon Shin
National Transportation Safety Board
Washington, District of Columbia

Member: Todd Gentry
Federal Aviation Administration
Washington, District of Columbia

Member: Paris D'Avanzo
Construction Helicopters, Inc.
Howell, Michigan

Member: Clayton Carson
Carson Helicopters, Inc.
Perkasie, Pennsylvania

Member: Rod Manogue
Carson Helicopters, Inc.
Perkasie, Pennsylvania

Member: Dave Blair
Sikorsky, a Lockheed Martin company
Stratford, Connecticut

Member:	Javier Casanova Sikorsky, a Lockheed Martin company West Palm Beach, Florida
Member:	Stu Drost Sikorsky, a Lockheed Martin company Stratford, Connecticut
Member:	David Gridley GE Aviation Lynn, Massachusetts

LIST OF ACRONYMS

ATT	aircraft total time
CAMP	continuous airworthiness maintenance program
CFR	Code of Federal Regulations
CT	computed tomography
CTSN	component time since new
CTSO	component time since overhaul
DC	District of Columbia
EIP	Equalized Inspection [and Maintenance] Program
FAA	Federal Aviation Administration
FDM	flight data monitoring
GE	General Electric
lbs	pounds
NTSB	National Transportation Safety Board
P/N	part number
psi	pounds per square inch
S/N	serial number
STC	Supplemental Type Certificate
TRDS	tail rotor drive shaft

C. SUMMARY

On April 20, 2020, about 0800 local time, a Sikorsky S-61N, N908CH, experienced a loss of control in flight and rolled on its side during an emergency landing at Camp Dwyer, Afghanistan. The flight was operated by Construction Helicopters, Inc., doing business as CHI Aviation, under the provisions of 14 *Code of Federal Regulations* (CFR) Part 135 as a cargo flight under contract with the United States Department of Defense. Two pilots and one crew chief were on board the helicopter. All three were seriously injured. The helicopter sustained substantial damage. In accordance with Annex 13 of the International Civil Aviation Organization, the National Transportation Safety Board (NTSB) accepted delegation of the investigation from the Afghanistan Civil Aviation Authority.

The investigation found that a sudden, uncommanded left pedal forward movement initiated a left yaw that continued until ground impact. Examination of the auxiliary servocylinder assembly found a fatigue crack on the housing of the yaw channel pedal damper check valve as well as cracks and fractures on its bolts.

D. DETAILS OF THE INVESTIGATION

1.0 HELICOPTER INFORMATION

1.1 HELICOPTER DESCRIPTION

The Sikorsky S-61N is type certificated under Federal Aviation Administration (FAA) type certificate data sheet No. 1H15 as a Transport Category helicopter under Categories A and B. The helicopter has a five-bladed main rotor system that provides helicopter lift and thrust. The accident helicopter was equipped with composite main rotor blades installed under the provisions of FAA Supplemental Type Certificate (STC) No. SR01585NY held by Carson Helicopters, Inc. A five-bladed tail rotor provides thrust for helicopter directional control. The helicopter was equipped with two General Electric (GE) CT58-140-2 turboshaft engines mounted side-by-side, forward of the main gearbox input housing. The helicopter was equipped with a reverse-tricycle wheeled landing gear. The operator installed an Appareo Vision 1000 flight data monitoring (FDM) device under STC No. SR02797CH.

The S-61N cockpit flight controls are a typical configuration that employs a cyclic control and pedals to control the helicopter's pitch, roll, and yaw, as well as a collective control for collective pitch changes to the main rotor blades. Inputs from the cockpit cyclic control, collective control, and pedals are transmitted to the auxiliary servocylinder assembly via control tubes (**Figure 1**). The auxiliary servocylinder hydraulically actuates the control linkages to the main rotor hydraulic servo-actuators for pitch, roll, and collective changes. Additionally, the auxiliary servocylinder hydraulically actuates the forward [tail rotor control] quadrant, located near the auxiliary servocylinder. The tail rotor control cables are connected to the forward control quadrant and the aft [tail rotor control] quadrant, located near the aft end of the tail boom. Control tubes connect the aft quadrant to the tail rotor bellcrank. A negative force gradient spring is also connected to the bellcrank. When the auxiliary hydraulic system, and thus the auxiliary servocylinder, is turned off, the negative force gradient spring is designed to aid the pilot's pedal inputs for directional control by overcoming the tail rotor blades' aerodynamic tendency to go to zero pitch.

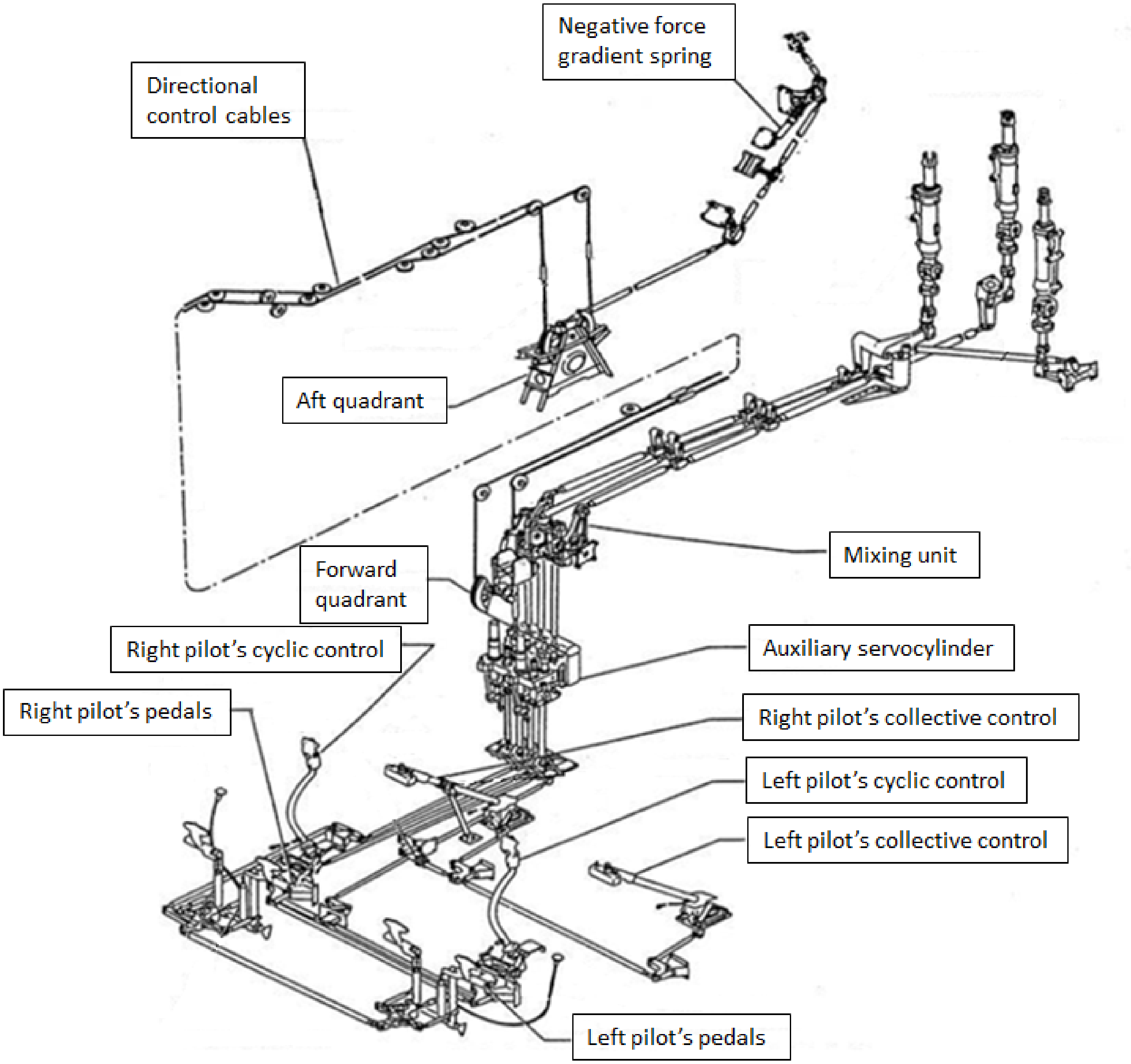

Figure 1. A diagram of the S-61N flight control system showing the major components of the cockpit flight controls and the directional control system. (Image courtesy of Sikorsky and edited by the NTSB)

1.2 ENGINE DESCRIPTION

The GE CT58-140-2 is an axial flow, free turbine engine with a maximum one-engine inoperative (2.5 minute) rating of 1,500 shaft horsepower. The gas generator is composed of a 10-stage compressor, an annular combustor, and a 2-stage turbine. The inlet guide vanes, with variable stators, are in the front of the first stage compressor. Three stages of variable guide vanes are located between the first and fourth stage compressors. A hydromechanical fuel control meters fuel to the combustor. A single-stage power turbine provides engine power output to the high speed shaft.

1.3 HELICOPTER HISTORY

The accident helicopter, serial number (S/N) 61776, was manufactured in 1977. According to helicopter records, on the day prior to the accident, the helicopter had an aircraft total time (ATT) of 38,495.8 hours; the No. 1 engine had a total time of 30,465.7 hours; and the No. 2 engine had a total time of 10,414.0 hours.

2.0 OBSERVATIONS AT THE ACCIDENT SITE[1,2]

2.1 GENERAL WRECKAGE OBSERVATIONS

The helicopter came to rest on its right side at a heading of about 74 degrees magnetic (**Figure 2**). There was no evidence of an inflight breakup of its airframe. The tail boom was twisted further to the right compared to the main fuselage. The main rotor gearbox remained attached to the airframe and the main rotor head remained installed. All five main rotor blade cuffs remained attached to the main rotor head. The inboard sections of four main rotor blades remained attached to their respective cuffs and the outboard sections of these blades were found in the vicinity of the main wreckage, with the furthest section found about 979 feet away from the main wreckage. The 'white' main rotor blade had separated from its cuff but was found near the main wreckage. Main rotor blade weights and along with blade fragments were found generally to the right of the main wreckage in various distances. All main rotor rotating controls, from the rotating swashplate to the pitch change links, were present.

Figure 2. The accident helicopter. (Image courtesy of CHI Aviation)

The No. 1 tail rotor drive shaft (TRDS) remained attached to the tail takeoff flange. The No. 2 TRDS remained connected to the No. 1 TRDS but the flanges and flexible coupling at the

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[1] NTSB investigators did not travel to the accident site. Photographs and observations were gathered by the operator and provided to the NTSB. Additional documentation was performed by the operator with guidance from the NTSB.

[2] 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. Additionally, clock positions are in the ALF frame of reference unless otherwise specified.

connection point was axially deformed. The belt driving the blower fan remained installed. The forward section of the No. 3 TRDS was found in the vicinity of the main wreckage. The aft end of this segment was fractured and the shaft exhibited curling deformation. The remainder of the No. 3 TRDS was installed on the tail boom and was connected to the intermediate gearbox. The flexible coupling at the intermediate gearbox connection was slightly deformed with a wavy appearance. The No.4 TRDS remained installed between the intermediate and tail gearboxes and had no significant damage.

The tail rotor gearbox remained installed on the vertical stabilizer. The tail rotor remained attached to the tail gearbox. All five tail rotor blades remained attached, with three blades exhibiting chordwise bending. All tail rotor rotating controls were present.

2.2 COCKPIT

The primary hydraulic pressure gauge remained installed on the instrument panel and indicated slightly above the 9 o'clock position (**Figure 3**).[3] The auxiliary hydraulic pressure gauge remained installed on the instrument panel and indicated slightly above the 3 o'clock position, which was about the 0 pounds per square inch (psi) on the gauge. Both engine speed selector levers were in the shut-off position and both fire emergency shut-off selectors (T-handles) were pulled (**Figure 4**).

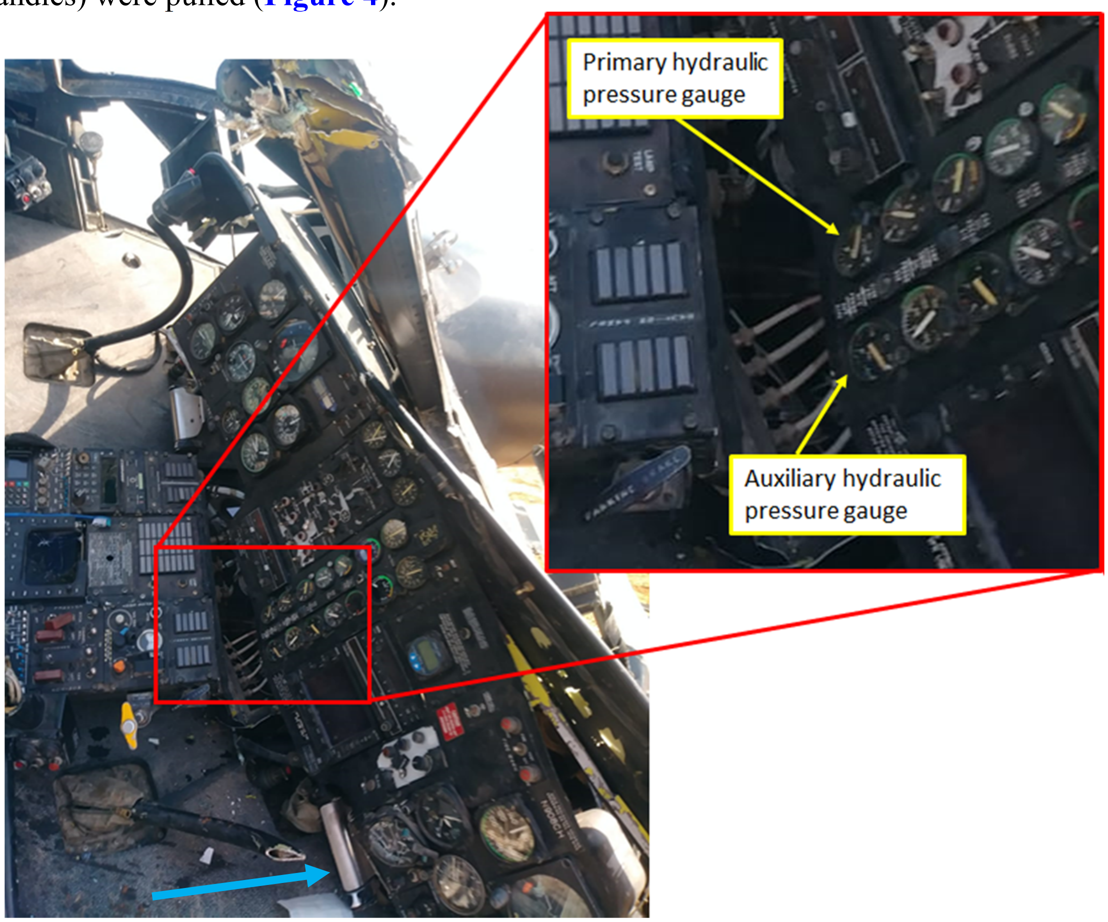

Figure 3. A view of the cockpit instruments. The blue arrow points to the right pilot's right pedal. The inset photo shows the primary and auxiliary hydraulic pressure gauge needle positions. (Image courtesy of CHI Aviation)

[3] On the hydraulic pressure gauge, the 9 o'clock position is the region that indicates normal hydraulic system pressure.

Figure 4. The engine speed selector levers and emergency shut-off T-handles. Note the cockpit roof appears upside-down due to its partial separation during the postcrash rescue of the crewmembers. (Image courtesy of CHI Aviation)

2.2.1 LEFT PILOT SEAT

The left pilot seat cyclic, collective, and pedals remained installed. The collective head was fractured but remained connected to the collective control via wiring. The left pedal was displaced fully forward and the right pedal was displaced fully aft (**Figure 5**). The collective-mounted hydraulic switch was found in the “AUX OFF” position (**Figure 6**).[4]

2.2.2 RIGHT PILOT SEAT

The right pilot seat cyclic control remained attached to its base but its upper portion, including grip, were not present. It could not be determined based on photographs if this grip was fractured or if it was cut to facilitate crew rescue. The

[4] The collective-mounted hydraulic switch has three positions: neutral (center), “AUX OFF” (down), and “PRI OFF” (up). The neutral position is used for normal flight and . The “AUX OFF” position is used to cut off hydraulic pressure to the auxiliary servocylinder. The “PRI OFF” position is used to cut off hydraulic pressure to the main rotor hydraulic (primary) servo-actuators.

collective head was fractured but remained connected to the collective control via wiring. The collective-mounted hydraulic switch was found in the center position (**Figure 7**). The left pedal could not be accessed due to crushing damage, therefore its position could not be determined. The right pedal was visible and appeared to be aft of its neutral position (**Figure 3**).

Figure 5. The left pilot's pedals. The left pedal (blue arrow) was displaced forward of neutral while the right pedal (red arrow) was displaced aft of neutral. (Image courtesy of CHI Aviation)

Figure 6. The left pilot's collective-mounted hydraulics switch. (Image courtesy of CHI Aviation)

Figure 7. The right pilot's collective-mounted hydraulics switch. (Image courtesy of CHI Aviation)

2.3 DIRECTIONAL CONTROL SYSTEM

The auxiliary servocylinder remained installed but its surrounding structure had partially collapsed to the right (**Figure 8**). The input control tubes to the auxiliary servocylinder remained connected at their rod ends but the tubes were fractured at various locations. The output control tubes from the auxiliary servocylinder remained connected at their rod ends, but there was no evidence of disconnection of the control tubes leading up to the mixing unit. The hydraulic lines to the auxiliary servocylinder remained attached and the plastic shield was intact. A small pool of hydraulic fluid was observed to the right of the auxiliary servocylinder (**Figure 9**).

The tail rotor control cables were fractured in multiple locations between the forward and aft control quadrants. A single control cable, routed through the right-side holes in multiple structural frames, was visible near the No. 1 TRDS, which was fractured and frayed at its forward end and continued aft below the blower fan, past the right-side air stairs. The aft end of this single control cable had torn through a structural frame toward the right side of the helicopter (**Figure 10**). Two control cables were observed within the tail boom and were continuous to the aft control quadrant, which remained installed within the tail boom structure. The control tubes between the aft control quadrant were continuous to the tail rotor gearbox. The negative force gradient spring remained attached to the airframe and the tail rotor bellcrank (**Figure 11**).

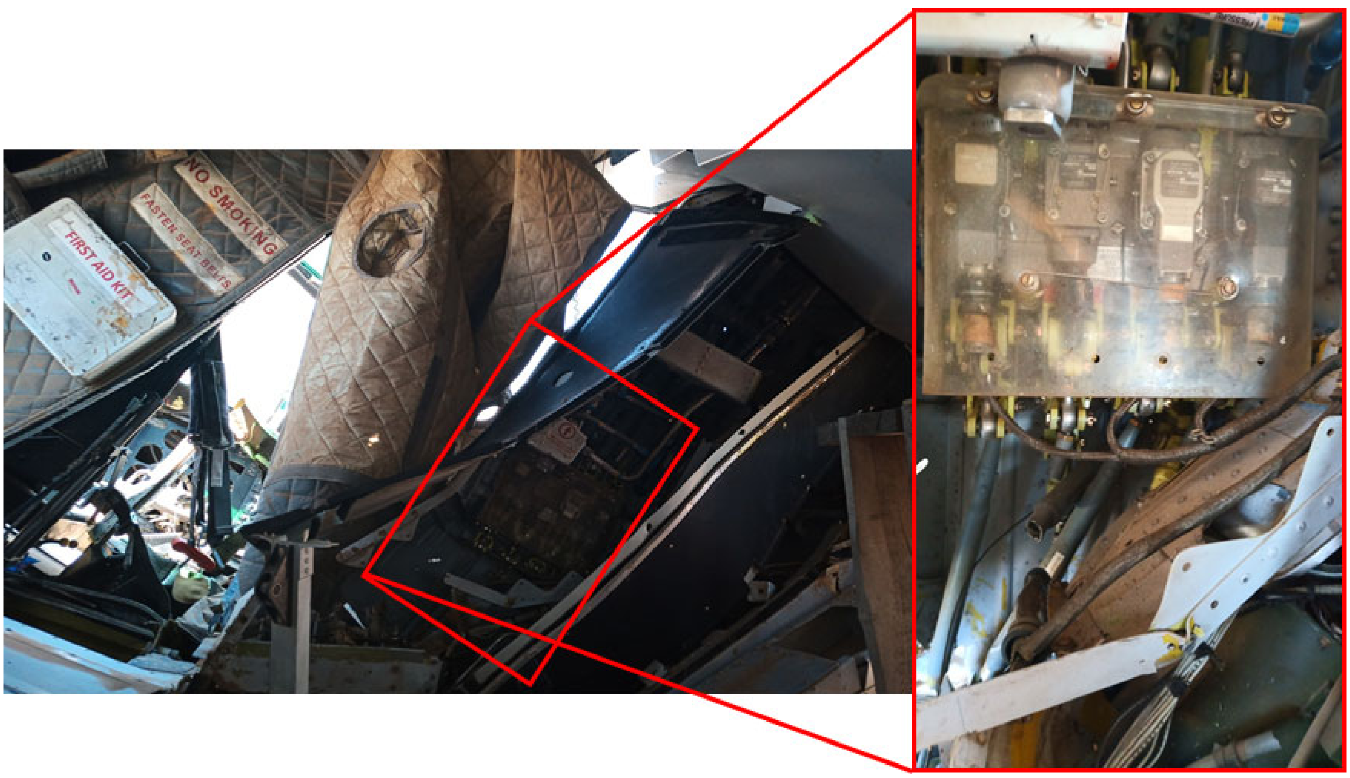

Figure 8. The auxiliary servocylinder installation. (Image courtesy of CHI Aviation)

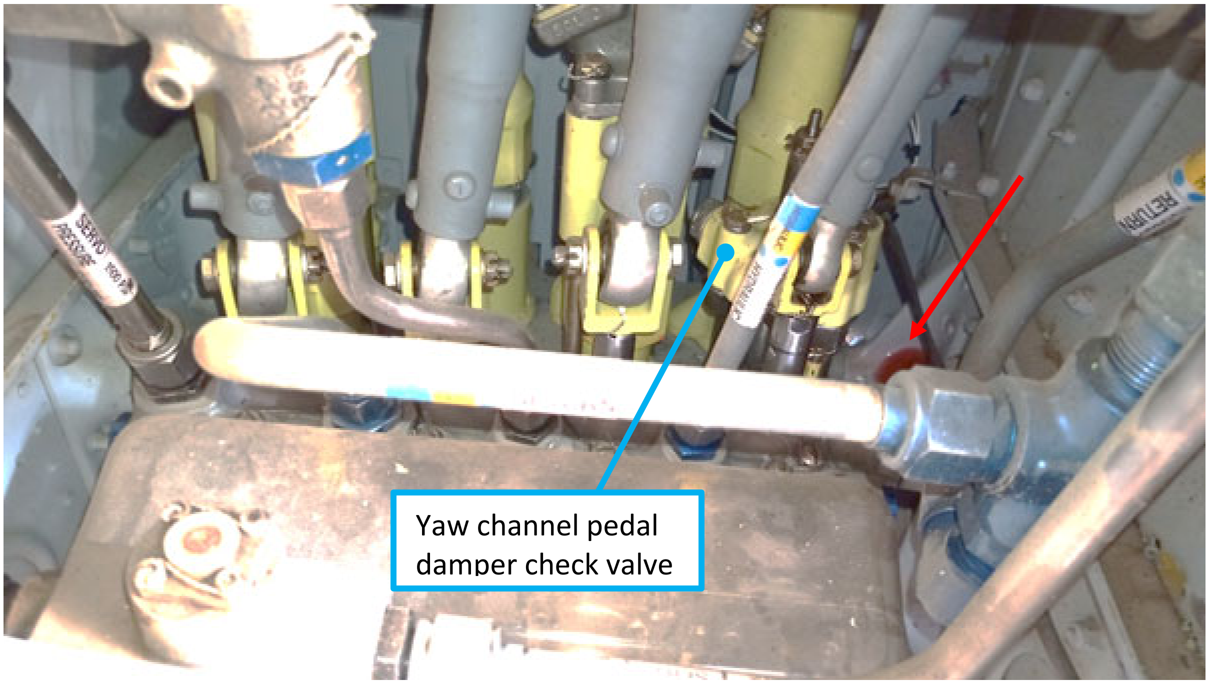

Figure 9. A red arrow points to a small pool of hydraulic fluid visible to the right of the auxiliary servocylinder. (Image courtesy of CHI Aviation)

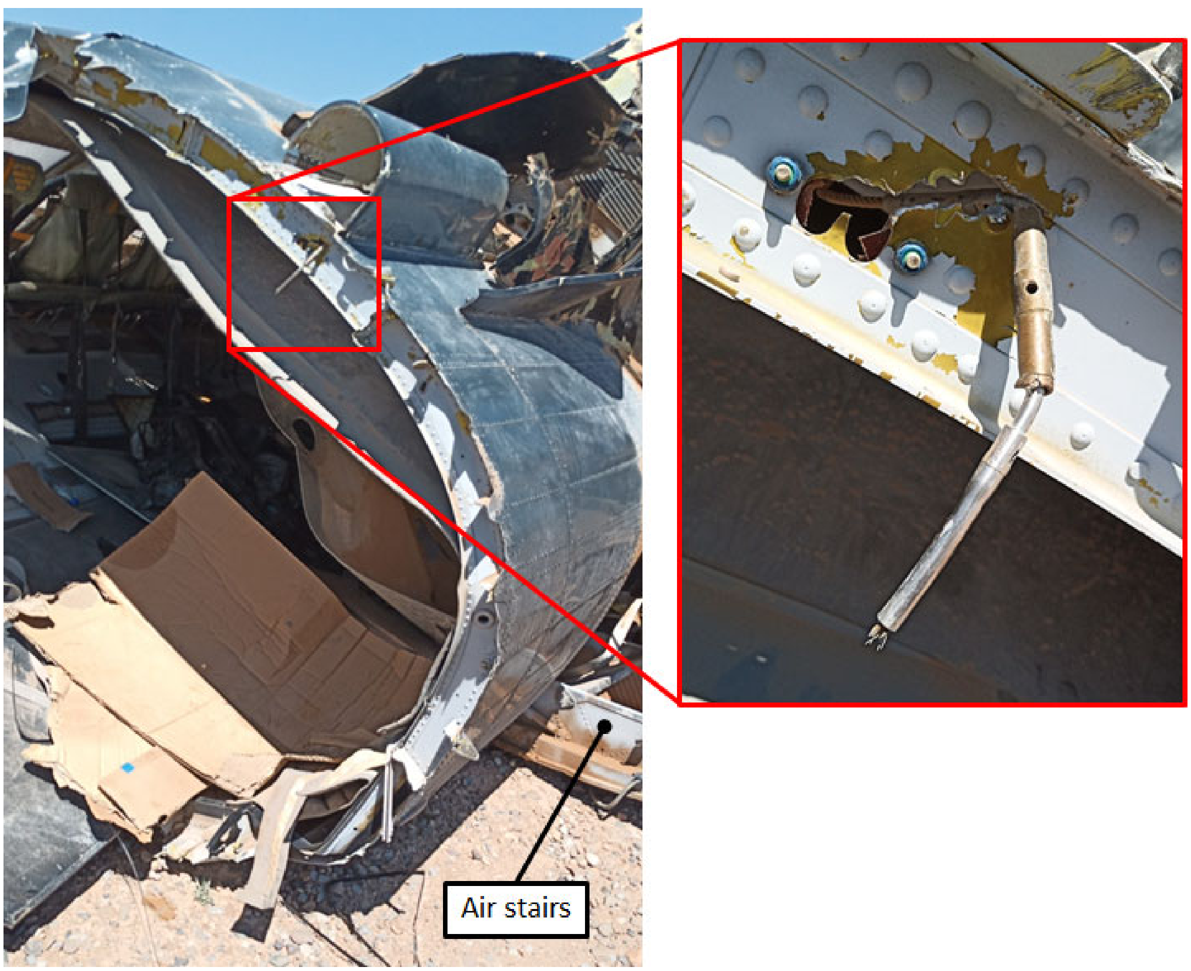

Figure 10. A fractured tail rotor control cable observed within a structural frame. (Image courtesy of CHI Aviation)

Figure 11. The negative force gradient spring (red arrow) installation on the vertical fin. (Image courtesy of CHI Aviation)

2.4 APPAREO VISION 1000

The accident helicopter had an Appareo Vision 1000 image recorder installed on the ceiling of the cockpit. The image recorder was forward-looking, with a view of the instrument panel, a portion of the left and right seat cockpit controls, and a partial view of the outside via the lower portion of the windscreen. The Vision 1000 recorded the accident flight and revealed that, about 8.75 seconds prior to the end of recorded data, the left seated pilot's left pedal moved to the fully forward position without pilot input, resulting in the helicopter yawing to the left. The left pedal remained in its fully forward position and the helicopter continued to yaw left for the remainder of the recording. The cockpit auxiliary hydraulic pressure gauge indicator was within the green arc during this time, and indicated about 1,500 psi about 1 second prior to the left pedal movement, after which it dipped to 1,300 psi (near the bottom of the green arc). For additional details on the data recovered from the Appareo Vision 1000, see the *Onboard Image Recorder Factual Report* in the docket for this investigation.

3.0 AUXILIARY SERVOCYLINDER

At the request of the NTSB, the operator recovered the auxiliary servocylinder assembly from the accident helicopter and shipped it to the NTSB in Washington, District of Columbia (DC) for further examination. On the yaw channel pedal damper check valve housing (P/N S6165-61517-2), the forward-right bolt[5] (P/N AN3H5A) was fractured but its bolt head remained attached to its safety wiring (**Figure 12**). The safety wiring remained attached to the forward-left bolt (also P/N AN3H5A) on the pedal damper check valve housing. Additionally, an extruded piece of an O-ring near the fractured bolt was present at the interface between the pedal damper check valve and the pedal damper body.

[5] The bolt position is when viewed with the auxiliary servocylinder assembly installed on the helicopter

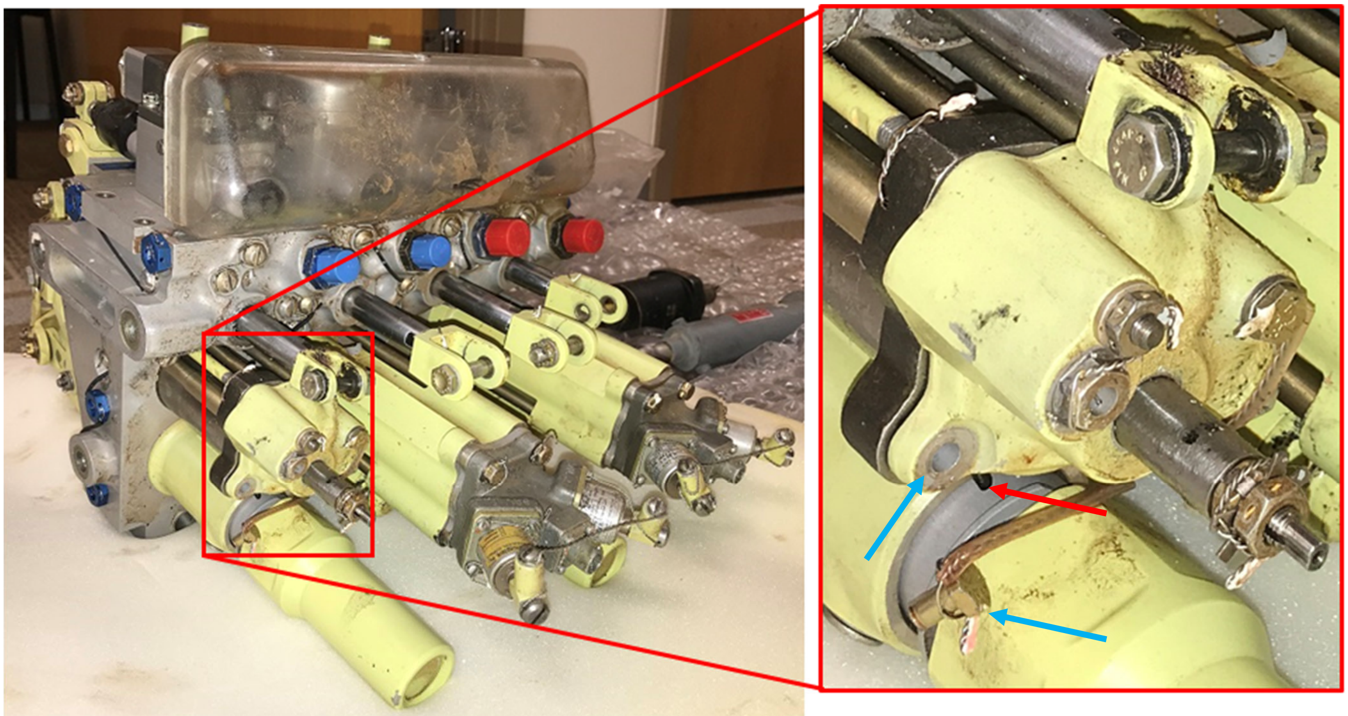

Figure 12. The auxiliary servocylinder as received. The blue arrows point to the fractured forward-right AN3H5A bolt and its bolt hole. The red arrow points to the extruded O-ring.

From October 27 to November 10, 2020, the auxiliary servocylinder was scanned using computed tomography (CT). The detailed findings for the CT images can be found in the *Computed Tomography Specialist's Factual Report* in the docket for this investigation.

From May 24-26, 2021, representatives from the NTSB, the FAA, CHI Aviation, Sikorsky, and Carson Helicopters convened at Sikorsky facilities in Trumbull, Connecticut to bench test and disassemble the auxiliary servocylinder.

3.1 AUXILIARY SERVOCYLINDER YAW CHANNEL DESCRIPTION

During normal operation of the auxiliary servocylinder, pressurized hydraulic fluid is supplied to all four channels (pitch, roll, collective, and yaw) of the auxiliary servocylinder assembly. Within the yaw channel, pressurized hydraulic fluid ports are located in the bypass valve, pedal damper, and the pilot valve (also known as the input valve). A hydraulic fluid return port is located between the input valve and power piston. The pedal damper is a closed loop system whose piston pushes hydraulic fluid from one side of the piston to the other side of the piston through a restrictor, with an internal spring that allows for limited movement without hydraulic dampening. This design prevents sudden, large displacement pedal movements by the pilots. As seen in **Figure 13**, movement of the input linkage via the pedals will result in a movement of the input valve, porting pressurized hydraulic fluid to one side of the power piston and the return port to the other side of the power piston. This results in a movement of the power piston that moves the remainder of the directional control system downstream of the auxiliary servocylinder to change the pitch of the tail rotor blades.

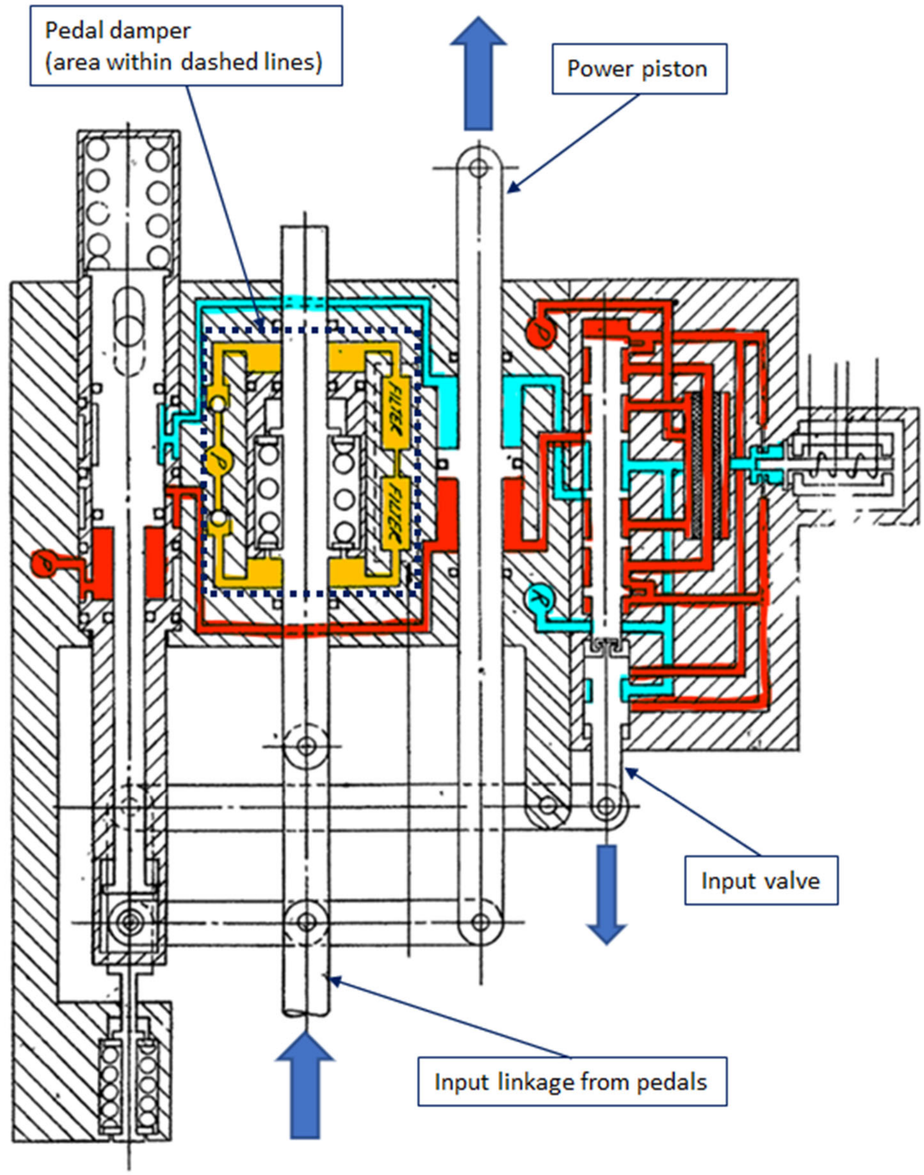

Figure 13. A generalized cross-sectional diagram showing the yaw channel of the auxiliary servocylinder assembly. The red lines indicate passageways for the pressurized hydraulic fluid while the blue lines indicate hydraulic return passageways. The orange area indicates the pressurized hydraulic fluid within the pedal damper. The blue arrows indicate the movement of linkages and valves for a left pedal input by the pilot.

3.2 BENCH TESTING

The input linkages to the yaw channel were bent. Based on the damage observed to the yaw channel of the auxiliary servocylinder, the proof pressure test was skipped. The yaw open loop spring was removed due to interference with the fore-aft linkage. Hydraulic pressure from the test bench was applied to the auxiliary servocylinder, increasing the pressure slowly to monitor for evidence of leaks. When the test bench hydraulic pressure was just under 200 psi, the yaw channel began to exhibit a leak at the pedal damper check valve housing in the area of the fractured AN3H5A bolt. A crack was also visible on the pedal damper check valve housing near the forward-right AN3H5A bolt (**Figure 14**). Bench testing was stopped at this point. The bench test hydraulic supply and return filters, both with a 3-micron filtration capability, were removed.

The supply-side filter exhibited a clean, fluid-soaked appearance and was free of debris. The return filter exhibited a clean appearance, showed only a small amount of fluid staining from the hydraulic fluid, and was free of debris.

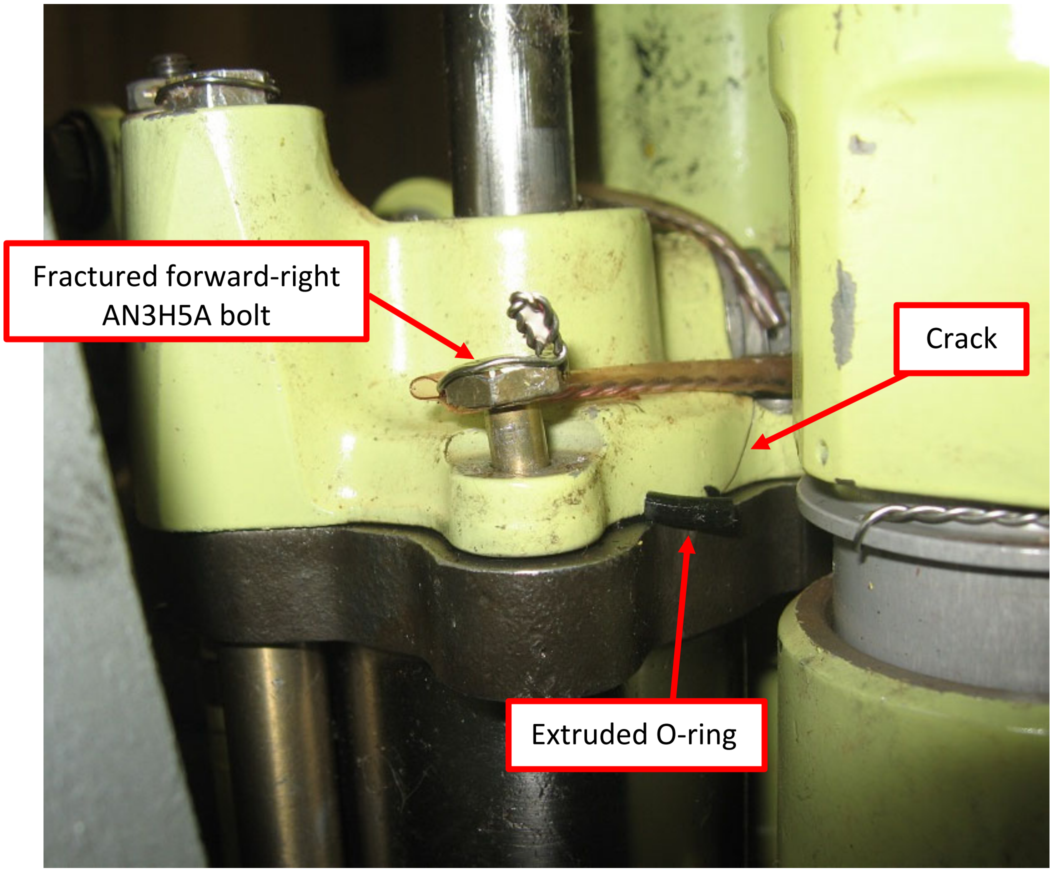

Figure 14. The auxiliary servocylinder pedal damper check valve housing. (Image courtesy of Sikorsky)

3.2 DISASSEMBLY

During removal of the input linkages, the slop eliminator was found to have a crack near its lower end, on its forward and aft sides. In the area of the crack, the slop eliminator was deformed inboard. The pedal damper was removed and the orifices in the auxiliary servocylinder housing were clear of debris or anomalous damage. The pedal damper check was removed and the forward-right AN3H5A bolt remained installed but a small gap was present underneath its bolt head (**Figure 15**). The pedal damper check valve housing's forward-right AN3H5A bolt was removed and the bolt exhibited a crack on the threaded shank (on the bolt head end) as well as a slight bend. The crack on the pedal damper check valve housing extended toward the threaded bore for plug P/N S6165-61525, but neither the plug nor its threaded bore exhibited cracks (**Figure 16**). The extruded O-ring on the check valve housing was removed and exhibited separation near its extruded location. Additional details of the metallography performed on the pedal damper check valve housing crack can be found in Section 3.3 of this report. The remainder of the pedal damper was disassembled and its subcomponents showed no evidence of anomalous damage.

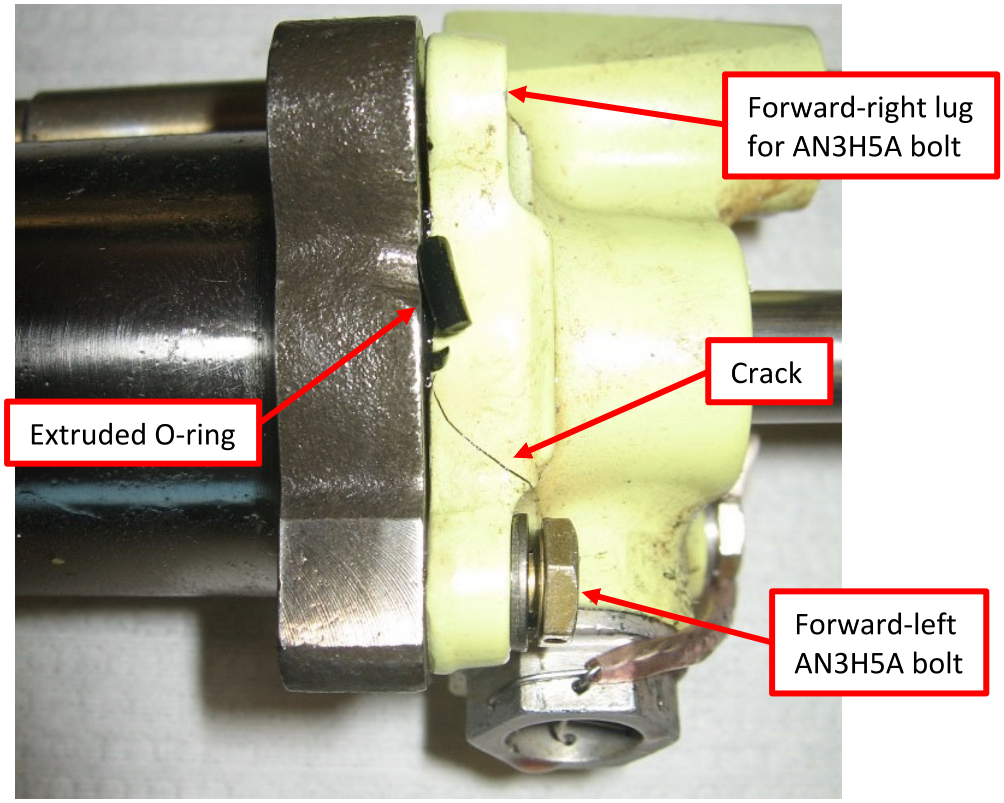

Figure 15. The pedal damper check valve housing still installed on the pedal damper. (Image courtesy of Sikorsky)

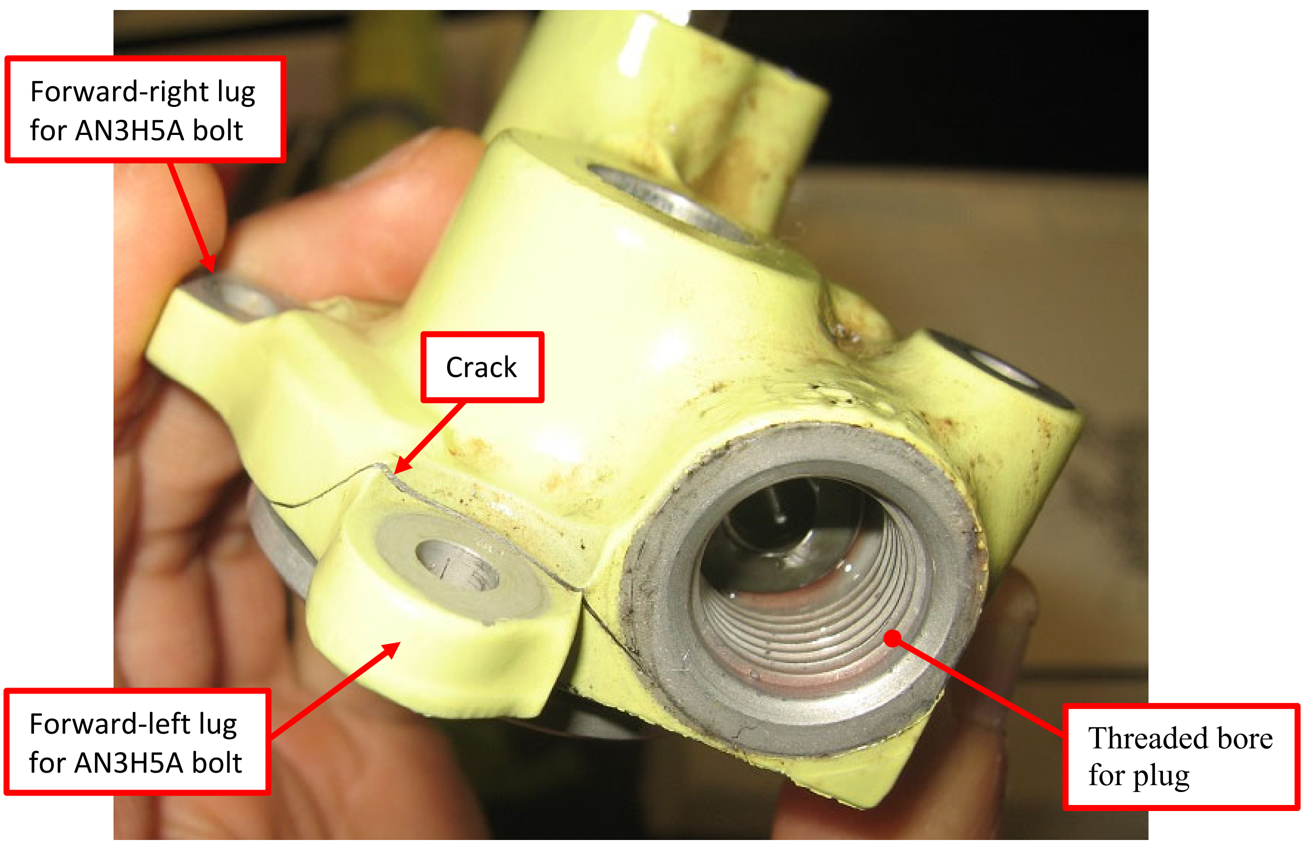

Figure 16. A view of the pedal damper check valve housing showing the extent of crack growth on the AN3H5A bolt hole lug. (Image courtesy of Sikorsky)

The yaw power piston rod end exhibited a slight bend. The pitch, roll, collective, and yaw power pistons were removed and their surfaces had a shiny appearance and typical in-service wear, none of which exhibited significant depth with a tactile check. All O-rings and backup rings on the pistons were in good condition and had no cuts or extrusions. The sleeves remained installed within the power piston bores except for the collective channel whose sleeve came out with the collective power piston. The internal surfaces of the sleeves had a clean appearance with no anomalous damage. The felt on the yaw power piston end cap was present and contained some dirt with a blackened appearance.

The yaw bypass valve was removed and disassembled. The spring showed evidence of contact within its housing. The technician disassembling the auxiliary servocylinder assembly noted that this spring-to-housing contact was not unusual. The remainder of the yaw bypass valve showed no evidence of anomalous damage. The collective bypass valve, pitch trim, and roll trim were removed as a subassembly and not disassembled further. On the servocylinder assembly housing, the bores for the bypass valves and trim did not exhibit anomalous damage. The servovalves for the pitch, roll, collective, and yaw channels, manufactured by Moog, were removed as a subassembly and not disassembled further. The yaw servovalve was examined at Moog at a later date. See section 3.4 of this report for additional details on the yaw servovalve examination.

3.3 PEDAL DAMPER CHECK VALVE HOUSING AND BOLTS

The pedal damper check valve housing and both the fractured and cracked AN3H5A bolts were examined by the Sikorsky Materials and Processing laboratory in Stratford, Connecticut from May-July 2021. Scanning electron microscope (SEM) examination of the fractured (forward-left) bolt showed signatures consistent with fatigue. Multiple fatigue origins were observed at the root of the first engaged thread. The area of the fracture surface was about 75% fatigue and about 25% overload. The material composition and hardness conformed to the required specifications, MIL-S-6049 and MIL-B-6812, respectively. The cracked (forward-right) bolt exhibited multiple cracks in the first three engaged thread roots. Both the fractured (forward-left) and cracked (forward-right) bolts appeared to conform to the required configuration based on grip length, thread length, and thread major and minor diameters.

The check valve housing crack was mechanically fractured in the lab to expose the fracture surface. The fracture surface exhibited fatigue for the vast majority of the surface, aside from a small portion of overload that was created when the lab opened the crack (**Figures 17 and 18**). The fatigue fracture surface showed no evidence of damage or contact wear. A red-colored oil, likely hydraulic fluid, was present within the crack when it was opened. The fatigue origin was located near the radius of the lug. The radius was measured to be about 0.003 inches, which did not conform with drawing requirements to break all sharp edges to 0.005 to 0.015 inches. The material composition and hardness conformed to drawing requirements, and the microstructure appeared typical for the material.

Additional details of the laboratory examination were provided in a memorandum by Sikorsky and can be found in Attachment 1 of this report.

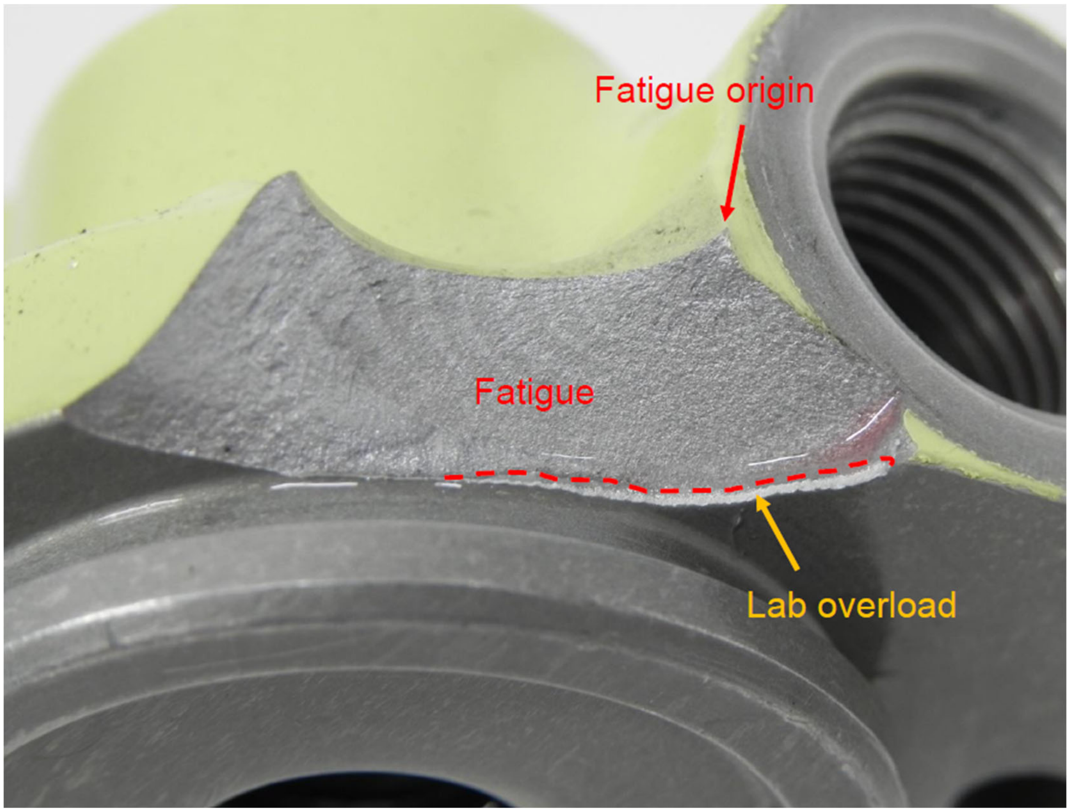

Figure 17. Areas of fatigue cracking identified on the forward-left lug of the pedal damper check valve housing. (Image courtesy of Sikorsky)

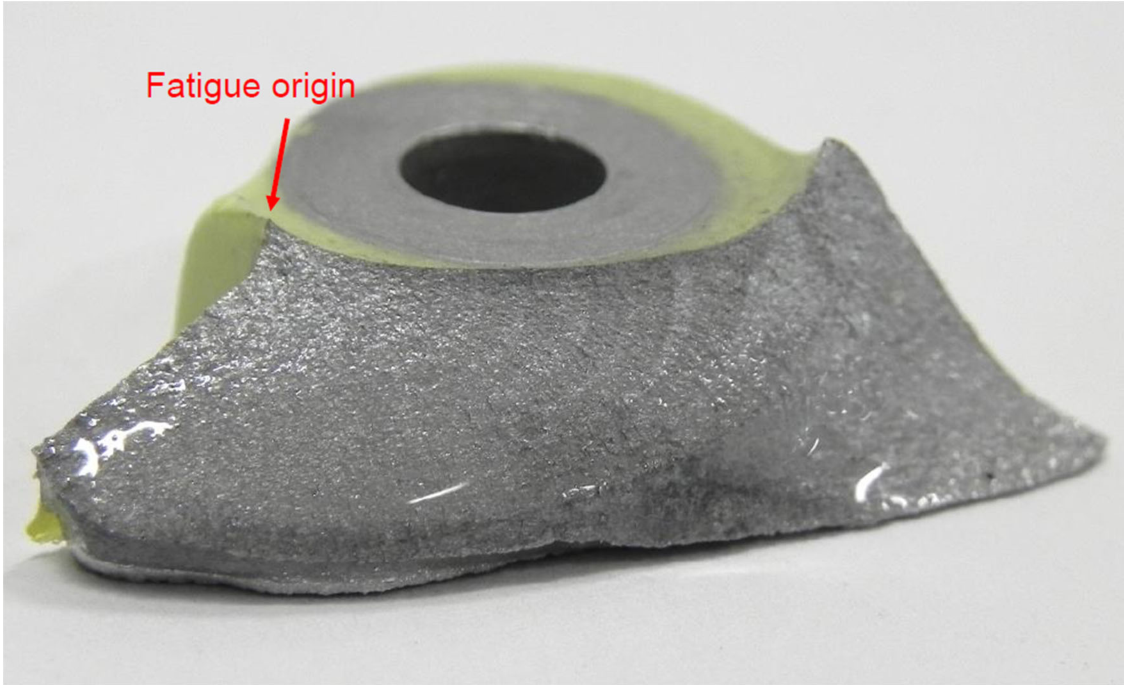

Figure 18. Fatigue cracking on the forward-left lug of the pedal damper check valve housing. (Image courtesy of Sikorsky)

3.4 YAW SERVOVALVE

On July 7, 2021, representatives from the NTSB, FAA, Sikorsky and Moog convened at Moog facilities in East Aurora, New York to bench test and disassemble the yaw servovalve, Moog P/N 010-59291 and S/N 50. The exterior of the servovalve was in good condition and its O-rings exhibited no cuts or extrusions. The servovalve was installed on a test bench and 1500 psi of hydraulic pressure was applied; there was no evidence of external leakages. A gain (flow rate vs. current) test was performed and the resultant trace was within the upper and lower limits, consistent with the hydraulic and electric functionality of the unit being within the required performance parameters. The unit's internal leakage was measured at 0.65 cubic inches per second, beyond the upper limit.

The electrical connector was removed and exhibited no anomalous damage. The wiring between the electrical connector and the motor was cut by the technician as part of the normal disassembly process. The motor cap was removed and the large O-ring between the motor cap and servo body exhibited small, grit-like debris. The motor was removed and the surface of the servo, to which the motor attaches, also had a small amount of the grit-like debris.[6] The connector-side of the surface of the servo had anomalous wear where the O-ring contact the servo surface. The input link exhibited typical service wear and no anomalous damage. The two [internal] filters were removed and grit-like debris was present on both filters. The two end caps were removed and their O-rings appeared to be in good condition. The spool and sleeve were removed and neither exhibited anomalous damage. On the servo body, a small linear gouge as well as circumferential damage was observed on the surface that contacts the sleeve (**Figure 19**).

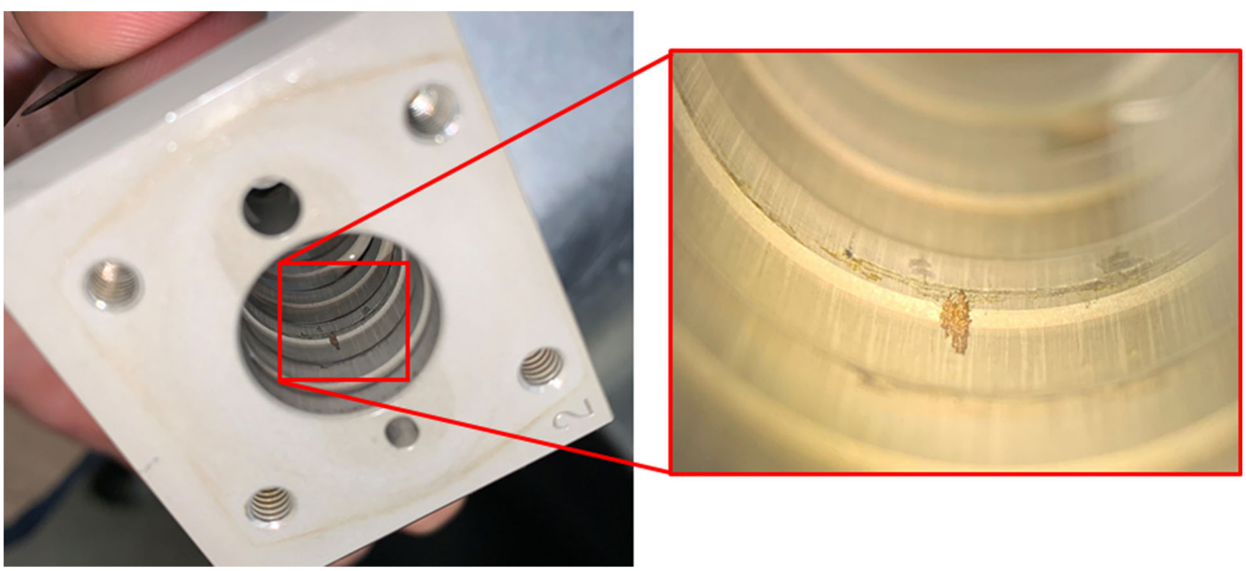

Figure 19. Damage observed within the sleeve bore of the yaw servovalve.

4.0 AUXILIARY HYDRAULIC PRESSURE TRANSMITTER

At the request of the NTSB, the operator recovered the auxiliary hydraulic pressure transmitter from the accident helicopter and shipped it to the NTSB in Washington, DC for further examination. The data plate on the transmitter showed it was P/N ST53A and S/N 4613. The auxiliary hydraulic

[6] Additional details of the debris examination can be found in the NTSB Materials Laboratory Report No. 21-077 in the docket for this investigation.

pressure transmitter was manufactured by Ametek PDS. On June 25, 2021, representatives from the NTSB, Sikorsky, and Ametek convened at Ametek PDS facilities in Binghamton, New York to bench test the auxiliary hydraulic pressure transmitter.

The electrical plug was removed from the transmitter, revealing a four-prong plug. The prongs were undamaged. A fitting was removed from the hydraulic port of the transmitter and there was no evidence of obstruction within the hydraulic port or the fitting. The transmitter was installed on a test bench and compressed air was applied to the test bench to detect evidence of leaks, none of which were found. The test bench compressed air pressure was increased to 2500 psi, the maximum pressure per the test data sheet, and the transmitter still did not exhibit evidence of leaks. The transmitter was tested through different pressure data points per the test data sheet. A second iteration of the test was performed to evaluate the consistency of the bench test results. **Table 1** shows the results of the bench test and **Figure 20** shows a graph of these results.[7]

Table 1. Bench test results for the auxiliary hydraulic pressure transmitter.

Test Point (psi)	Required Autosyn Indication (degrees)	Actual Autosyn Indication Test #1 (degrees)	Actual Autosyn Indication Test #2 (degrees)
0	20	215	239
500	84	263	293
1000	148	316	354
1250	180	354	18
1500	212	22	52
2000	276	101	118
2500	340	144	175

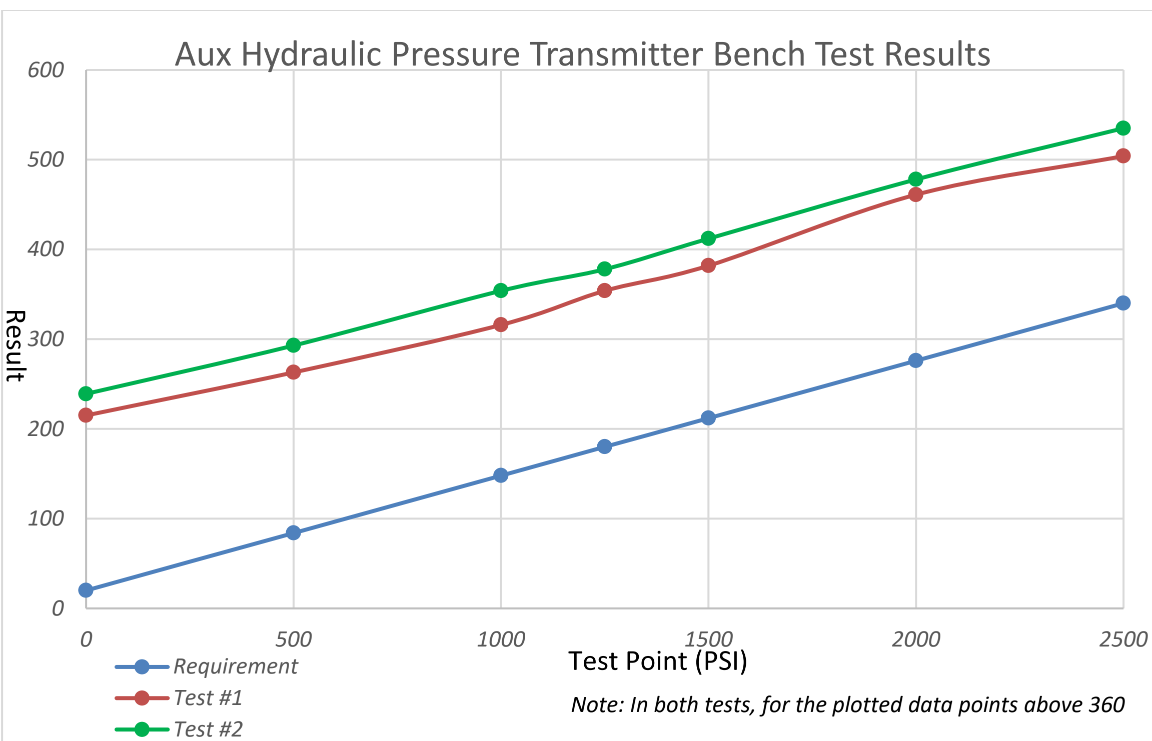

Figure 20. Graphical bench test results of the auxiliary hydraulic pressure transmitter.

[7] The autosyn values are read from 0 to 360 degrees. In order to compare the linear behavior of the autosyn indication from the transmitter for two bench tests in **Figure 19**, 360 degrees was added. For example, in Test #1

5.0 NEGATIVE FORCE GRADIENT SPRING

At the request of the NTSB, the operator recovered the negative force gradient spring assembly from the accident helicopter and shipped it to the NTSB in Washington, DC for further examination. A label on the assembly showed P/N S6140-66604-20 and S/N CCS1704. On May 27, 2021, representatives from the NTSB, Sikorsky, and Carson Helicopters convened at Carson Helicopter facilities in Perkasie, Pennsylvania to examine the negative force gradient spring assembly. A representative from CHI Aviation attended the activity via video conference. The assembly was installed on a test fixture and a pressure gauge was used to read the indicated force at the first sign of movement of the [test] guide. For the first test, the guide moved at about 375 psi, equivalent to 520 pounds (lbs) of force. For the second test, the guide moved at about 400 psi, equivalent to 550 lbs of force. For the third test, the guide moved at 375 psi, equivalent to 520 lbs of force.

The cap (adjusting nut) was removed and the guide was observed to not be flush with the cylinder, but was protruding about 0.125 – 0.250 inches.[8] The guide was adjusted to be flush with the cylinder by the technician, an adjustment normally performed during overhaul of the assembly, but prior to testing of the assembly. After the guide adjustment, the [previously performed] first movement testing was performed again. For the first test, the guide moved at about 430 psi, equivalent to 610 lbs of force. For the second test, the guide moved at about 450 psi, equivalent to 625 lbs of force. For the third test, the guide moved at a range of 440-450 psi, equivalent to 620-625 lbs of force.

The negative force gradient spring assembly was disassembled to examine the internal components. The spring was in good condition with no evidence of fractures or anomalous damage. A total of 7 spacers were present in the spring installation.[9] The grease within the assembly appeared to be in good condition with no evidence of deterioration. No other anomalous damage was observed throughout the disassembly. The negative force gradient spring assembly was reassembled and a third iteration of the first movement test was performed. For the first test, the guide moved at about 475 psi, equivalent to 650 lbs of force. For the second test, the guide moved at a range of 460-470 psi, equivalent to 640-650 lbs of force. For the third test, the guide moved at 470 psi, equivalent to 645 lbs of force.

6.0 TAIL ROTOR CONTROL CABLES

At the request of the NTSB, the operator removed the tail rotor control cables from the wreckage and shipped them to the NTSB in Washington, DC for further examination by the NTSB Materials Laboratory. Examination of the tail rotor control cable fractures revealed overstress failure. Additional details of the tail rotor control cable examination can be found in NTSB Materials Laboratory Report No. 21-059 in the docket for this investigation.

7.0 MAIN ROTOR BLADES

At the request of the NTSB, the operator recovered the five main rotor blades and blade fragments from the accident site and shipped them to NTSB facilities in Ashburn, Virginia. On October 14-15, 2020, representatives from the NTSB, the FAA, Sikorsky, CHI Aviation, and Carson Helicopters convened at NTSB facilities in Ashburn, Virginia to examine the main rotor blades. The main rotor blades and their fragments were reconstructed (**Figure 21**).

[8] The guide can move relative to the cylinder during installation and removal from the helicopter.
[9] The overhaul manual for the negative force gradient spring allows for up to 8 spacers within the spring installation.

Figure 21. The reconstructed main rotor blades.

Numerous blade skin and core pieces that could not be matched to a blade were set aside. All five main rotor blades exhibited significant fragmentation on their outboard ends. The inboard ends of the blades were generally whole with distinctive fractures in a generally chordwise direction. Additional details of the findings from the main rotor blade reconstruction and examination can be found in NTSB Materials Laboratory Report No. 20-062 in the docket for this investigation.

8.0 HELICOPTER MAINTENANCE

CHI Aviation maintained the accident helicopter under an FAA approved continuous airworthiness maintenance program (CAMP). At the time of the accident, revision 7 of the operator's S-61 CAMP manual, dated September 26, 2019, was in effect.

The operator's S-61 CAMP required a safety inspection at a 15-hour interval. The safety inspection was composed of primarily general visual inspections of components and fluid levels throughout the helicopter. The safety inspection required an inspection of the auxiliary servocylinder, including its filter bypass indicator. According to the accident helicopter's daily flight log, the 15-hour safety inspection was last performed on April 18, 2020 at an ATT of 38,492.8 hours, two days before the accident.

The operator's S-61 CAMP also required a five-phase inspection, performed at 30-hour intervals, identified as Phase I through Phase V. Each phase inspection covered one or more specific areas (zones) of the helicopter. **Table 2** shows a description of each zone. Phase I required inspection of zones 1 and 3. Phase II required inspection of zone 2. Phase III required inspection of zones 5, 6, and 9. Phase IV required inspection of zone 7. Phase V required inspection of zones 4 and 8.

Table 2. The areas of inspection associated with each zone.

Zone	Area
1	[Tail] Pylon/Stabilizer
2	Powerplant
3	Rotor/Transmission
4	Tail Cone
5	Landing Gear
6	Fuel Cell Installation
7	Cockpit/Electronics
8	Cabin
9	Hull

During the Phase I inspection, the negative force gradient spring, bellcranks and their supports, rods and rod end assemblies in the tail pylon and stabilizer area were to be inspected. The hydraulic system, including the reservoir, manifold, pressure switches and transmitters, lines, fittings, and check valves were to be inspected for damage, security, leaks, and general condition. The auxiliary servocylinder links and balance springs, as well as bellcranks and their supports, were also required to be inspected.

During the Phase V inspection, the direction control cables, pulleys, rods and rod ends, control quadrants and their supports were to be inspected for, and not limited to, security, damage, and wear. Additionally, the auxiliary servocylinder filter was required to be removed and inspected for contamination. Hydraulic accessories, lines, and fittings were to be inspected for, and not limited to, leaks, damage, and general condition.

The operator's S-61 CAMP contained a requirement in the Phase V inspection to test the auxiliary servocylinder per the S-61 overhaul manual. The operator stated this requirement was mistakenly included in the CAMP and would be removed in the next revision. According to the Sikorsky S-61 Equalized Inspection and Maintenance Program (EIP), manual No. SA 4047-13, from which the operator's S-61 CAMP was developed, the Phase V inspection does not include a test of the auxiliary servocylinder per the S-61 overhaul manual. However, the EIP contains a note that in lieu of overhaul of the servovalves only, the auxiliary servocylinder assembly may be tested per the S-61L/N Overhaul Manual No. SA 4045-83.

Table 3 shows the last date and ATT each of the Phase inspections were performed on the accident helicopter per its daily flight log.

Table 3. The date and ATT for each of the last Phase inspections performed on the accident helicopter.

Phase	Date	ATT (hrs)
I	March 8, 2020	38,370.3
II	March 15, 2020	38,398.9
III	March 24, 2020	38,242.3
IV	April 1, 2020	38,450.1
V	April 11, 2020	38,478.6

8.1 AUXILIARY SERVOCYLINDER ASSEMBLY S/N 664

According to the operator's CAMP manual, the auxiliary servocylinder assembly had a 2500-hour interval for overhaul. The accident auxiliary servocylinder assembly (S/N 644) was last overhauled from May to September 2017 at JB Helicopter Accessory Service Limited in Langley, British Columbia, Canada.[10] According to the overhaul work order, the pedal damper check valve housing was fluorescent penetrant inspected, as required by Sikorsky Aircraft S-61L/N Overhaul Manual No. SA 4045-83, and showed no evidence of cracks or fractures. The overhauled auxiliary servocylinder assembly received a Transport Canada Authorized Release Certificate (Form One) on September 1, 2017, which reflected a component time since new (CTSN) of 34,184.2 hours and a component time since overhaul (CTSO) of 0 hours. Based on a review of available past overhaul records for auxiliary servocylinder assembly S/N 664, it could not be determined if and when the pedal damper check valve housing was last replaced nor how many hours of service it had accumulated. According to a representative of the overhaul facility, in their history of performing overhauls of the auxiliary servocylinder assembly, they had never found a crack in the pedal damper check valve housing nor replaced a pedal damper check valve housing. Additionally, according to the representative of the overhaul facility, the bolts for the pedal damper check valve housing were always replaced with new bolts per the S-61L/N Overhaul Manual.

The auxiliary servocylinder assembly was installed onto the accident helicopter on February 16, 2019 at an ATT of 37,101.9 hours[11]. On July 9, 2019, at an ATT of 37,611.5 hours, there was an entry in the discrepancy section of the daily flight log that stated "aux hydraulics leaking" and "aux servo yaw channel leaking." The auxiliary servocylinder assembly was removed and had a CTSN of 34,694.0 hours and a CTSO of 509.6 hours. The auxiliary servocylinder was repaired from July-August 2019 at JB Helicopter Accessory Service Limited in Langley, British Columbia, Canada.[12] According to the repair paperwork, the yaw piston seals were replaced and the unit was returned to CHI Aviation in Afghanistan.

The operator subsequently installed the auxiliary servocylinder assembly onto the accident helicopter on August 26, 2019 at an ATT of 37,734.6 hours and remained installed until the accident. (The auxiliary CTSN and CTSO remained the same since the time of its last removal.) On November 11, 2019, at an ATT of 38,021.0 hours, there was an entry in the discrepancy section of the daily flight log that stated "yaw pedals move L/H during normal operation." The corrective action section of the flight log stated the yaw open loop spring was adjusted. Based on an ATT of 38,495.2 hours recorded the day prior to the accident (April 19, 2020), the auxiliary servocylinder assembly had a CTSN of 35,454.6 hours and a CTSO of 1,270.2 hours the day prior to the accident.

Table 4 contains a summary of the auxiliary servocylinder assembly's recent history. Attachment 2 of this report contains the component log card for auxiliary servocylinder assembly S/N 644. Attachment 3 of this report contains the Transport Canada Authorized Release Certificates for the last overhaul of auxiliary servocylinder assembly S/N 644, dated September 1, 2017 as well as its last repair, dated August 1, 2019. Attachment 4 of this report contains the daily flight log entries for July 9, 2019 and November 11, 2019.

[10] JB Helicopter Accessory Service Limited work order No. 25941.
[11] N908CH was located in Afghanistan at this time.
[12] JB Helicopter Accessory Service Limited work order No. 26954.

Table 4. Recent maintenance and inspection history of auxiliary servocylinder assembly S/N 644.

Date	ATT (hrs)	CTSN (hrs)	CTSO (hrs)	Maintenance Action
Feb 16, 2019	37,101.9	34,184.2	0	Installed on N908CH after overhaul.
Jul 9, 2019	37,611.5	34,694.0	509.6	Removed from N908CH due to leaking.
Aug 26, 2019	37,734.6	34,694.0	509.6	Installed on N908CH after repair.
Nov 11, 2019	38,021.0	34,980.4	796.0	Yaw open loop spring adjustment due to left pedal movement during normal operations.
Apr 11, 2020	38,478.6	35,438.0	1,253.6	Last Phase V inspection
Apr 18, 2020	38,492.8	35,452.2	1,267.9	Last safety (15-hour) inspection
Apr 19, 2020	38,495.2	35,454.6	1,270.2	Day before the accident flight.

8.2 MISCELLANEOUS ITEMS

According to the maintenance records, the negative force gradient spring was last serviced on August 5, 2019 at an ATT of 37,680.3 hours as part of its normally scheduled 1,200 hour maintenance interval. The auxiliary hydraulic pressure transmitter was removed and replaced on August 18, 2019 at an ATT of 37,703.2 hours due to a discrepancy that the auxiliary hydraulic pressure gauge not providing a reading. On October 4, 2019, at an ATT of 37,889.8 hours, the aft yaw quadrant control rod replacement was due, and was subsequently replaced. On February 27, 2020, at an ATT of 38,335.3 hours, the daily flight log discrepancy section stated that the primary hydraulics would not turn off. The corrective action was to replace the auxiliary hydraulic pressure switch.

9.0 PAST UNCOMMANDED YAW EVENTS RELATED TO THE AUXILIARY SERVOCYLINDER PEDAL DAMPER CHECK VALVE AND AN3H5A BOLTS

9.1 PAST EVENTS

According to Sikorsky, in the 1978-1979 timeframe there were 3 instances from one operator involving a loss of hydraulic pressure to the auxiliary servo system on their S-61 helicopters. Of these three events, two occurred in the air and one occurred on the ground (during a postflight shutdown of the helicopter). In all three instances, it was reported that the auxiliary hydraulic pressure gauge indicated 0 psi. In two of these instances, one on the ground and one in the air, a visual inspection found two of the pedal damper check valve's AN3H5A bolts had fractured, allowing the pedal damper check valve housing to lift and result in a loss of hydraulic fluid. In the third instance, an airborne event, the crew reported a "violent 45-degree yaw to [the left] and a 5 degree roll to [the right]". A subsequent inspection found the pedal damper check valve housing had cracked in addition to fracturing of two AN3H5A bolts. In all of the AN3H5A bolts examined for these events, they were reported to have failed in fatigue with none of the bolts exhibiting signatures of excessive torque loading. It was reported that improper operator maintenance on the installation of the AN3H5A bolts may have been a factor in their failure.

A fourth event, which occurred in 1991 by a different operator, reported an uncommanded yaw to the right and a nose-up pitch, with "recovery achieved in 3 to 4 seconds." Two of the AN3H5A bolts for the pedal damper check valve housing were found to be fractured in fatigue, with fatigue origins at the first engaged thread root. It was reported there was no evidence of pre-existing anomalies at the fatigue origins and that material composition and hardness met requirements for the bolt design. Furthermore, there was reported to be no indications of over or undertorque or improper installation of the bolts. Lastly, there were no details regarding the auxiliary hydraulic pressure gauge indication at the time of the uncommanded yaw.

9.2 SIKORSKY SAFETY ADVISORY NO. SSA-S61-08-001

Sikorsky Safety Advisory No. SSA-S61-08-001, dated February 28, 2008, discussed events where a fracture of the pedal damper check valve bolts (P/N AN3H5A) resulted in a loss of auxiliary hydraulic servo pressure and a subsequent uncommanded yaw of the helicopter. The letter stated that proper torque of the AN3H5A bolts was crucial, and that failure to use the correct bolts and apply the proper torque during their installation may result in a failure of these bolts. A search of the NTSB and Sikorsky records could not determine an event in the timeframe of this advisory that would have been the catalyst for its release.

Attachment 5 of this report contains a copy of Sikorsky Safety Advisory No. SSA-S61-08-001.

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