ACCIDENT

Aircraft Type and Registration:	Sikorsky S-61N Sea King, G-ATBJ
No & Type of Engines:	2 General Electric Co CT58-140-2 turboshaft engines
Year of Manufacture:	1965 (Serial no: 61269)
Date & Time (UTC):	1 February 2018 at 1100 hrs
Location:	Marchwood, Hampshire
Type of Flight:	Commercial Air Transport (Non-Revenue)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damaged beyond economical repair
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	11,233 hours (of which 1,501[1] were on type) Last 90 days - 26 hours Last 28 days - 0 hours
Information Source:	AAIB Field Investigation

Synopsis

The helicopter was being transferred from Marchwood, Hampshire, to a maintenance base having been transported, by sea, from the Falkland Islands. As the helicopter took off for a hover check it pitched nose-down. The commander promptly lowered the collective and the helicopter struck the ground on its nose, before coming to rest on its landing gear.

The investigation found that the spherical bearing within the swashplate had seized as a result of corrosion, compounded by inactivity during the voyage from the Falkland Islands. The checks prior to the flight did not identify the control restriction.

Safety action has been taken by the helicopter manufacturer to highlight the correct pre-flight procedures to follow after prolonged aircraft inactivity, and by the operator to remind flight crews to conduct flight control servo system[2] checks to the maximum extents of control movement.

Footnote

1 The commander also had 2,809 hours on the Westland Sea King (WS-61).
2 The flight control servo system checks are also referred to as the full and free checks.

History of the flight

Background information

G-ATBJ had previously been operating in the Falkland Islands for four years until its last flight on 31 December 2017. It was then prepared for return by sea to the UK; this included having its main[3] and tail rotor blades removed; no covers were used to protect the rotor head and transmission. On 8 January 2018, the helicopter was moved onto a roll-on/roll-off sealift ship and transported from the Falkland Islands to Marchwood Sea Mounting Centre, Hampshire, where it was unloaded on 29 January 2018. G-ATBJ was transported below decks during the voyage. The following day, the helicopter was prepared for flight which included having its main and tail rotor blades fitted; a ground run was then performed by flight crew[4].

Accident flight

On 1 February 2018, the flight crew planned to perform a hover check. If successful, the helicopter was to be flown to Bournemouth Airport, Dorset, before refuelling and continuing to the operator's base at Cornwall Airport, Newquay.

Upon arrival at the helicopter, the co-pilot performed the external checks while the commander commenced the internal checks. Two of the operator's engineers were also in attendance and remained outside the helicopter throughout.

The crew discussions indicated the need to progress quickly due to limitations associated with having to rely on a limited number of external batteries as no external power cart was available.

After the first and second attempts to start engine 1 failed, the crew noted that the bus voltage, to which the main, alternate and external batteries were connected, was 23V, so they swapped the external battery for another one. The third attempted start was also unsuccessful and the crew, noting that this battery voltage was down to 23V, elected to try to start engine 2. They commented that there were two external batteries in the aft hold but that they would need those later at Bournemouth.

The engine 2 start was successful but, because the subsequent checks required the rotors, and hence the hydraulic pumps and electrical generators, to remain disengaged, the commander commented that they needed to be "AS QUICK AS WE CAN" to minimise the use of the battery to pressurise the hydraulics from the DC motor-generator (motorising).

The recordings indicate that the low pressure warning for the primary hydraulic system extinguished soon after they were pressurised. However, the auxiliary hydraulic system took a further 18 seconds, during which the commander stated, "WE'RE NOT GOING TO GET

Footnote

3 Whilst operating in the Falkland Islands G-ATBJ utilised composite 'Carson' main rotor blades but, prior to the accident flight, steel blades had been fitted.

4 The commander was the same for the ground run on 30 January 2018 and the accident flight the following day, but the co-pilots were different for each flight.

IT [auxiliary hydraulic pressure] WE HAVEN'T GOT ENOUGH OOMPH IN THE SYSTEMS NOW". During the after-start checks, a flying controls servo system check was completed, but not to the full extent of control movement[5]. During these checks the Pilot Flying (PF) stated "…AND THEY [main rotor blades] ARE MOVING IN THE RIGHT SENSE…I'M NOT DOING FULL AND FREE, WE HAVEN'T GOT TIME."[6]

The checks were completed before the helicopter's rotors were engaged. When the rotors were engaged, the crew noted that the auxiliary hydraulic pressure dropped to about 1,000 psi (normal pressure range is 1,300 to 1,500 psi) but then started increasing and reached its normal level as the rotor speed increased. With rotors running, the mechanical hydraulic pump, driven from the main gearbox, provided sufficient pressure to extinguish the auxiliary hydraulic system low pressure warning. No other warnings were recorded during the accident flight. The crew then started engine 1.

Before takeoff, pre-flight checks were completed and clearance to lift and depart was received from ATC. The commander released the parking brake and unlocked the tailwheel. The co-pilot then advanced the engine speed select levers to achieve 104%, monitoring the triple tachometer as he did so. While the co-pilot monitored the engine instruments, the commander started to raise the collective until the helicopter was light on its wheels.

Initially the helicopter started to move forward, so the commander arrested this movement with the cyclic and trimmed out the aft cyclic input; he then continued to raise the collective. As the helicopter lifted it started to move forward again and the co-pilot caught the movement in his peripheral vision. As the commander continued to raise the collective, the helicopter pitched nose-down and started to climb. As it started to pitch the co-pilot observed a large amount of aft cyclic being applied by the commander.

The helicopter did not respond to the aft cyclic input, so the commander promptly lowered the collective to land the helicopter. The crew felt a "thump through the seats" as the helicopter struck the ground with its nose. The mainwheels made ground contact causing the tail to pivot downwards onto the tailwheel. The time between the last wheel leaving the ground and the initial impact was less than three seconds.

Despite the co-pilot being slightly dazed he commenced the emergency shutdown checklist and called to the commander to apply the rotor brake. Both pilots then evacuated the helicopter and, once outside, went to check that the engineers were unhurt. There were no injuries.

Footnote

5 The pilots believed that a full and free check to the extremities of the controls' movement was not possible as the helicopter's electrically-driven hydraulic pumps would have disengaged under a high demand as they were being powered by the battery. However, the helicopter manufacturer has advised that, if the controls are moved slowly, full movement could be obtained without the pumps disengaging.

6 Both pilots highlighted that they did not intend to avoid full and free checks, but they felt that they were not achievable in the circumstances having previous experience on the S-61 after failed attempts using batteries.

Both pilots stated that everything appeared normal up until the moment when weight came off the wheels. The commander also stated that he believes the cyclic forces were unusually light when moved fore and aft during the takeoff but the sidetoside movement forces felt normal.

Accident site

The accident site was close to a helipad within a loading area at Marchwood Sea Mounting Centre, Hampshire. The helicopter had come to rest, on its landing gear, on an approximate heading of 270° with the tailwheel about 10 m from the centre of the marked helipad.

The front of the helicopter had struck the ground during the accident sequence. The front equipment bay was crushed, (Figure 1) resulting in the detachment of the bay door. Scuff marks on the concrete surface, 9.5 m from the centre of the helipad, indicated the location that the helicopter initially struck the ground (Figure 2). The tailwheel strut had been driven through the upper stops, with buckling of the skin around frame 493 at the rear of the fuselage.

Figure 1

G-ATBJ after accident (transport ship in background)

Figure 2
G-ATBJ impact mark (note: cones positioned after accident)

Meteorology

Observations from Southampton Airport, 4 nm north-north-east of Marchwood, indicated that there were FEW amounts of medium to high based cloud and good visibility, no showers were reported at the Airport. At the time of the accident, the surface wind was predominately from 310°, varying between 260° and 360°, at about 11 kt. The temperature was 6°C and the QNH was 1005 hPa.

Weight and balance

The aircraft had a takeoff weight of 15,805 lb; this included 1,500 lb of fuel. Its maximum certified takeoff weight was 20,500 lb. Its Centre of Gravity (CG) was -8.5 in aft of datum, which is within the flight limits of +12 in and -16 in at this takeoff weight.

Recorded information

The helicopter was fitted with a Multi-Purpose Flight Recorder (MPFR). This retained the last two hours of audio and 78 hours of data. The audio included the ground run carried out on the helicopter two days prior to the accident. Pilot control inputs were recorded but the data did not include any parameters relating to actuator or swashplate positions. The states of the primary and auxiliary hydraulic systems low pressure warnings (triggered below 1,000 psi) were recorded but not the actual hydraulic system pressures. The MPFR operates whenever the dc essential bus is powered.

The event was also captured on a recording from a CCTV camera which was monitoring the helicopter prior to takeoff.

Recorded cyclic control position

The MPFR recorded cyclic as a nominal percentage of movement from the rigged position, a negative percentage value equates to pulling the cyclic rearward to pitch the helicopter up and a positive percentage relates to forward cyclic. The last three MPFR annual calibration checks were reviewed to establish the range of control input movement. The results showed that there were variations of only a few percent over the years for the values associated with the extreme control positions. The range of values for the cyclic pitch covered by the checks were between -44% and 26% for fully aft and fully forward respectively and these are the limits shown on Figures 3 and 4.

Pre-flight checks – accident flight

Figure 3 shows the limited extent of the cyclic inputs made by the crew during the pre-flight *Flight control servo system* check.

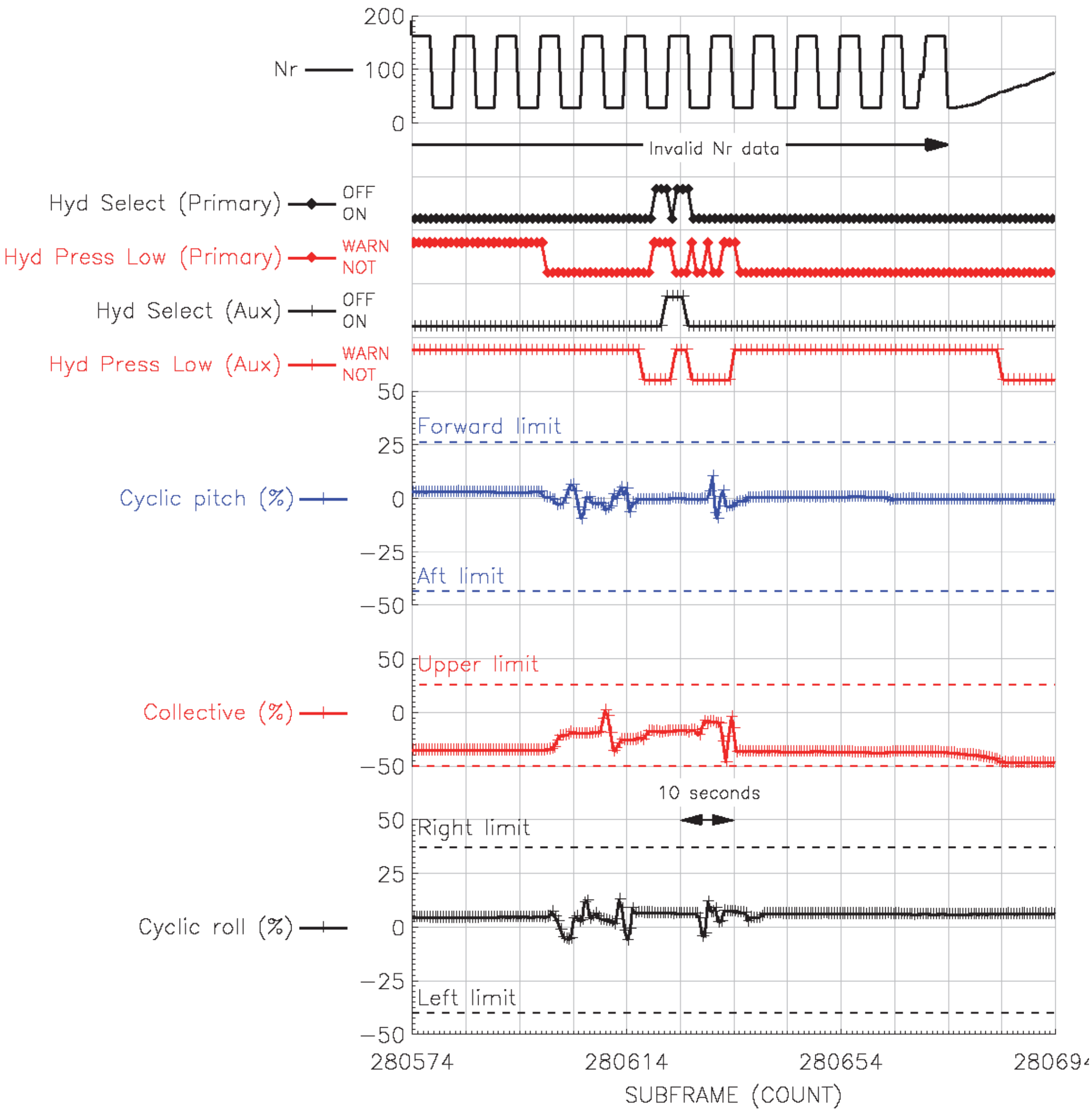

Figure 3

Flight control servo system check from the accident flight

Accident flight

Figure 4 is a plot of pertinent parameters recorded during the takeoff. Just after takeoff, the helicopter started to pitch nose-down, reaching a pitch rate of approximately -7 °/s. The commander applied aft cyclic but, even at the full aft limit, there was no significant effect on the pitch rate. He rapidly lowered the collective and the helicopter struck the ground at a pitch attitude of approximately 20° nose-down.

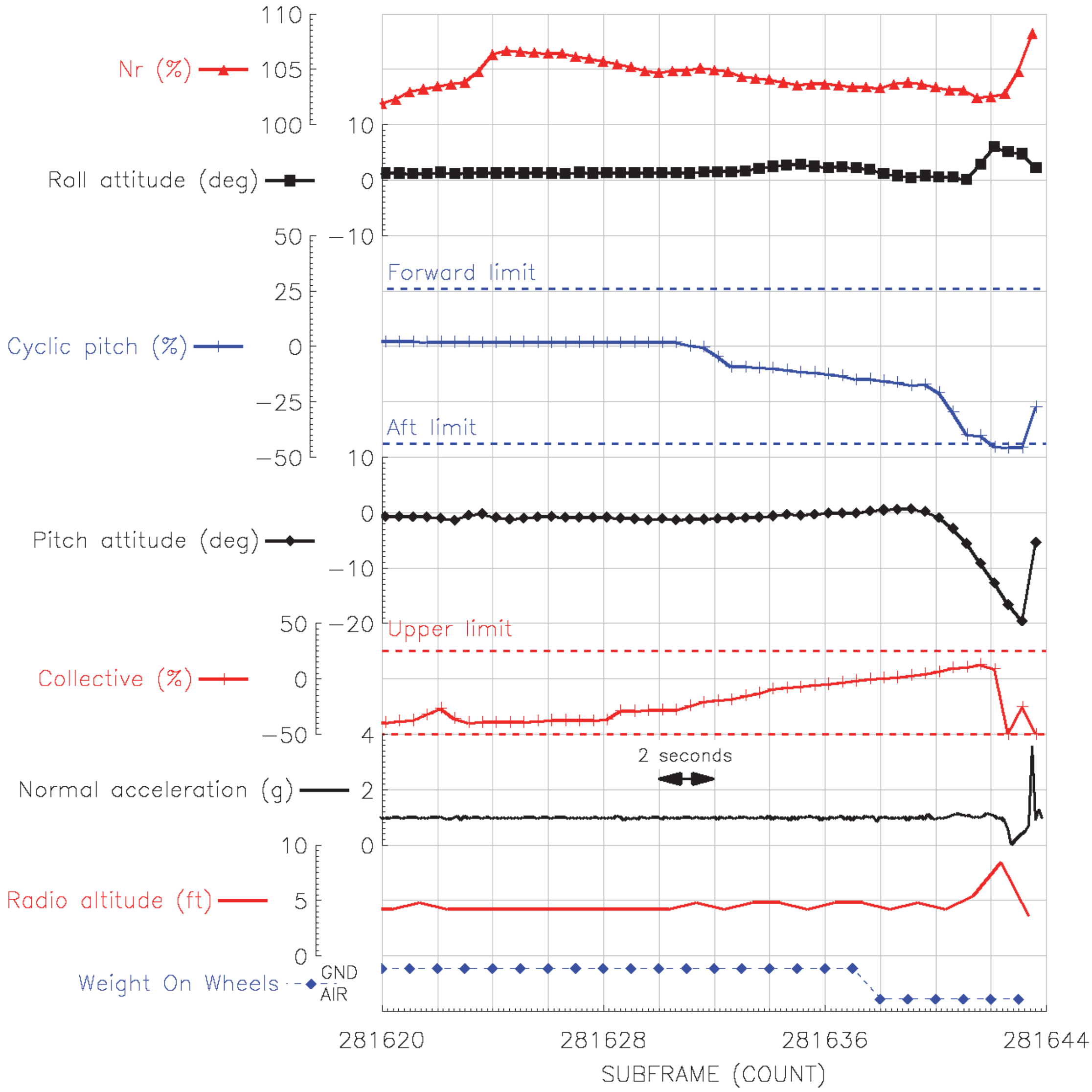

Figure 4

Pertinent recorded parameters for the accident flight

Figure 5 is a snapshot from the CCTV recording. This shows the main rotor disk did not appear to have any significant rearward component given the full aft cyclic input which was being made at that time.

Figure 5

CCTV snapshot at the point of impact

Ground checks two days earlier

The audio and data associated with the ground run carried out two days before the accident were reviewed. As on the day of the accident, time pressure due to the limited battery power was apparent from the crew conversations. While motorising under battery power and carrying out the flight control servo system check with the auxiliary low pressure warning initially active, the crew commented that there was "no aux pressure there of any sort, it's kind of working". Comment was also made to just check that the blades were moving in "the right sort of way". During the check, the range of cyclic pitch movement recorded was between -12% aft and 18% forward as opposed to the full range of movement required by the procedure of approximately -44% aft to 26% forward.

Range of cyclic control movement used

During the investigation, G-ATBJ's historic data was reviewed to determine the use of the full range of cyclic movement. In the 78 hours of recorded data there was only one check where the controls were fully exercised.

During the period between being unloaded from the ship and lifting off during the accident flight and when the MPFR was operating, the data indicates that cyclic pitch inputs were exercised over less than half of the full available range. This includes periods during which operational procedures were carried out which required full cyclic inputs to be made.

The recorded data included multiple flights on 15 separate days prior to the helicopter's return to the UK. Flight control servo system checks were carried out prior to the first flight of each day, using varying amounts of control inputs, but none exercised the full range of the controls required by the procedure.

The operator advised that it was possible that the engineers had pulled the MPFR circuit breaker during daily checks, and this could explain the lack of recorded full range checks. However, no documentation was provided to explain why this action might have been taken.

The operator was asked to review the full and free checks from previous recordings in its flight data monitoring programme. A sample of these recordings indicates that the full and free check was not always conducted to the full extent of control movement available. The operator noted that observations in simulator checks and during flights also indicated that the check was not always completed to the full range.

Safety action by the operator

On 20 June 2018, the operator issued Flying Staff Instruction (FSI) 2018-35 to remind all crews to conduct the flight controls servo system check, which includes a full and free check, as required by the Operations Manual Part B, Section 02, Appendix 2. The FSI contained the detailed check as an Appendix.

After FSI 2018-35 was issued, the operator carried out a review of compliance on a sample of flights. This review identified that the control extremes were mostly but not always being reached; the majority of deviations being associated with a lack of full travel of aft cyclic. The operator considered that this may have been associated with seating positions and physical body shape, and that it would review this possibility in more detail.

The operator has advised that it will continue to monitor that its pilots perform the check, to the extremities, through routine simulator checks and, through its flight data monitoring programme, during operational flying.

Helicopter information

General

The Sikorsky S-61N helicopter Mk 1 is a single main rotor helicopter with a torque-correcting tail rotor. The main rotor has five blades, which can either be of composite or steel construction. The fuselage is an aluminium alloy monocoque design with a boat-type hull.

Two General Electric CT 58-140-2 series turboshaft engines, mounted on the top of the fuselage, drive the main and tail rotor transmission through the main gearbox, which is positioned aft of the engines.

G-ATBJ was configured with 19 seats and was being used for personnel and cargo transportation within the Falkland Islands prior to being shipped back to the UK for maintenance. It held a valid Certificate of Airworthiness and Airworthiness Review Certificate.

Flight controls

The pilot's and co-pilot's flight controls are mechanically linked, and their inputs are transmitted mechanically through control rods and bellcranks from the collective, cyclic and tail rotor control pedals to four auxiliary hydraulic servos. These servos, situated in a control compartment behind the aft cockpit bulkhead, power the controls via a mixing unit and the primary servos.

The mixing unit consists of bellcranks and connecting links which proportion and transmit the control movements to the main rotor primary servos and to the tail rotor pitch change mechanism. The three primary servos are mounted on the main gearbox and transfer control movements to the main rotor swashplate. The control configuration of the S-61N is shown in Figure 6.

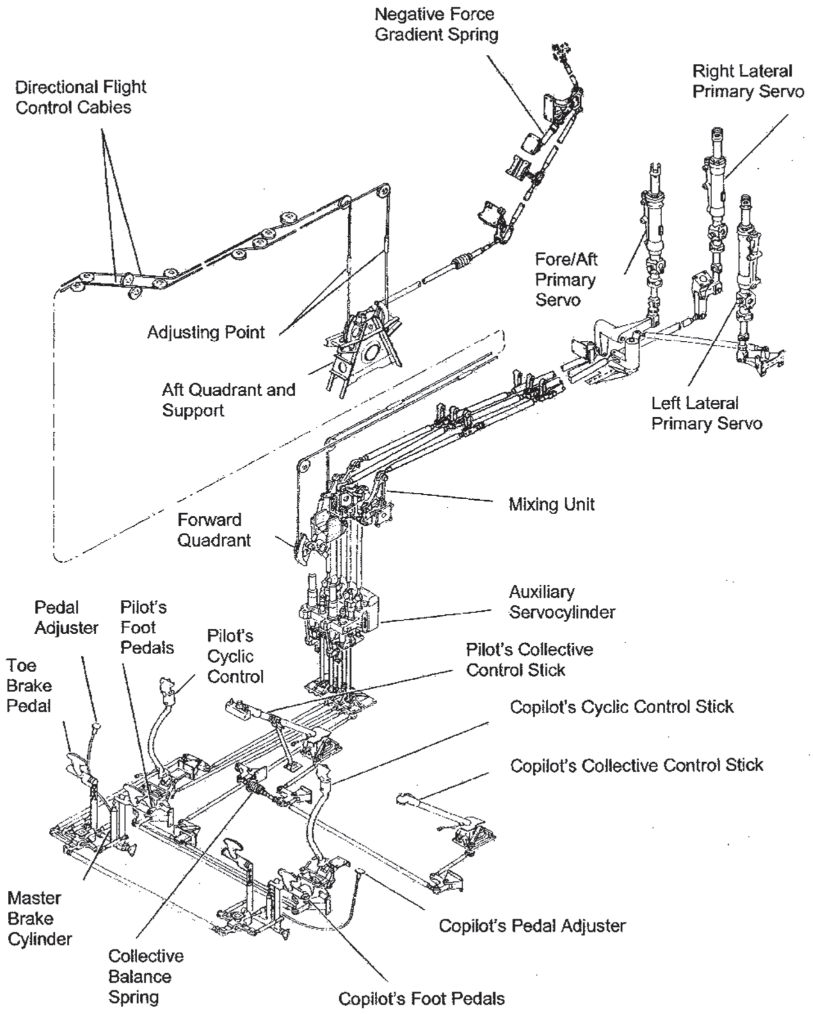

Figure 6

S-61N flight control general layout (reproduced with permission)

During normal operation, both the primary and auxiliary hydraulic servo systems are used, but the helicopter can be flown with one of the systems inoperative. The main rotor forces are too great to allow the helicopter to be flown manually without hydraulic assistance.

Each servo, when hydraulically powered, receives control inputs through a 'sloppy link'. As the sloppy link is moved, it opens a pilot valve within the servo. This diverts hydraulic pressure to the piston within the servo allowing it to extend/retract as commanded. Once the linkage is in the desired position, the pilot valve seals the flow to the hydraulic piston causing the movement to stop. If the servo is not hydraulically powered, a spring-loaded bypass valve opens allowing the upper and lower chambers of the actuator to be connected. This allows the servo power piston to move freely without hydraulic assistance whenever force is applied to the power piston, as fluid can flow freely between the chambers.

The hydraulic pumps are driven by the main gearbox whenever the main rotors are running or by a DC motor-generator which is electrically powered from batteries when on the ground, known as motorising the system. Although the full range of swashplate and cyclic/collective control movement is possible while operating using the DC motor-generators, due to limitations in hydraulic pressure available when motorising, the rate at which the hydraulics servos can respond to control inputs without stalling is reduced.

To allow the helicopter to be started at locations such as Marchwood, which did not have an available ground power cart, G-ATBJ carried two external batteries which were to be used as an external power supply. The S-61N is fitted with two batteries the main (connected to the essential bus) and the alternate (connected to the emergency bus). The external battery also connects to the essential bus and during start the 'start switch' is made which connects the emergency bus to the essential bus. This means that all three batteries are connected during start and, being the same nominal voltage, will share the load roughly equally. With limited battery charge available and no means of charging the batteries in flight, ground operations under battery power were minimised to maintain battery charge.

Swashplate

The main rotor head is splined onto the main gearbox output, its principal components are the hub, swashplate and bifilar vibration absorber. The swashplate transmits movement of the flight controls to each main rotor blade through pitch control rods. A spherical bearing, sometimes referred to as a ball-ring socket, allows the swashplate to be tilted off its horizontal plane and moved on its vertical axis. The rotating swashplate is connected to the rotary wing hub by rotating scissors and the pitch control rods. The stationary swashplate is connected to the main gearbox by stationary scissors and the primary servo cylinders. The rotating swashplate can rotate around the stationary swashplate. When the servo cylinders are actuated, movements of the stationary swashplate are transmitted to the rotating swashplate and then to the main rotor blades via the pitch control rods (Figure 7).

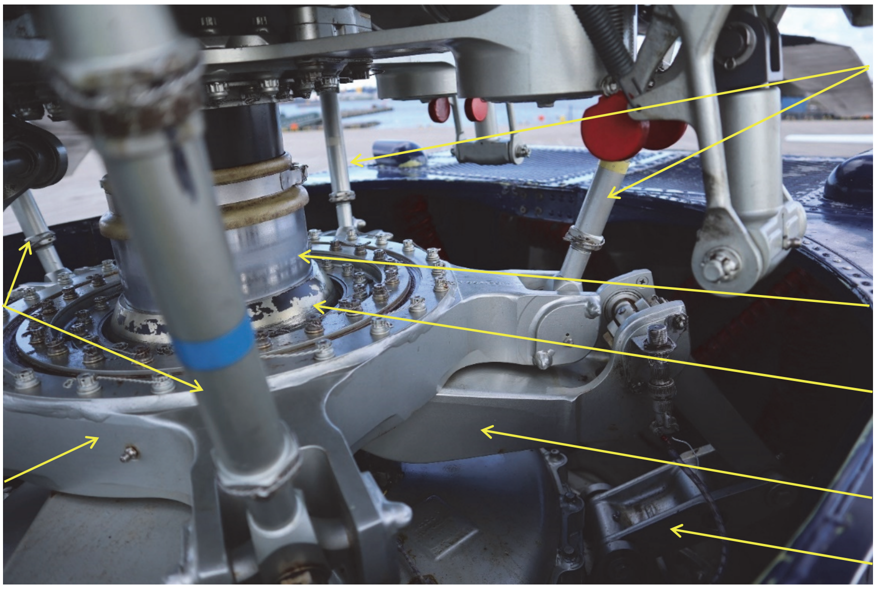

Figure 7

S-61N swashplate configuration

The anodised aluminium spherical bearing is held in position by two opposing phosphor bronze sockets which are inserted into the stationary swashplate housing. The lower socket is located on a flange at the bottom of the housing. The upper socket is held in place by a retainer and spacer. An adjustable shim is used to set the height of the retainer and hence the amount of clamping it provides to the spherical bearing (Figure 8). In-service adjustment of the shim can be made if the vertical play of the bearing exceeds 0.070 in. The bearing is packed with grease when assembled and cannot be replenished during normal maintenance.

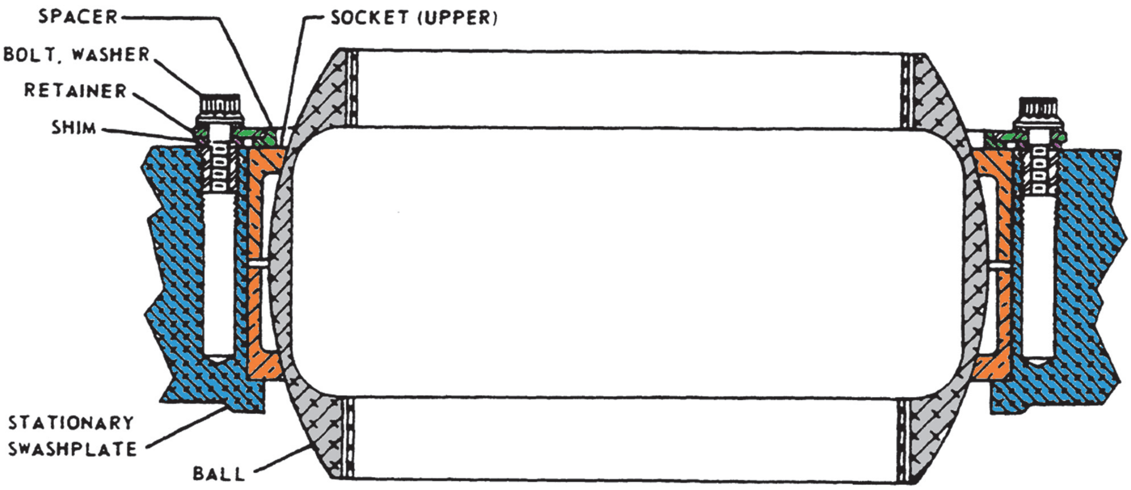

Figure 8

Arrangement of S-61N swashplate spherical bearing (reproduced with permission)

Manufacturer's S-61N flight manual

The S-61N flight manual contains details of the procedures to be followed at helicopter start. In particular, with regard to the checks required of the flight control servo system, Part 1, Section II, *Normal Procedures* of the S-61N Flight Manual states:

'<u>EXTERNAL POWER ENGINE STARTS AND ROTOR ENGAGEMENT</u>

…

4. Flight control servo system – CHECK fully as described below prior to first flight of the day, optionally or partially as desired for subsequent flights.

a. Auxiliary and primary servo hydraulic pressure indicators – Normal range.

a.1. Copilot's flight control servo switch – momentarily select PRI OFF and AUX OFF in turn and confirm respective pressure indicator drops to zero and caution light illuminates.

b. Pilot flight control servo switch – PRI OFF. Primary servo pressure indicator should indicate a drop to zero and caution light should illuminate. Momentarily select AUX OFF using copilot servo switch and confirm auxiliary pressure is normal and caution light remains off.

NOTE

There should be no measurable control jumps when securing or restoring primary servo hydraulics. Some main rotor blade pitch motion is to be expected.

c. Trim release button (on cyclic stick) – Depress. Collective pitch lever – Actuate full up.

d. Actuate cyclic stick from one extreme to the other in lateral, then fore-and-aft directions. Repeat cyclic stick movements with collective down.

e. Flight control servo switch – ON. Primary servo hydraulic pressure normal; caution light OFF.

…'

An abridged version of this procedure was available to the crew in the operator's Normal Checklist and Operation Manual Part B, Section 02, Appendix 2:

'HYDRAULIC SYSTEMS

Motor Generator .... MOTORIZE

Flying Controls .... Check Full and free movement

Hydraulic Switches: Check Interlocks as below

***PF** - Servo Switch .... PRI OFF*

***PM** - Servo Switch .... AUX OFF Check Auxilliary system remains in Green Arc, Primary system goes to zero pressure.*

***PF** - Controls .... ALL FULL & FREE*

***PF** - Servo Switch .... AUX OFF Check systems change over with no delay*

***PM** - Servo Switch .... PRI OFF Check no change over occurs*

***PF** - Controls .... CYCLIC/COLL FULL & FREE*

***PF** - Servo Switch .... BOTH Check systems change over with no delay*

***PM** - Servo Switch .... BOTH Check both systems restored*

***Note**: Liaise with start crew during full and free checks to ensure Main and Tail Rotor Blades responds* [sic]*. When checking for full and free movement with each system selected off, ensure that no coupled indications are evident.'*

Helicopter examination

To facilitate road transport, the main and tail rotor blades, tail pylon and sponsons were removed and the helicopter was transported to the AAIB, where a detailed examination of the helicopter control system could be carried out. All control linkages were intact, continuous and correctly installed.

The auxiliary and primary servos were examined for leakage or damage and then removed. Computed Tomography scanning was completed prior to being transported to the helicopter manufacturer's facility for testing and disassembly; no anomalies were identified.

The investigation also considered other areas that could have contributed to the nose-down pitching movement including the Auto-Flight Control System (AFCS) or trapped water affecting the Centre of Gravity. However, these were discounted as possible causes.

During the removal of the primary servos it was identified that the spherical bearing within the stationary swashplate assembly was seized. The swashplate was able to translate up and down the guide tube but could not tilt. There was evidence that the guide tube had deflected during operation as grease on the mast had come into contact with the inner surface of the guide tube (Figure 9); however, there was no evidence of metal-to-metal contact between the mast and guide tube. Once it had been removed, examination of the swashplate assembly confirmed that the spherical bearing could not articulate in any direction. The swashplate (Figure 10) was transported to the manufacturer's facility for further disassembly.

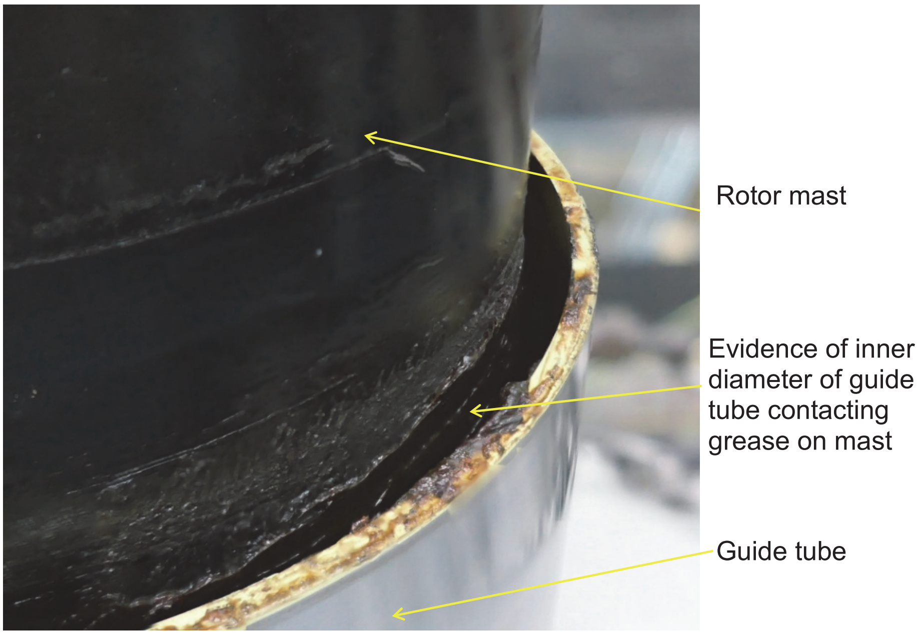

Figure 9

Flattening of grease between rotor mast and guide tube

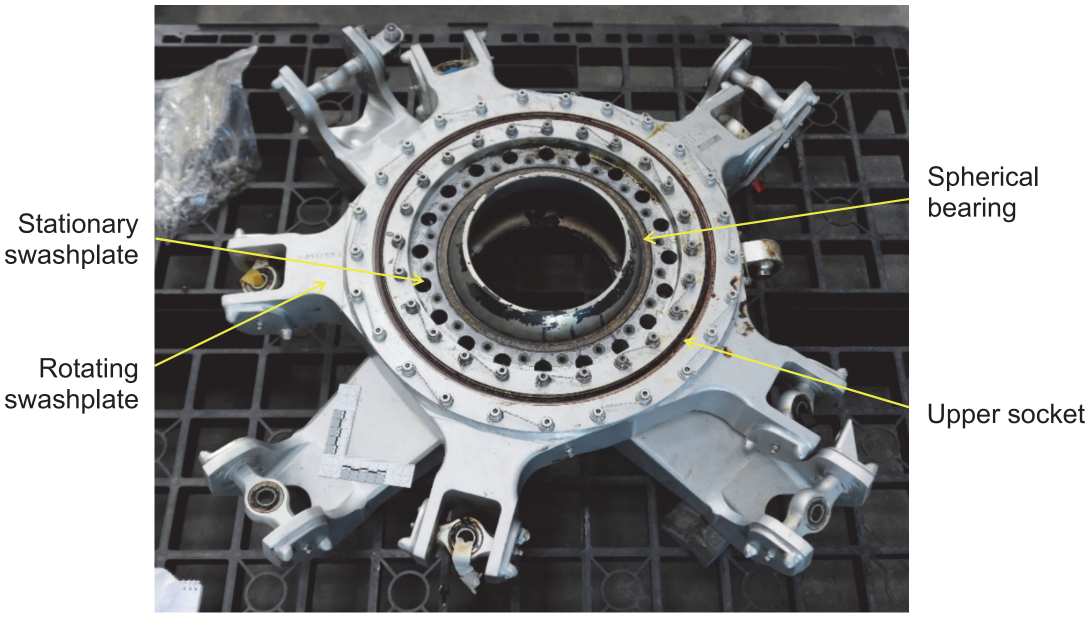

Figure 10

G-ATBJ swashplate after removal from the helicopter
(retainer, shim and spacer already removed in this image)

Examination of the sockets identified that both the upper and lower sockets had become skewed such that there was a gap between the lower socket and its retaining flange of up to 0.150 in. The upper socket had also skewed with a variation of up to 0.023 in. The sockets were re-seated thus allowing the spherical bearing to be released.

The grease between the sockets and the spherical bearings was in very poor condition, with crystalline deposits within it (Figures 11 and 12). Elemental analysis of the deposits found them to contain aluminium, chlorine, sodium, copper, tin and oxygen. This indicates that the aluminium spherical bearing had corroded, and deposits had been retained within the grease. A section of the grease was cleaned from the bearing to reveal areas of corrosion pitting to a depth of 0.018 in (Figure 13). A build-up of plaque-like material was adhered to the bearing. Analysis of this material found it to be bronze material that had released from the socket, combined with the grease and adhered to the bearing surface.

Figure 11

G-ATBJ spherical bearing once removed from swashplate

Figure 12

G-ATBJ upper spherical bearing socket showing corrosion product adjacent to bearing surface

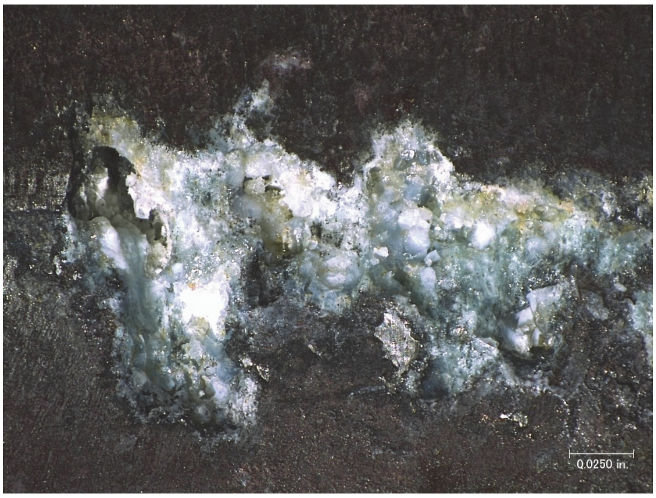

Figure 13

G-ATBJ example of spherical bearing corrosion pit

Once the spherical bearing was cleaned, a ring showing signs of severe corrosion was identified around the location where the lower socket had been. Closer inspection identified that a number of deep corrosion pits were located along the intersection between spherical bearing and where the top of the lower socket bearing face made contact (Figure 14).

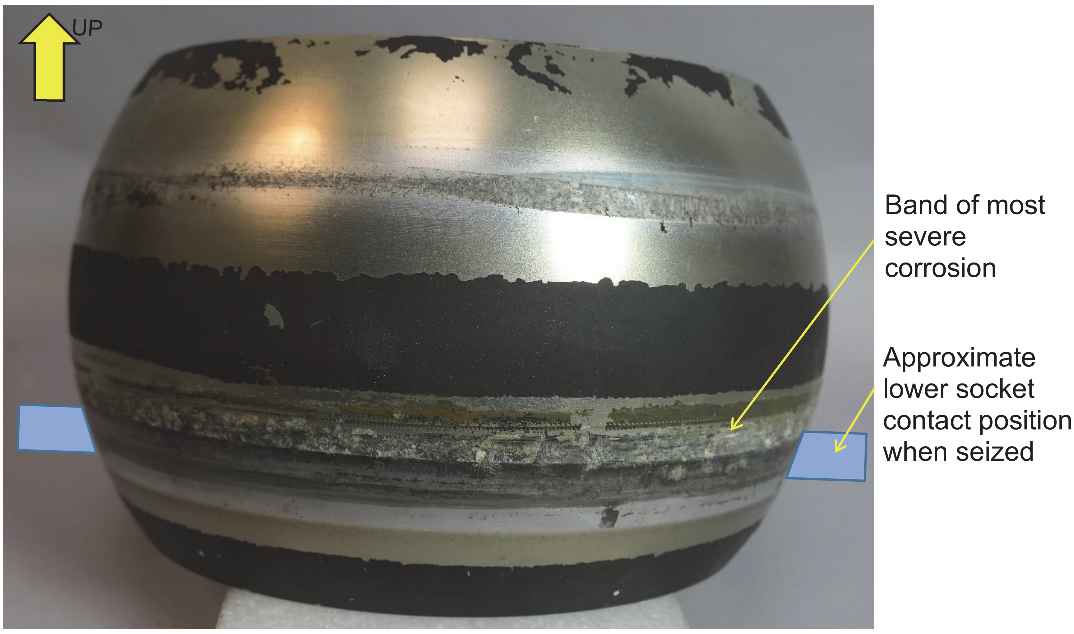

Figure 14

Spherical bearing showing area of heavy corrosion above the location of the lower socket

Swashplate Service history

The swashplate fitted to G-ATBJ was last overhauled in January 2014. It was fitted to the helicopter in June 2016, 44 months before the accident, during which it had accumulated 2,493.5 operating hours. In-service assessment of the vertical play is required every 500 hours and was most recently completed 33.5 hours prior to the event. During the assessment, the vertical play was measured as 0.080 in, 0.010 in outside of limits and so the shim was adjusted to increase spherical bearing clamping. There were no reports of any issues with the swashplate subsequent to the 500-hr check.

S-61N maintenance

The level and type of maintenance to be completed on the S-61N is defined by the helicopter manufacturer and is detailed in the S-61N Equalized Inspection and Maintenance Program, SA 4047-13 (EIMP). This document defines what and when inspections, servicing, component replacements and checks need to be carried out during the lifecycle of the helicopter. In addition, the Aircraft Maintenance Manual (AMM) contains guidance related to long-term parking that is of relevance, including recommended use of protective covers over the rotor head and swashplate that would minimize the effects of a salt atmosphere. The AMM also identifies the conditional inspections to be performed after exposure to saltwater or salt spray.

Operators often develop their own Approved Maintenance Plans (AMP) which incorporate the manufacturer's requirements but are better aligned to the type of operation being undertaken by the helicopter.

The EIMP defines several inspection types, the most frequent being a Pre-flight Inspection. There are also Safety Inspections, Progressive Period Inspections, Special Frequency Inspections, Unscheduled Maintenance Check and Major Inspections. A Safety Inspection is defined as an inspection that:

> *'shall be done once each fifteen (15) flight hours. If the helicopter is not flown daily or is stored for any extended period, the Safety Inspection must be done within the 24-hour period immediately preceding the next scheduled flight.'*

As G-ATBJ had not been operated for over 30 days while it was in transit, a Safety Inspection should have been carried out on the aircraft prior to flight. The operator's AMP (S-61N AMP MP/01016/1381) subsumes the intent of the Safety Inspections defined in the EIMP into its 'Daily' maintenance requirements. These Daily inspections contain mandatory items that must be carried out within a period not exceeding 10 flying hours or 24 elapsed hours prior to flight.

For the swashplate assembly, the EIMP required an Inspection and Check to be carried out as part of the Safety Inspection, a remark was also made to '*Check for binding in the ball-ring socket per Maintenance Manual*'. In reviewing the AMP, it was identified that this check was not annotated within the original maintenance requirements and therefore was not carried out as part of the Daily inspections.

Section 80 65-12-7 of the S-61N Maintenance Manual, SA 4045, refers to swashplate maintenance. Paragraph 3 D, titled '*Check for Binding in Ball-Ring Socket*' defines the check referred to in the EIMP. This check requires a binding check to be carried out by motorising the servos systems and, by exercising the collective and cyclic with an observer on the service platform, assessing that the motion and travel of the swashplate is smooth and continuous. This check was not completed during the pre-flight preparations on 29 or 30 January 2018.

Safety action by the helicopter manufacturer and the helicopter operator

On 22 July 2019, the helicopter manufacturer issued a Safety Advisory to highlight to operators the necessity of performing the prescribed Safety Inspections after long-term storage of the aircraft, specifically the inspection/check of the swashplate.

The helicopter operator has incorporated the assessment of the ball ring socket for freedom of movement in the Daily inspections. In addition, it has made the decision that, in the future, helicopters that have been transported by sea will then be road transported from their port of entry to the maintenance facility. The operator has also undertaken to investigate increased environmental protection for its helicopters during sea voyages.

Other information

With the spherical bearing within the swashplate seized, the torque load applied to the swashplate from the servos would cause the guide tube and supporting structure to flex until the servos stalled. This flex would allow some relative movement of the swashplate about its centre in relation to the rotor head and would subsequently allow the rotor blades to move in the correct sense to a cyclic input. A video taken of the manipulation of a seized swashplate from another S-61 was provided to the AAIB by the helicopter manufacturer. This confirmed that some guide tube movement is likely when a cyclic load is applied (Figure 15). This would translate into blade movement as the guide tube is flexed. From the information provided it was not possible to correlate the amount of blade pitch change in relation to the cyclic input.

The manufacturer conducted an analysis of the control system geometry to determine whether a full back stick input could be applied without any apparent movement of the swashplate. The calculations were based on a simple model of guide tube flexing and hydraulic actuator sloppy link movement, with stalled servos, and was able to account for most, but not all, of the aft cyclic input range being available to the pilot. The level of flex in the control runs was not known. As discussed, this would yield some blade movement in the right sense by virtue of the guide tube flexing but with a significantly restricted range.

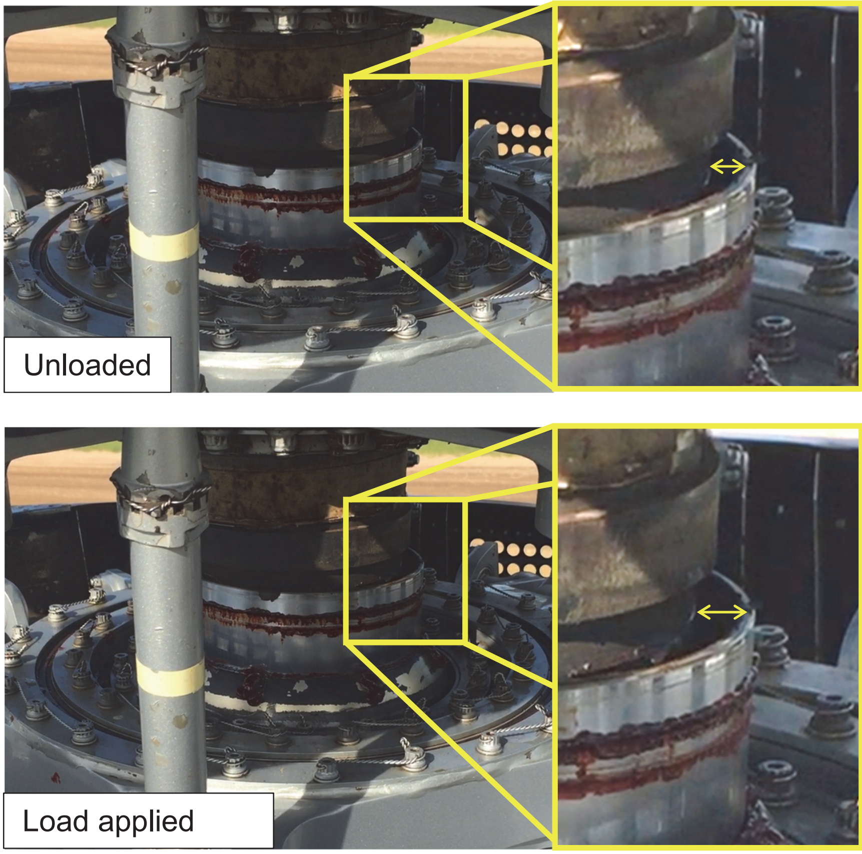

Figure 15

Stills from video of another S-61 showing levels of guide tube deflection when cyclic was applied to a seized swashplate

Analysis

The uncommanded pitch nose-down on lift off from Marchwood following the first flight after transportation by ship from the Falkland Islands was most likely as a result of a restriction of the swashplate which had seized. The seizure had not been detected during the reinstatement of helicopter in preparation for flight or in the pre-flight control checks.

Swashplate seizure

It is possible that there was some corrosion present within the spherical bearing sockets prior to the shipment of the helicopter back to the UK. However, with regular operation, there was no opportunity for any corrosion to dwell and allow the ball-ring to seize. During the shipping of the helicopter from the Falkland Islands, where the rotor head was unprotected, water ingress between the sockets is likely to have occurred, either from inclement weather or due to spray from the sea. Any water that was captured in the socket area would have welled above the lower socket. The dissimilar materials of the spherical bearing and the socket would promote galvanic corrosion if exposed to salt water. This would promote rapid corrosion propagation and adherence between the socket and bearing surfaces.

Following a period of inactivity, the helicopter should have been subject to a Safety Inspection as detailed in the S-61N Equalized Inspection and Maintenance Program, SA 4047-13 (EIMP). As part of the Safety Inspection of the swashplate assembly, the EIMP requires a '*Check for Binding in Ball-Ring Socket*'. It is likely that this check, had it been carried out, would have identified the seized swashplate before the accident flight.

Upon application of cyclic control inputs during the pre-flight checks the swashplate will have initially tilted. With the socket and bearing locked together the force will have lifted the lower socket out of position, in doing so it will have wedged the spherical bearing in position, preventing any further movement.

Any cyclic load applied subsequently would have resulted in guide tube deflection with an associated small change in blade pitch.

Flight control servo system checks

At the time of the accident, G-ATBJ carried two external batteries which were to be used as an external power supply for remote starting and ground motoring. With limited battery charge available it was perceived that ground operations under battery power should be minimised so that there would have been enough charge available for the engine start at Bournemouth.

After engine 2 had been started, the crew completed a limited check of the flight controls and observed the main rotor blades moving in the correct sense. This would have confirmed to the handling pilot that he had freedom of movement and continuity in the controls. Given this and the fact that the cyclic was able to move to the rear stop, it is unlikely the crew would have noticed the seized swashplate prior to takeoff. However, had an external observer monitored the main rotors and the swashplate during this check, the seizure may have been identified.

Conclusion

The cyclic control restriction was found to be as a result of seizure of the spherical bearing with the swashplate. The seizure was determined to be as a result of corrosion build-up within the bearing sockets. Prolonged inactivity during the transportation of the helicopter from the Falkland Islands allowed corrosion to develop sufficiently to cause the bearing to seize. Following the helicopter's arrival in the UK, Safety Inspection checks detailed in the S-61N Equalized Inspection and Maintenance Program, SA 4047-13 were not carried out; it is likely that the seized swashplate would have been identified if they had.

Despite the seizure, the investigation determined that full fore/aft travel of the cyclic control could still be achieved which indicates that this is not a reliable indication that the swashplate is free to move. During pre-flight checks by maintenance engineers and the flight crew, the flight control servo system checks were not completed to the full extremes of travel. With a seized swashplate, the rotor blades changed pitch due to flexing of the guide tube and the blade movement was incorrectly identified as a positive confirmation of control authority. There was no confirmation by external observation of the main rotor and swashplate operation during the limited range pre-flight checks.

The perceived limitations of the hydraulic system when pressuring the hydraulics from the battery powered DC motor (motorising) compounded by the restrictions of using an external battery for starting were identified as contributory factors because control movements were not made to the full extremes of the cyclic envelop during the pre-flight checks.

Safety actions

The helicopter operator

On 20 June 2018, the operator issued Flying Staff Instruction (FSI) 2018-35 to remind all crews to conduct the flight control servo system check, which includes a full and free check, as required in Appendix 2 of the Operations Manual Part B S61 Section 02. This FSI contained the detailed check as an Appendix.

The operator has continued to monitor that its pilots perform the check, to the extremities, through routine simulator checks and, through its flight data monitoring programme, during operational flying.

The operator has incorporated the assessment of the ball ring socket for freedom of movement in the Daily inspections. In addition, it has made the decision that, in the future, helicopters that have been transported by sea will be road transported from their port of entry to the maintenance facility.

The operator has also undertaken to investigate increased environmental protection for its helicopters during sea voyages.

The helicopter manufacturer

On 22 July 2019, the helicopter manufacturer issued a Safety Advisory to highlight to operators the necessity of performing the prescribed Safety Inspections after long-term storage of the aircraft, specifically regarding the inspection/check of the swashplate.

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Bulletin correction

On page 20 of the report, it was incorrectly stated that the swashplate vertical play was measured as **0.008 in, 0.001 in** outside of limits.

The text should read:

> During the assessment, the vertical play was measured as **0.080 in, 0.010 in** outside of limits and so the shim was adjusted to increase spherical bearing clamping.

The online version of this report was corrected on 12 March 2020.