Norwegian Safety Investigation Authority

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REPORT AVIATION 2022/08

Aviation incident offshore by Ekofisk Lima in the North Sea on 25 September 2021 involving Sikorsky S-92A, LN-ONH operated by Bristow Norway AS

The Norwegian Safety Investigation Authority (NSIA) has compiled this report for the sole purpose of improving flight safety.

The purpose of the NSIA's investigations is to clarify the sequence of events and causal factors, elucidate matters deemed to be important to the prevention of accidents and serious incidents, and to make possible safety recommendations. It is not NSIA's task to apportion blame or liability.

Use of this report for any other purpose than for flight safety should be avoided.

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

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Aviation incident report

Table 1: Data

Type of aircraft:	Sikorsky Aircraft Corporation S-92A
Nationality and registration:	LN-ONH
Owner:	VIH Aviation Group Ltd., Canada
Operator:	Bristow Norway AS, Norge
Crew:	5
Passengers:	0
Accident site:	Offshore, by Ekofisk Lima, 56.509552°N 003.222427°Ø
Accident time:	Saturday 25 September 2021 at 2115 hrs

All times given in this report are local time (UTC + 2), if not otherwise stated.

Notification

On 26 September 2021 at 1050 hrs, Bristow Norway alerted the Norwegian Safety Investigation Authority about an incident the previous night. A Sikorsky Aircraft Corporation S-92A helicopter, LN-ONH, had lost most of the oil pressure in the main gearbox on its return to Ekofisk Lima after search and rescue training. The crew also recieved a caution that one of the main gearbox oil pumps had failed.

The NSIA alerted the following organisations:

- International Civil Aviation Organisation – ICAO
- National Transportation Safety Board – NTSB
- European Aviation Safety Agency – EASA
- Sikorsky Aircraft Corporation – Sikorsky
- Civil Aviation Authority Norway – CAA Norway

NTSB appointed an accredited representative, who together with advisors from Sikorsky Aircraft Corporation has aided the investigation.

Summary

On 25 September 2021, LN-ONH was used for a search and rescue training mission. After completing the mission, the helicopter was on its way back to Ekofisk Lima. During the right downwind phase of the landing pattern, when Ekofisk Lima was 1.9 nm away and 90° off LN-ONH's right side, the main gearbox suddenly started to quickly lose oil pressure. The oil pressure went from 58 psi to 6 psi in 30 seconds. The crew immediately changed course for Ekofisk Lima and proceeded to perform a successful landing.

The investigation has found that one of the oil pumps' Vespel spline adapter had failed, and the oil pump could therefore no longer supply pressure. The Norwegian Safety Investigation Authority considers it likely that a combination of factors contributed. A higher service life on the component than logged, natural variation in the Vespel spline adapter's production and materials, and the individual torque load on the pump are all contributing factors.

The loss of oil pressure did not lead to an immediate risk of failure of the main gearbox.

About the investigation

Purpose and method

The NSIA initially classified this incident as a serious aviation incident. After speaking with Sikorsky Aircraft Corporation and evaluating how the oil system functions, the incident was reclassified as an aviation incident. During the reclassification, the NSIA has emphasised that the incident was not close to becoming an accident. The NSIA has still chosen to investigate the incident since it contains several interesting aspects.

The purpose of this investigation has been to clarify what caused one of the Vespel spline adapters on LN-ONH to fail and lead to a loss of oil pressure. The NSIA has also considered what can be done to improve safety and prevent the recurrence of similar incidents in the future.

The investigation was conducted in line with the NSIA's framework and analysis process for systematic safety investigations (the NSIA method[1]).

Sources of information

The NSIA has collected information from several sources, including interviews with the crew, data from cockpit voice recorder and flight data recorder, the helicopter manufacturer and the helicopter operator.

The investigation report

The first section of the report, Factual information, describes the sequence of events, associated data and information gathered in connection with the accident, and describes the NSIA's examinations and related findings.

The second section, Analysis, describes the NSIA's assessments and analyses of the sequence of events and contributing factors, on the basis of factual information and examinations carried out. Details and factors that are found to be less relevant in order to explain and understand the accident are not discussed in depth.

The report ends with the NSIA's conclusions.

[1] *See https://www.nsia.no/About-us/Methodology*

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1. Factual information

1.1 History of the flight

On the evening of 25 September 2021 LN-ONH was returning to Ekofisk Lima (ENLE) after completing a search and rescue (SAR) training mission. Due to the prevailing wind conditions, it was the first officer in the left seat who was performing the landing and who was pilot flying (PF).

The flight was normal up until halfway of the right downwind phase of the landing pattern. When the helicopter was roughly 1.9 nm away and 90° off the helipad, the crew suddenly heard the aural alert for low oil pressure in the main gearbox, '*GEARBOX PRESSURE, GEARBOX PRESSURE'.* The crew immediately changed course directly to ENLE for a short final and landing. The commander who was pilot monitoring (PM), observed the instrument panel and saw that the warning light for the oil pressure was illuminated and that the oil cooler was in bypass.

The first officer has told the NSIA that they did not perform the emergency procedure until they had landed at ENLE. They decided that it was more important to land quickly given that they were so close to the oil rig and their knowledge of the oil system of the S-92A. They believed that starting the emergency procedure would postpone the landing.

The commander has explained to the NSIA that the oil pressure dropped quickly. Normally, the oil pressure is around 60 psi. The aural alert for the oil pressure is activated when the pressure is under 35 psi. 22 seconds after the alert, the commander observed that the pressure was 10 psi and dropping. 28 seconds after the alert he noticed that they had a failure indication on oil pump #1. The oil pressure had by this time decreased to 6 psi.

Data from the flight data recorder (FDR) showed that the oil pressure dropped from 59 to 32 psi in three seconds. It stabilised at around 5–6 psi after 33 seconds.

One minute and 50 seconds after the low oil pressure alert LN-ONH landed on ENLE. The crew proceeded to do a normal shut-down and contacted maintenance. Maintenance personnel removed both oil pumps for inspection and discovered that the Vespel[2] spline adapter that drives oil pump #1 was completely worn down. They also inspected the Vespel spline adapter #2, which also showed signs of wear.

1.2 Injuries

Table 2: Injuries

Injuries	Crew	Passengers	Other
Fatal			
Serious			
Minor/none	5	0	

1.3 Damage to aircraft

Damage to two Vespel spline adapters. No other damage.

[2] ®Vespel is the marketing name of a group of polyimide-based plastics produced by DUPONT.

1.4 Other damage

No other damage.

1.5 Personnel information

The commander started his career by taking a private helicopter education in Norway in 1991. He subsequently travelled to the US and took his Commercial Pilot Licence (CPL (H)) and Airline Traffic Pilot License (ATPL (H)). The commander stayed in the US for eight years and worked as a helicopter pilot in the Gulf of Mexico from 1995 to 1999. He was employed by Norsk Helikopter, now Bristow Norway AS (Bristow), in 1999 and has worked there since. He has flown SAR helicopters for Bristow for the last six years and has flown the S-92A since it came to Sola in 2006. Sola is the commander's home base.

The commander had valid rights for the S-92A and a medical licence without restrictions.

Table 3: Flight time commander

Flight time	All types	On type
Last 24 hours	3	3
Last 3 days	8	8
Last 30 days	18	18
Last 90 days	54	54
Total	14 520	5 760

1.5.1 THE FIRST OFFICER

The first officer took his helicopter education in the US from 2000 to 2002. He was employed by Norsk Helicopter in 2005. He has mainly been based at Sola and has flown to and from oil rigs in the North Sea. He started flying SAR helicopters in April 2021.

The first officer had valid rights for the S-92A and a medical licence without restrictions.

Table 4: Flight time first officer

Flight time	All types	On type
Last 24 hours	3	3
Last 3 days	6	6
Last 30 days	20	20
Last 90 days	45	45
Total	10 177	9 050

1.6 Aircraft information

1.6.1 GENERAL INFORMATION

Sikorsky Aircraft Corporation (Sikorsky) S-92A is a heavy passenger helicopter with two turbine engines. It has a main rotor with four rotor blades and a tail rotor. The helicopter fuselage is mainly constructed of aluminium but also composite material. The helicopter is partly based on Sikorsky

S70/UH-60 and they share several dynamic components. The first flight of the S-92A was in 1989. After development and testing was completed the helicopter was type certified by FAA in 2002 and later for Europe by JAA/EASA in 2004. The S-92A has room for 19 passengers and two pilots in offshore configuration. The helicopter also has several different cabin configurations for SAR missions. The helicopter is equipped with flotation devices certified for emergency landings at sea up to sea state 6 which means a wave height of 4–6 metres.

The S-92A entered service in Norway to transport oil workers to and from oil rigs in the North Sea in 2005, and today it is the only helicopter type in use on the Norwegian continental shelf. The helicopter is also used for SAR missions on the Norwegian shelf. As of 22 April 2021, there were 44 S-92As registered in Norway.

1.6.2 DATA FOR LN-ONH

Table 5: General data LN-ONH

Manufacturer & model:	Sikorsky Aircraft Corporation S-92A
Serial number:	920094
Year of manufacture:	2008
Type certificate number:	R00024BO
Airworthiness Review Certificate (ARC) valid to:	October 2022
Total number of flight hours:	2,761
Flight since last inspection:	4 hours
Number of landings:	11,371
Engines:	General Electric CT7-8A
Fuel:	Jet A-1
Empty mass	7,030 kg (15,500 lbs)
Maximum take-off mass:	12,020 kg (26,500 lbs)
Maximum allowable speed:	165 kt

1.6.3 WEIGHT AND BALANCE

The helicopter's weight and balance at the time of the incident were within the limitations of the manufacturer's Rotorcraft Flight Manual.

1.6.4 THE MAIN GEARBOX

1.6.4.1 Construction

The primary task of the main gearbox is to transfer power from the two engines to the main rotor and the tail rotor. It reduces the engine rpm of 21,945 to an rpm of 257.8 for the main rotor[3]. The main gearbox also drives two 75 kVA AC generators, two oil pumps and three hydraulic pumps. The lubrication system for the main gearbox is described in more detail in 1.6.4.2. The main gearbox is attached to the top of the fuselage and is also the mount for the main rotor. The mass of the main gearbox is 794 kg.

[3] *Based on a main rpm of 105%.*

The main gearbox is divided into five modules; left and right Input Modules; left and right Accessory Modules and the Main Gearbox Module. Each Accessory Module has a generator and hydraulic pump attached (see Figure 1). The oil pumps are connected to the Main Gearbox Module. The pumps and generators are driven by shafts with spline connections.

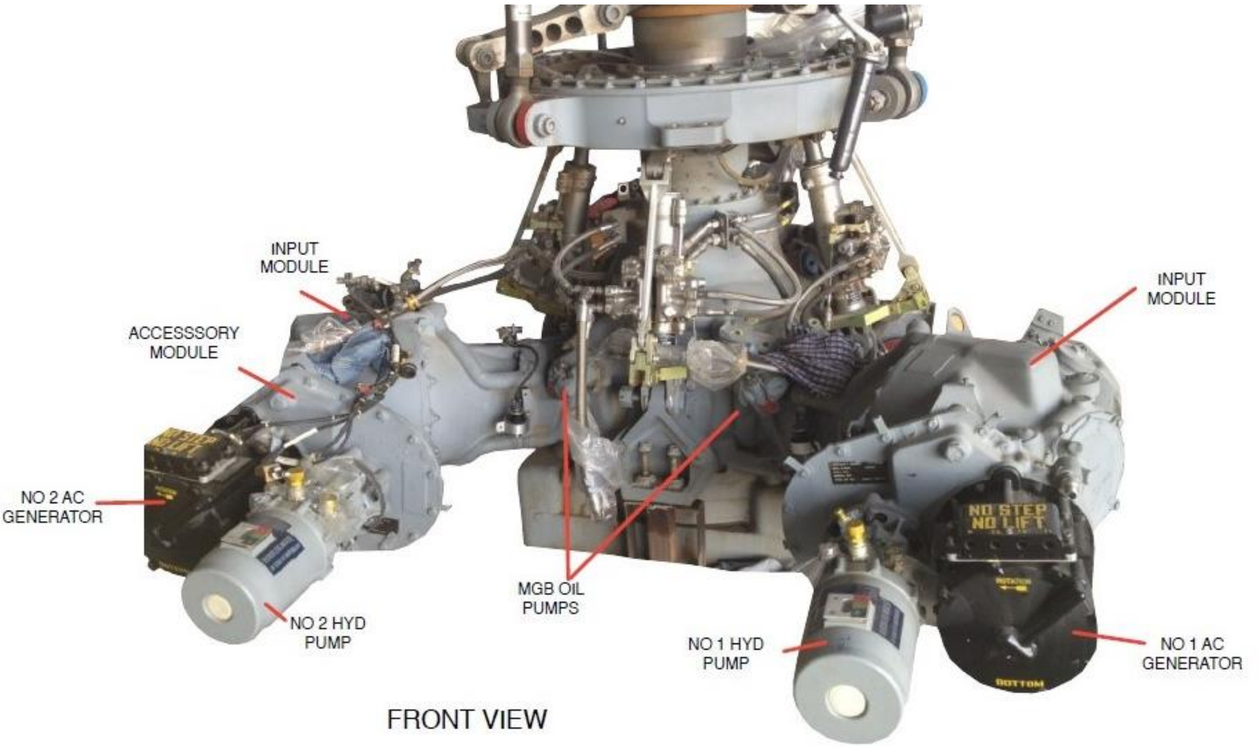


Figure 1: Main gearbox seen from the front. The main rotor mast goes straight up from the Main Gearbox Module in the middle of the photo. Photo: Sikorsky/NSIA

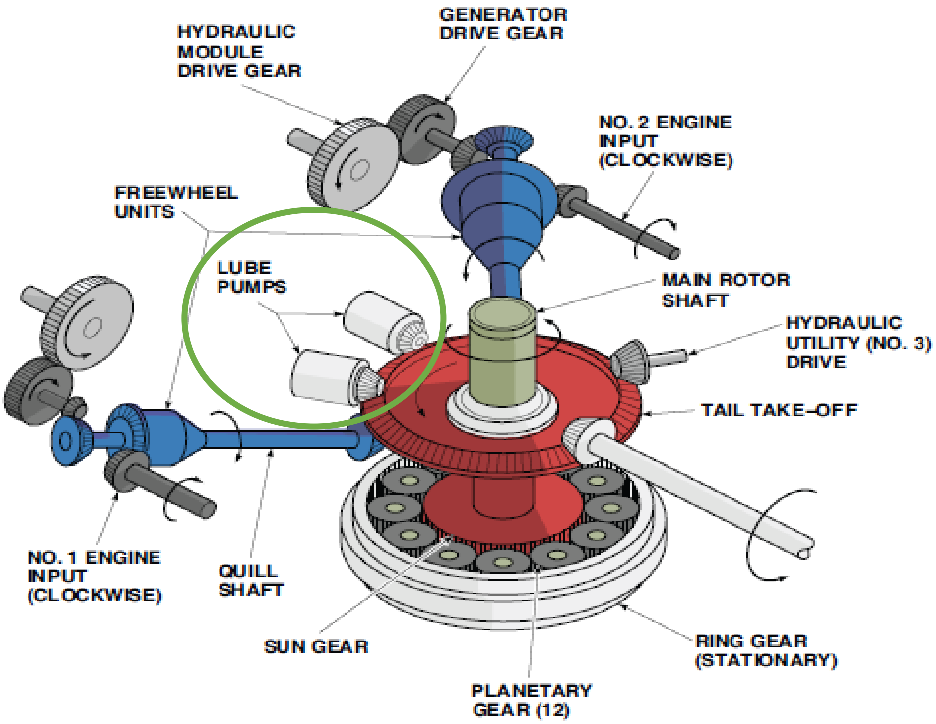
1.6.4.2 The lubrication system

The main gearbox has its own lubrication system with two parallel pumps and a separate oil cooler. The primary task of the lubrication system is to cool and lubricate the main gearbox. Each pump consists of two parts, a lube element and a scavenge element. The oil pipes are integrated into the gearbox housing, and they are therefore internal, except for the oil cooler loop which is external.

The lube elements draw oil from the oil sump in the main gearbox module and supply oil to the gearbox gears and bearings. In addition to scavenging due to gravity, the scavenge elements draw oil from the periphery of the gearbox to the oil sump. The scavenge pumps are separate, which means that the left scavenge pump scavenges the left side of the gearbox and the right scavenges the right side. The lubrication system has an oil filter and several sensors and chip detectors. See 1.6.4.3 below.

The oil pumps are driven by a bevel gear in the main gearbox module (see Figure 2). The Vespel spline adapter is positioned outside the spline on the oil pump driveshaft and engages the bevel gear. Both the driveshaft and the bevel gear are metal. The adapter ensures good contact between the oil pump and the bevel gear. In addition, it is meant to limit wear by eliminating metal on metal contact.

If the Vespel spline adapter of one of the oil pumps fails, without the pump jamming, the pump is free to rotate and does not hinder oil flow. Sikorsky has told the NSIA that the oil flow from the functioning oil pump will drive the failed oil pump. The failed oil pump will in this scenario function as a pseudo regulating valve. See the black arrow in Figure 5. This leads to the oil pressure stabilising at around 5–10 psi. Sikorsky has informed the NSIA that the S-92A can, in theory, continue operating with such low oil pressure for longer than it has fuel.



MGB ASSEMBLY OPERATION

Figure 2: Illustration of how the bevel gear drives the oil pumps. Schematic: Sikorsky/NSIA

Figure 3: The oil pump. The Vespel spline adapter is marked with a ring. Photo: Sikorsky/NSIA

Figure 4: The oil pump and driveshaft with the Vespel spline adapter removed. The Vespel spline adapter slides on the driveshaft. Photo: Sikorsky/NSIA

The gearbox holds 37.9 litres (10 US gallons) of oil. The oil is pumped from the sump via the separate, external oil cooler and into the main gearbox. If there is a leak in the external part of the lubrication system, the oil cooler can be isolated by the Oil Bypass Valve. The oil will then flow directly from the lube element to the components in the gearbox. The Oil Bypass Valve disconnects the oil cooler automatically if the oil pressure drops below 35 psi, but the valve can also be manually controlled from the cockpit.

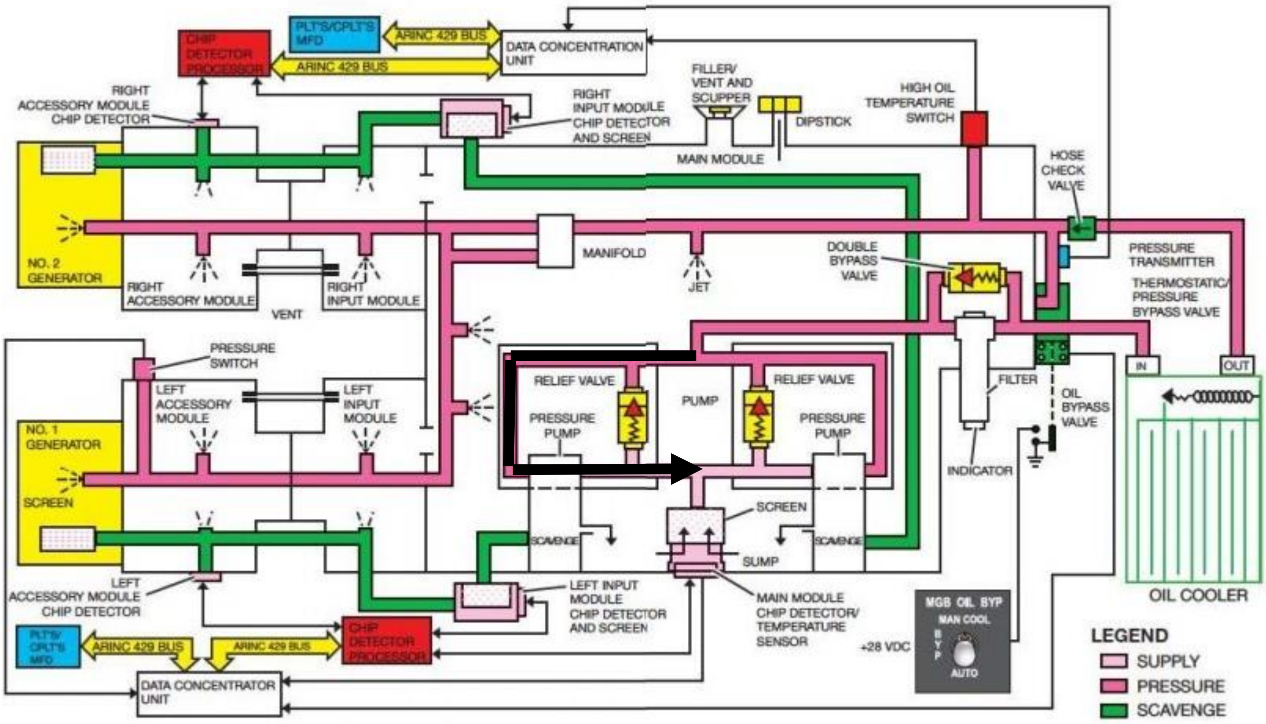


Figure 5: Illustration of the lubrication system for the main gearbox. The black arrow illustrates how the oil flows through one oil pump if the Vespel spline adapter fails without the pump jamming. Schematic: Sikorsky/NSIA

1.6.4.3 Alerts related to the lubrication system

The main gearbox is monitored by several sensors. Data from the sensors is managed by the Avionic Management System (AMS) and presented by the Engine Indicating and Crew Alerting System (EICAS) on the Multi-Function Display (MFD) in the cockpit. Below is a description of the relevant sensors and associated alerts on the MFD[4].

- An oil pressure sensor (1) measures the oil pressure before the oil is distributed within the gearbox. There is also an oil pressure sensor (2) that measures the oil pressure at the very end of the system in the left accessory module. Both left and right input module has a vacuum switch that measures the oil pressure in the scavenge line. 4. In addition, there are several temperature sensors and chip detectors that monitor the gearbox, but they are not relevant for this incident. If oil pressure sensor 1 measures a value under 45 psi or oil pressure sensor 2 measures a value under 24 psi, the alert MGB OIL PRES is triggered.
- If oil pressure sensor 1 measures a value under 35 psi and oil pressure sensor 2 measures a value under 24 psi, the alert MGB OIL PRES is triggered with associated aural alert 'GEARBOX PRESSURE, GEARBOX PRESSURE'
- If oil pressure sensor 1 measures a value under 5 psi and oil pressure sensor 2 measures a value under 24 psi, the alert MGB OIL OUT is triggered with associated aural alert 'GEARBOX OIL OUT, GEARBOX OIL OUT'. Sikorsky has informed the NSIA that this alert is not triggered unless the oil pressure is below 5 psi for at least 10 seconds.
- If one of the vacuum switches in the left or right input module registers that the low pressure disappears, this is alerted as MGB PUMP 1 FAIL and MGB PUMP 2 FAIL respectively.

[4] *Yellow highlight = amber caution light. Red highlight = red warning light.*

1.6.5 MAINTENANCE

The helicopter is maintained at different levels and intervals. For the incident involving LN-ONH, it is the 50-flight hour (FH) inspection that is relevant. As part of the 50 FH inspection, the retaining bolts for the oil pump are checked. If they move when they are torqued with 85 inch-pounds (~10 Nm), the oil pump is to be removed and the fastenings inspected. If they don't move when torqued with 85 inch-pounds (~10 Nm), they shall be torqued with 110 inch-pounds (~12 Nm).

The procedure for removing the oil pump contains a caution that the Vespel spline adapter can come off, in full or in part, when the oil pump is removed. If this occurs, the Vespel spline adapter must be replaced with a new one. The NSIA has reviewed the documentation for the 50 FH inspections that have been done since the Vespel spline adapter was replaced on 18 April 2020. There are no indications that the oil pump was removed during any of these inspections.

Wear on the Vespel spline adapters cannot be detected during day-to-day inspections.

1.6.5.1 Replacement of Vespel splines

In November 2020, Sikorsky adjusted the service life of the Vespel spline adapter from 375 to 750 FH[5]. This was done in collaboration with the S-92A operators and subject to an evaluation of the wear rate of the Vespel spline adapter. It must also be replaced after a new, overhauled or repaired oil pump has been installed.

When the Vespel spline adapters on LN-ONH were replaced on 18 April 2020, the helicopter had a total flight time of 2,061 FH. At the time of the incident the helicopter had a total flight time of 2,761 FH. The Vespel spline adapter was therefore due to be replaced at the next 750 FH inspection.

The Vespel spline adapter is defined as a consumable. This means it is a component that cannot be overhauled or repaired, and is thus discarded when it is replaced. Consumables do not have a defined serial number, but a part number and a batch number. Each replacement of Vespel spline adapters is logged, and consumables are logged when they are removed from storage. However, there is no follow-up of how worn a Vespel spline adapter is when it is replaced. It is up to the judgement of each individual technician to determine if something is not normal.

1.7 Meteorological information

The weather was fair with scattered clouds on the Saturday in question. The air temperature was 15 °C and the water temperature was 16 °C, and there were moderate waves.

1.7.1 METAR

The following METARs were published for Ekofisk Lima:

ENLE 251850Z 17014KT 9999 SCT010 SCT200 15/ 14 Q1013 W16/ S4=

ENLE 251920Z 18014KT 9999 SCT010 SCT200 15/ 13 Q1013 W16/ S4=

ENLE 251950Z 18014KT 9999 SCT010 SCT200 15/ 13 Q1013 W16/ S4=

ENLE 252020Z 15012KT 9999 FEW010 SCT200 15/ 14 Q1013 W16/ S4=

[5] *After the incident Sikorsky has readjusted this to 375 FH.*

1.8 Aids to navigation

Not relevant.

1.9 Communications

LN-ONH was routinely in contact with the Air Traffic Service at Ekofisk.

1.10 Aerodrome information

1.10.1 EKOFISK LIMA (ENLE)

Ekofisk Lima is a habitation and oil field control platform in the North Sea that opened in 2014. The platform has 526 beds, two helicopter hangars and multiple oil field control functions and systems. The platform is both the landing site and SAR base for the Ekofisk oil field. Bristow has run SAR operations from ENLE since 2014.

1.11 Flight recorders

LN-ONH was equipped with a Curtis-Wright D51615-142-090 combined Cockpit Voice Recorder and Flight Data Recorder with serial number A12016-002. It has the capability of storing 120 minutes of audio and 25 hours of data. The data from this recorder was downloaded by Bristow, with the NSIA present, and made available to the investigation.

Figure 6 shows the oil pressure and oil temperature during the incident. It shows that the oil pressure dropped from 60 psi to 33 psi in three seconds. It took a further 33 seconds before the pump stopped rotating and started acting as a pseudo regulating valve. The oil temperature started to rise after about one minute. Thereafter it rose steadily during the incident, but never reached a temperature high enough to trigger an alert.

Figure 7 shows relevant parameters from the flight. The NSIA has also obtained information that the Auxiliary Power Unit (APU) was started at 19:21:36, 30 seconds after the helicopter landed on the oil rig.

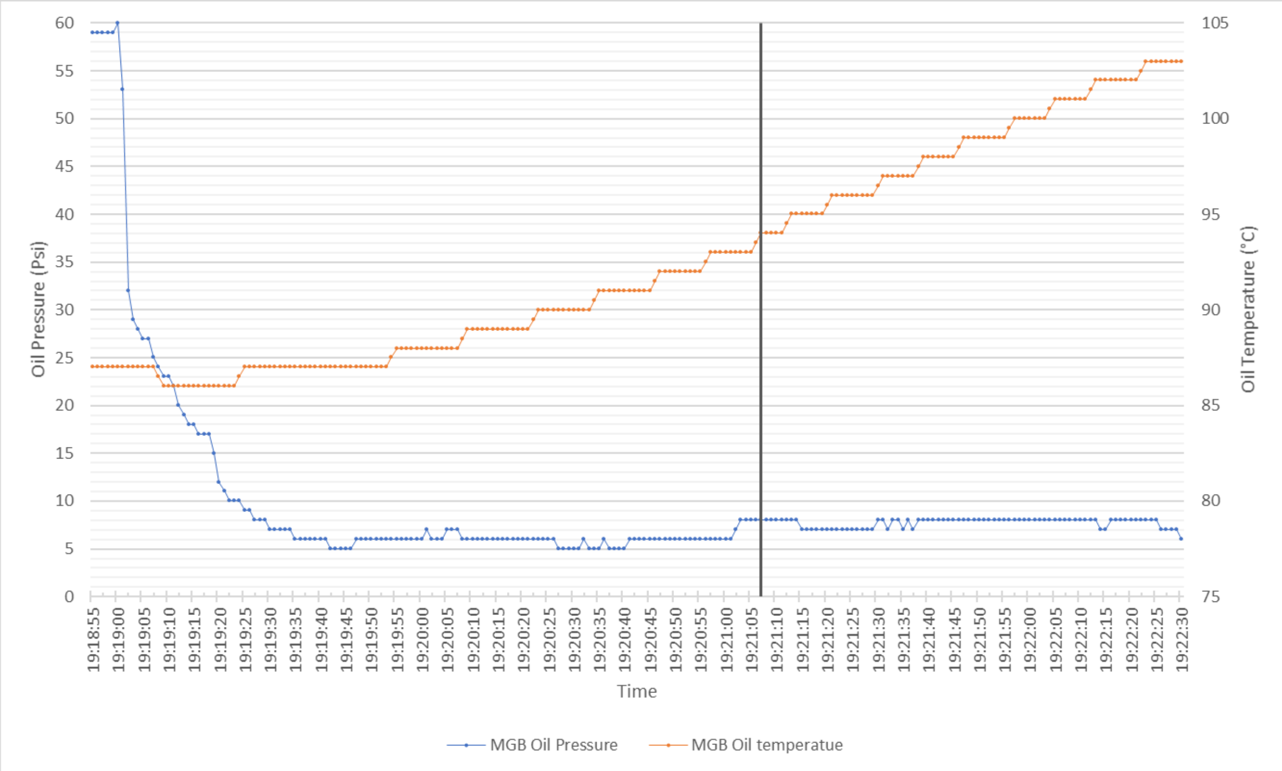


Figure 6: Oil pressure and temperature during the incident. The black line marks the landing on the oil rig. Source: FDR/NSIA

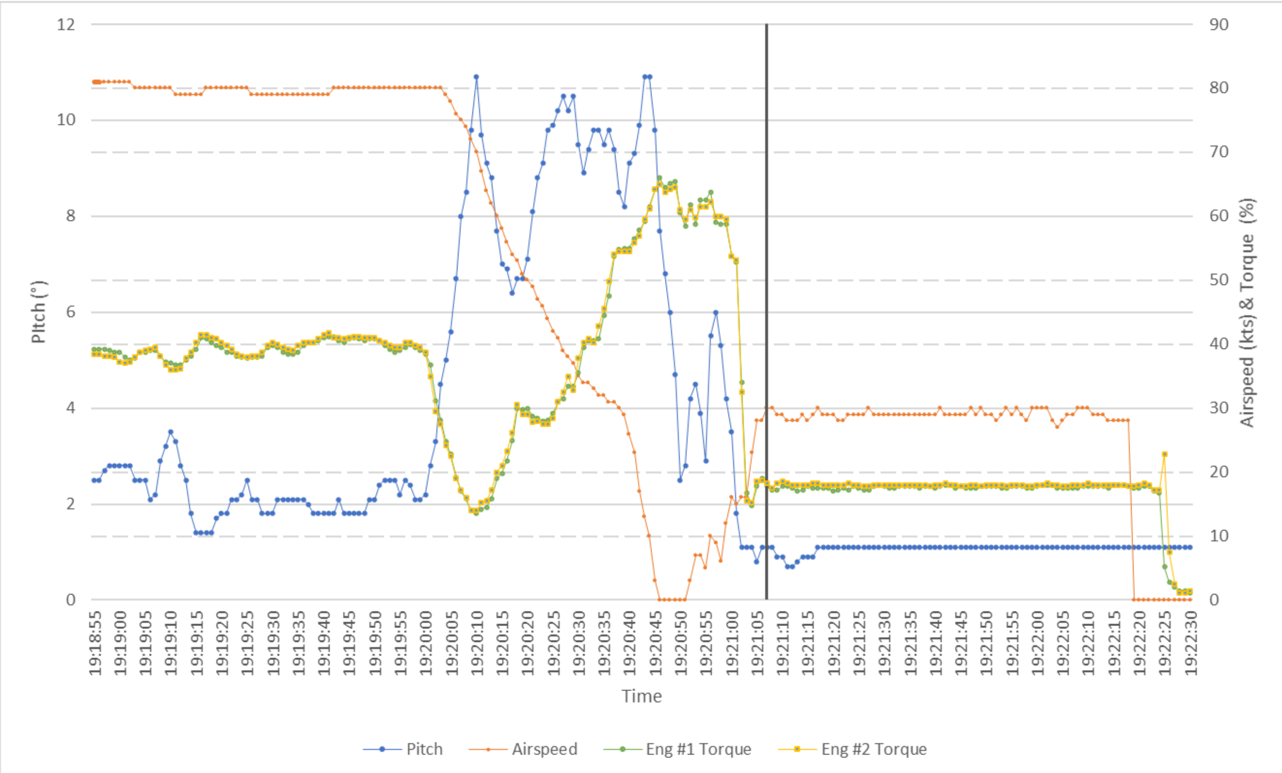


Figure 7: Pitch, airspeed and torque for both engines during the incident. The black line marks the landing on the oil rig. Source: FDR/NSIA

1.12 The accident site and wreckage information

Not relevant.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

Not relevant.

1.15 Survival aspects

The pilots were equipped with a flight suit, which contains inflatable floatation elements. The other three on board had survival suits.

1.16 Tests and research

Both the Vespel spline adapters and the oil pump connected to the worn-down adapter was sent to Sikorsky for inspection and analysis. Due to the COVID pandemic, the NSIA was not present at all the inspections. Inspectors from the NTSB or the FAA were present at the inspections that the NSIA was unable to attend. This is in accordance with the guidelines set out in ICAO Annex 13.

Figure 8: Photos of the removed Vespel spline adapters. The photo clearly demonstrates that spline adapter #1 is completely worn down internally. Wear can also be seen on spline adapter #2. Photo: Bristow/NSIA

1.16.1 INSPECTIONS OF THE VESPEL SPLINE ADAPTER

1.16.1.1 Non-destructive testing

Sikorsky carried out non-destructive testing of the Vespel spline adapters under the observation of a representative from the FAA. The testing was done at Sikorsky Materials and Processing Lab in Stratford, Connecticut, USA.

Vespel spline adapter #1 was examined using Fourier Transform Infrared (FTIR) spectroscopy to determine its chemical composition. The composition matched with the data stored in Sikorsky's material library for Vespel material. The adapter was also imaged using microscopes. There were clear signs of heat damage to the internal diameter of the adapter.

Both the inner and outer diameter of the spline were covered in material residue. The adapter was cleaned, and all the residues were collected for further analysis. The adapters were also CT-scanned. These pictures showed a large axial crack on the inner diameter of the spline.

Vespel spline adapter #2 also had some wear on the inner diameter, but nothing abnormal for a Vespel spline adapter with a high service life.

The driveshaft of oil pump #1 was examined under a microscope and no signs of wear or defects were found.

1.16.1.2 Destructive testing

Subject to agreement with the NSIA and with a representative of the NTSB present, Sikorsky performed destructive testing of Vespel spline adapter #1.

The examination began with FTIR of the cotton swabs that had been used to clean the oil pump driveshaft, the inner diameter and the outer diameter of the Vespel spline adapter. All three samples contained residues of Vespel SP-1[6] and synthetic transmission oil.

The material residues were also examined using a normal optical microscope and an electron microscope. The samples were also analysed using Energy Dispersive Spectroscopy (EDS) to determine which elements the samples contained. Nothing abnormal was detected, most of the sample was made up of organic carbon and oxygen (Vespel) and phosphorous and sulphur which probably stem from cooked oil.

The crack that was discovered on the inner diameter during the CT-scanning was examined next. It was first inspected under a microscope, before opening the crack to investigate the crack surface. The crack was opened by sectioning the Vespel spline adapter on the opposite side of the crack, then the crack was forced open and the Vespel spline adapter split in two.

The fracture surface was examined using an electron microscope. These images showed a dimpled surface, which is typical for a ductile overload fracture. No unusual wear patterns or characteristics were observed. The Vespel spline adapter did not contain any voids or porosity. No foreign material was found in the crack. The original fracture surface was similar to the crack that was created when the Vespel spline adapter was sectioned.

[6] *Vespel is produced as different variants. Vespel SP-1 is pure polyimide without any additives.*

1.16.2 OIL PUMP INSPECTION

On 17 January 2022 oil pump #1 was inspected and tested by Crane Aerospace. The NSIA was present during the testing. The box containing the oil pump and Vespel spline adapter was opened, and the oil pump was inspected visually. It was noted that a lock wire was missing from the regulating valve. It was possible to rotate the pump by hand and there were no signs of binding. The pump driveshaft is normally a gold colour but was found to be purple and black. This is indicative of overtemperature. Nothing else unusual was detected.

The pump was then mounted in a test rig and an Acceptance Test Procedure was performed, which it passed. The purpose of the test was to identify whether there was anything wrong with the pump and to determine the pump's current performance. No faults or anomalies were detected, and the pump operated within expected limits. It was noted that the pump had an output flow of 15.8 Gallons per minute (GPM), while it should normally lie between 14.6–14.8 GPM.

During assembly and/or overhaul of the MGB lube pump, it is normal for the manufacturer to adjust the regulating valve to achieve the correct system pressure prior to the pump being mounted on a MGB assembly. Slight variations from helicopter to helicopter mean it is normal to have to adjust the regulating valve when the MGB assembly is mounted on the helicopter. This will adjust the output flow. The pressure the pump supply is directly proportional to the output flow, and is directly proportional to the torque load on the pump.

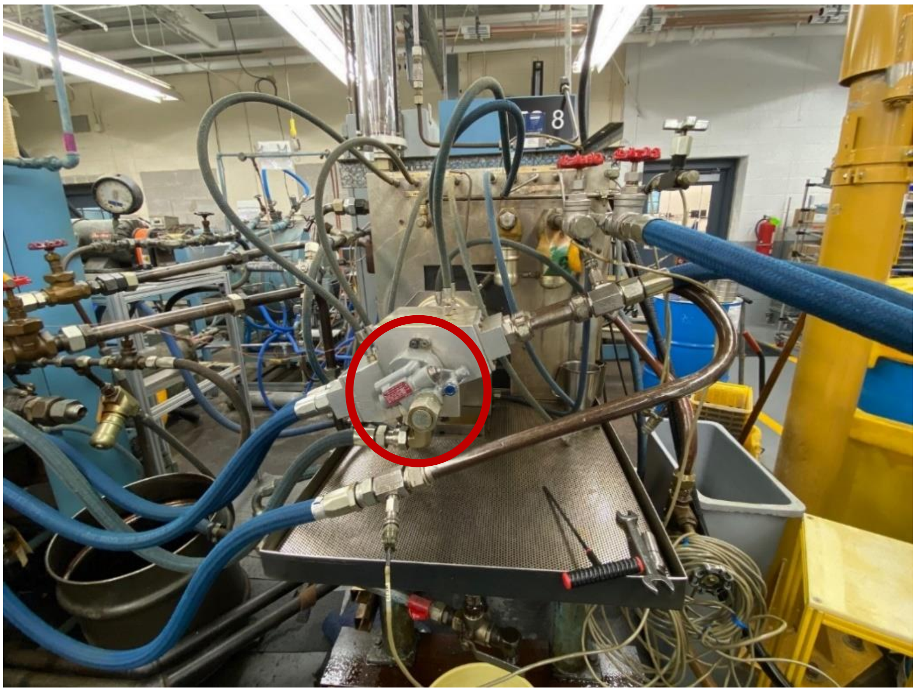


Figure 9: The oil pump from LN-ONH in the test rig. The pump is marked with a red ring. Photo: Crane Aerospace/NSIA

1.17 Organisational and management information

At the time of the incident, Bristow Norway AS had roughly 430 employees. The company operated 28 S-92A helicopters, and its main administrative and operative base was at Stavanger airport, Sola. Equinor awarded Bristow new contracts for transport of oil workers out of Bergen airport, Flesland and Florø airport in 2016.

1.18 Additional information

1.18.1 OPERATIONAL PATTERN OF SAR-HELICOPTERS

The SAR helicopters are frequently used for shuttle flights. These are flights transporting people and goods between platforms in the same oil field. These operations entail the helicopter spending a lot of time on the helideck with the main rotor turning. This time is not logged and is therefore not part of the FH for the helicopter. Bristow conducted its own internal investigation after the incident, and a sample from May 2021 showed that the helicopter had the rotor running 38% more than logged FHs. In its internal investigation, Bristow stated that it would evaluate the Aircraft Maintenance Programme for the SAR helicopters located offshore to account for the challenges of non-logged running time.

1.18.2 EMERGENCY CHEKLIST AND TRAINING IN SIMULATOR

Sikorsky develops the procedures in the Rotorcraft Flight Manual. Figure 10 shows the current emergency procedure for MGB OIL PRESS WARNING. The emergency procedure has changed as the lubrication system for the helicopter type has been modified over the years. The alerts, and correct response to these, have changed considerably. The last version of Bristow's operationalisation of this procedure is shown in Figure 11. It is this procedure Bristow's pilots are trained in.

Priviously, the system did not have an alert for MGB PUMP FAIL or an automatic oil bypass system. If the oil pressure warning was activated, the pilot had seven seconds to activate the oil bypass switch. Neither was there any MGB OIL OUT warning, and the *Land immediately* criterion was the oil pressure falling below 5 psi. Figure 12 shows an excerpt from the MGB PUMP FAIL procedure where Sikorsky states that the oil pressure will stabilise between 5 and 10 psi.

Bristow's pilots train in performing emergency procedures in a simulator. Over a three-year period, they train in six main groups of systems. The main gearbox, and accompanying lubrication system, is one of these six groups. The simulator has to be programmed as to how it should behave in different situations. In interviews with the NSIA, both pilots have expressed surprise as to how quickly the oil pressure dropped. Their experience from the simulator was that it dropped gradually and stabilised at a higher value than 5 psi. In its internal investigation, Bristow recommends using the incident as further training scenario for its S-92A pilots.

7.2 MGB OIL PRESS WARNING

WARNING

A total loss of main gear box oil pressure may result in main gear box failure in less than 10 minutes. If the MGB OIL OUT warning illuminates, land immediately.

Symptom:

MGB OIL PRESS

"GEAR BOX PRESSURE" aural alert

MGB oil Pressure below 35 psi on the EICAS page

Action:

1. Descend to a minimum safe altitude while reducing airspeed below 100 KIAS. If conditions permit, descend below 500 feet above the water/terrain. Maintain airspeed between 80 and 100 KIAS until committed to land.

2. APU CTRL – ON.

3. APU GEN – ON.

If **MGB OIL BYPASS** is not illuminated:

4. MGB OIL BYP switch – BYP.

If **INPUT/ACC 1/2 HOT** and/or **MGB PUMP 1/2 FAIL** caution(s) also illuminate(s):

5. Throttle (affected engine) – IDLE, unless dual engine power is required for continued safe flight.

6. Adjust airspeed between 80 and 100 KIAS.

7. If practical, maintain pitch attitude above 2° nose up.

If ALL of the following symptoms exist:

MGB PUMP 1 FAIL or **MGB PUMP 2 FAIL** caution

MGB OIL BYPASS caution

MGB oil pressure is 7 psi or greater:

8. MGB OIL BYP – MAN COOL.

9. Land as soon as possible. If required, use dual engine power for landing.

FAA APPROVED JULY 30, 2012
Revised May 23, 2018 3-5

This Document Contains Technical Data Controlled by the EAR. See WARNING and classifications on first page.

Part 1, Section III
Emergency Procedures
Supplement No. 45

S-92

SA S92A-RFM-000
SA S92A-RFM-002
SA S92A-RFM-003
SA S92A-RFM-004
SA S92A-RFM-005
SA S92A-RFM-006

If ANY of the following symptoms of an imminent gear box failure exist:

MGB OIL OUT warning AND MGB oil pressure is below 5 psi on the EICAS page

Increased power required at constant collective setting and airspeed

Yaw kicks

Unusual noise or vibrations

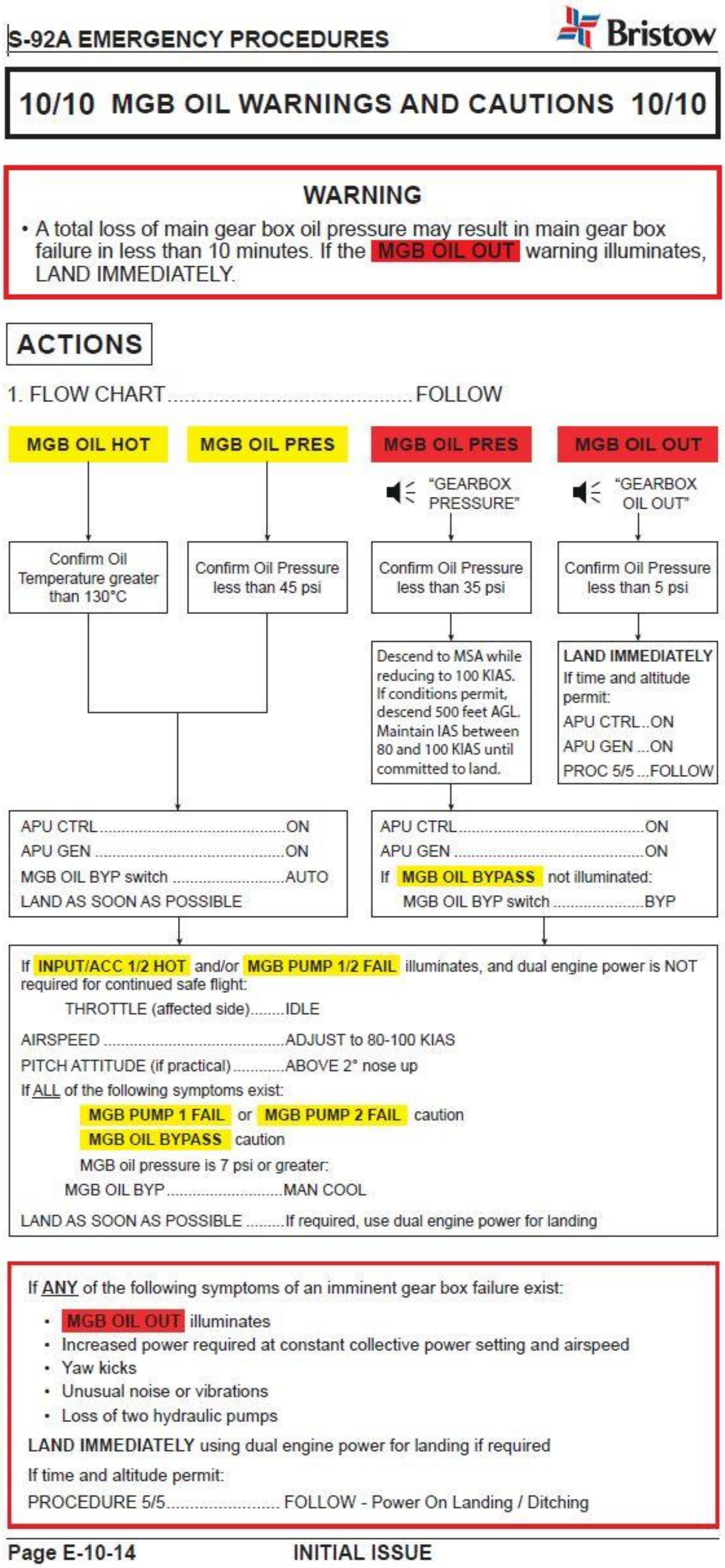
Loss of two hydraulic pumps

10. Land immediately. If required, use dual engine power for landing.

If time and altitude permit:

11. Ditching checklist – Execute, if applicable.

Figure 10: Current emergency procedure for low oil pressure for LN-ONH. Source: Sikorsky/NSIA



S-92A EMERGENCY PROCEDURES — Bristow

10/10 MGB OIL WARNINGS AND CAUTIONS 10/10

WARNING

- A total loss of main gear box oil pressure may result in main gear box failure in less than 10 minutes. If the MGB OIL OUT warning illuminates, LAND IMMEDIATELY.

ACTIONS

1. FLOW CHART .... FOLLOW

MGB OIL HOT → Confirm Oil Temperature greater than 130°C

MGB OIL PRES (caution) → Confirm Oil Pressure less than 45 psi

MGB OIL PRES (warning) — "GEARBOX PRESSURE" → Confirm Oil Pressure less than 35 psi → Descend to MSA while reducing to 100 KIAS. If conditions permit, descend 500 feet AGL. Maintain IAS between 80 and 100 KIAS until committed to land.

MGB OIL OUT — "GEARBOX OIL OUT" → Confirm Oil Pressure less than 5 psi → **LAND IMMEDIATELY** If time and altitude permit: APU CTRL..ON, APU GEN ...ON, PROC 5/5 ...FOLLOW

(MGB OIL HOT / MGB OIL PRES caution):
APU CTRL ....ON
APU GEN ....ON
MGB OIL BYP switch ....AUTO
LAND AS SOON AS POSSIBLE

(MGB OIL PRES warning):
APU CTRL ....ON
APU GEN ....ON
If MGB OIL BYPASS not illuminated:
MGB OIL BYP switch ....BYP

If INPUT/ACC 1/2 HOT and/or MGB PUMP 1/2 FAIL illuminates, and dual engine power is NOT required for continued safe flight:
THROTTLE (affected side)........IDLE
AIRSPEED ....ADJUST to 80-100 KIAS
PITCH ATTITUDE (if practical) ....ABOVE 2° nose up
If ALL of the following symptoms exist:
MGB PUMP 1 FAIL or MGB PUMP 2 FAIL caution
MGB OIL BYPASS caution
MGB oil pressure is 7 psi or greater:
MGB OIL BYP ....MAN COOL
LAND AS SOON AS POSSIBLE ....If required, use dual engine power for landing

If ANY of the following symptoms of an imminent gear box failure exist:
- MGB OIL OUT illuminates
- Increased power required at constant collective power setting and airspeed
- Yaw kicks
- Unusual noise or vibrations
- Loss of two hydraulic pumps

LAND IMMEDIATELY using dual engine power for landing if required
If time and altitude permit:
PROCEDURE 5/5........................ FOLLOW - Power On Landing / Ditching

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Figure 11: Bristow's operationalisation of Sikorsky's emergency procedures for alerts related to oil pressure. Source: Bristow/NSIA

CONSIDERATIONS

1. An MGB PUMP 1 FAIL or MGB PUMP 2 FAIL caution indicates a pump failure and will lead to oil pressure between 5-10psi, and will cause the auto bypass system to activate.
2. A main gear box pump failure may also result in high temperatures in the corresponding accessory and input modules, indicated by an INPUT/ACC 1 HOT or INPUT/ACC 2 HOT caution.

Figure 12: Excerpt from S-92A's rotorcraft flight manual that mentions the consequences of one oil pump failing. Source: Sikorsky/NSIA

1.18.3 OTHER INCIDENTS

In 2005, there was another incident on the Norwegian continental shelf where the oil pressure of a S-92A suddenly dropped to 5–6 psi. It was found that this incident was also caused by a Vespel spline adapter that was completely worn down. The attributing factor was a poor surface finish on the pump driveshaft, which accelerated the wear of the Vespel spline adapter. After the incident, Sikorsky readjusted the replacement interval of the adapter to 50 FH and changed the surface finish of the pump driveshaft to ensure less wear. They also added a check valve in the pump to stop oil flowing back into the pump in the wrong direction.

In 2008, another incident occurred in Brunei involving a helicopter operated by Brunei Shell Petroleum, which was also related to the Vespel spline adapter. In this incident the Vespel spline adapter had moved on the driveshaft, such that only half the adapter was engaged. This led to increased wear, and the adapter was completely worn down. This helicopter had an oil pump with a check valve installed. This led to the oil pressure stabilising at 15–17 psi.

In 2008, the alert system was less developed than it is today. The crew of the Brunei helicopter therefore had no information about why the oil pressure dropped, or which side of the main gearbox was affected. When they lost oil scavenging in one half the gearbox churning[7] occurred and they had to land in the jungle. After the incident, the alert system was changed to provide better information to the pilots. The Vespel spline adapters were extended to ensure that they could not move. The check valve was also removed from the pump. This means that the oil pressure will drop lower, but according to Sikorsky reduces the likelihood of churning and overheating.

After the incident in 2008, no incidents involving the Vespel spline adapter have been reported. The replacement interval has therefore over the years been extended, most recently to 750 FH in 2020.

Bristow has also told the NSIA of another occurrence of excessive wear of a Vespel spline adapter. This was discovered during a routine replacement after 750 FH on 30 July 2021. The adapter and associated oil pump were sent to Sikorsky for analysis. Sikorsky has informed the NSIA that CT-scanning showed that the left Vespel spline adapter had an average wear percentage of 83%[8], while the right adapter had an average wear percentage of 18%.

1.19 Useful or effective investigation techniques

No methods qualifying for special mention have been used in this investigation.

[7] Churning occurs when there is too much oil in a gearbox. This leads to air being whipped into the oil causing overtemperature, increased wear and loss of efficiency.
[8] 83% of the material of the splines was worn away.

2. Analysis

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2.4 Training in a simulator 26
2.5 Wear of the Vespel spline adapter and airworthiness 26

2. Analysis

2.1 Introduction

This analysis explores possible factors that may have attributed to the fact that the Vespel spline adapter was completely worn down. The analysis starts with the sequence of events before it looks at the limitations of the lubrication system and training in emergency procedures. Finally, the wear of the Vespel spline adapter and airworthiness are discussed.

2.2 Course of events

Until the aural alert for low oil pressure in the main gearbox, the crew had no indication that anything was wrong. It was favourable that the helicopter was right by the oil rig, and therefore a safe landing site, when the oil pressure dropped. This provided the possibility to land immediately after the situation arose.

Based on the experience, training and system knowledge the crew possessed, they made the decision that it was more important to land quickly than to complete an emergency procedure. If the crew had started the emergency procedure at this point, it would probably have postponed the landing in a critical phase.

The decision to land immediately without completing the emergency procedure was made quickly and was in the NSIA's opinion, sensible in this case. The NSIA would still like to emphasise that emergency procedures are important aids. They are collective memories which are established after experience and are meant to structure and ease the work in the cockpit.

When the Vespel spline adapter broke, the oil pump stopped supplying pressure. The loss of oil pressure led to the automatic bypass of the oil cooler. The active oil scavenging of the half of the gearbox that was affected also stopped. This led to the oil temperature starting to rise. According to the emergency procedure the affected engine should be throttled to idle, if possible, to reduce the rise in oil temperature.

As mentioned in 1.6.4.2, the S-92A can fly with low oil pressure. There is no longer any redundancy, however, and the helicopter is exposed to vulnerabilities. A decision has to be made as to whether the flight should continue or an emergency landing with associated risk should be made.

All five on board was equipped with survival devices. This, together with the fine weather means that those on board probably had a good chance of survival in the event of ditching[9] at sea.

2.3 Knowledge of the lubrication system

Replaying the CVR from the event shows that the crew on multiple occasions discussed 5 psi as a lower limit for the oil system after it had dropped to 6 psi. Had the situation been different and a landing site had not been immediately available, the situation would have been more dramatic. The NSIA believes that it is unfortunate that the difference between the criteria for *land immediately* and *land as soon as possible* is as little as a single psi, ref. 1.6.4.3, and that the crews have very limited information as to why.

[9] *Ditching is a controlled landing on water by an aircraft that is not constructed to do so.*

Having to ditch a helicopter is something that should be avoided unless it is absolutely necessary. As the lubrication system functions today, it is possible that a crew must operate over time with an oil pressure that feels completely marginal. The crews flying the S-92A have no information about why the oil pressure drops to such a low level and the consequences of this. It is also unfortunate that it is unknown to the crews that the oil pressure has to be below 5 psi for 10 seconds before the OIL OUT warning is triggered.

When the margins between *land immediately* and *land as soon as possible* are so small, the NSIA believes that access to better information would assure the crews. Knowing why the oil pressure drops to such a low level when they are alerted that one of the oil pumps has failed, and that the helicopter can fly with the remaining oil pressure, would make the situation more clear-cut.

2.4 Training in a simulator

Bristow's crews mainly train emergency procedures in a simulator. It is therefore important that the simulator manages to recreate situations as realistically as possible to ensure the crews are familiar with them. In this case, both the commander and the first officer expressed surprise as to how quickly the oil pressure dropped. Training for a situation where the training does not match the actual experience when the situation occurs leads to undue uncertainty.

It is important to give crews a range of possible situations to illustrate the breadth of what they might experience. It is therefore favourable to train on variations of each situation. The NSIA is positive to the fact that Bristow recommends using this incident in its training programme and encourages other helicopter operators to do the same.

2.5 Wear of the Vespel spline adapter and airworthiness

The NSIA has conducted several tests to determine why the Vespel spline adapter was completely worn down. None of the tests have identified production or material flaws. Nor is it possible to deem it a design flaw as Vespel spline adapters are used multiple places on the S-92A and they appear to be reliable. There has not been found any faults in the oil pump that explains why the Vespel spline adapter was worn down.

The wear rate of the Vespel splines will be dependent on several factors. There will be natural variation in tolerance and surface finish of the Vespel spline. In addition, variation in the main gearbox will also require the regulation valve on the oil pump to be adjusted. This affects the torque load on the pump. If the torque load is in the higher range of the norm, the quality of the Vespel spline adapter is in the lower and the service life is higher than logged due to shuttle flying operations, the Vespel spline might be worn down faster than stipulated.

The NSIA would like to emphasise the importance of operators conducting an independent evaluation of the background material they receive from a manufacturer with respect to maintenance intervals. Operational patterns that differ from the premise of the manufacturer must be taken into account.

If a 38% increase in service life is assumed, as the internal investigation by Bristow found, the service life of the Vespel spline adapters on LN-ONH was 966 hours. This is significantly more than the 700 logged hours. The NSIA believes that this incident illustrates that the service interval of 750 FH, which did not take into account the time the main rotor was running, was too long in relation to the actual wear rate of the Vespel spline adapter.

The Vespel spline adapter is a component that must be replaced after a certain time interval, and this replacement is safety critical. However, since the component is defined as a consumable, there is no tracking of how it behaves in service. Even though there have been no incidents involving the Vespel spline adapter when the service interval has been 375 FH the NSIA has questioned EASA about why such a critical component is not subject to a more rigorous follow-up regime. Since the system is redundant, the NSIA does not propose a safety recommendation about this topic.

3. Conclusion

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3.2 Investigation results 29

3. Conclusion

3.1 Main conclusion

The oil pressure of LN-ONH's main gearbox was reduced because one of the two oil pumps failed. The reason the oil pump failed was that the Vespel spline adapter between the oil pump driveshaft and the bevel gear in the main gearbox was completely worn down. The NSIA considers it likely that this was due to a combination of factors, such as higher service life than logged, natural variation in production and materials as well as the torque load on the pump.

This did not lead to an immediate danger of critical failure of the main gearbox.

3.2 Investigation results

A. The flight was normal up until halfway of the right downwind phase of the lading pattern.

B. The oil pressure dropped from 59 to 32 psi in three seconds and stabilised at around 5–6 psi after 33 seconds.

C. 1 minute and 50 seconds after the low oil pressure alert LN-ONH landed on ENLE.

D. The oil pressure dropped because the Vespel spline adapter that connected the oil pump to the bevel gear was completely worn down.

E. If the Vespel spline adapter to one of the oil pumps fails, without the pump jamming, the pump is free to rotate and does not hinder oil flow.

F. It is not possible to detect wear on the Vespel spline adapters during day-to-day inspections.

G. No unusual wear patterns or characteristics were observed.

H. The Vespel spline adapter did not contain any voids or porosity.

I. No fault was found in the oil pump that explains why the Vespel spline adapter was worn down.

J. The Vespel spline adapters had a higher service life than logged.

K. The crew's experience of the situation was not in line with what they had trained for in the simulator.

L. There is no follow-up of how the Vespel spline adapters behave in service.

M. There was no immediate danger of critical failure of the main gearbox.

4. Safety recommendations

4. Safety recommendations

The Norwegian Safety Investigation Authority does not propose any safety recommendations after this incident.

Norwegian Safety Investigation Authority
Lillestrøm, 22 September 2022

Abbreviations

Abbreviations

AMS	Avionic Management System
APU	Auxiliary Power Unit
ATPL (H)	Air Traffic Pilots Licence – Helicopter
CPL (H)	Commercial Pilots Licence – Helicopter
CVFDR	Cockpit Voice and Flight Data Recorder
EASA	European Aviation Safety Agency
EDS	Electron Dispersive Spectroscopy
EICAS	Engine Indicating and Crew Alerting System
ENLE	Ekofisk Lima
FTIR	Fourier Transform Infrared Spectroscopy
GPM	Gallons Per Minute
ICAO	International Civil Aviation Organisation
MFD	Multi Function Display
MGB	Main gearbox
NSIA	Norwegian Safety Investigation Authority
NTSB	National Transport Safety Board
PF	Pilot Flying
PM	Pilot Monitoring