Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT
Boeing 767-322ER, N670UA
Shannon Airport, Co. Clare, Ireland

7 April 2022

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 7 April 2022, appointed John Owens as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report.

Aircraft Type and Registration:	**Boing 767-322ER, N670UA**
No. and Type of Engines:	**2 x Pratt & Whitney PW4060 Engines**
Aircraft Serial Number:	**29240**
Year of Manufacture:	**1999**
Date and Time (UTC)[4]:	**7 April 2022 @ 04:47 hrs**
Location:	**Shannon Airport (EINN)[5]**
Type of Operation:	**Commercial Air Transport**
Persons on Board:	**Crew – 9 Passengers – 117**
Injuries:	**Nil**
Nature of Damage:	**Nil**
Commander's Licence:	**Airline Transport Pilot (ATP) Certificate, issued by the Federal Aviation Administration (FAA) of the United States of America (USA)**
Commander's Age:	**58 years**
Commander's Flying Experience:	**24,500 hours, of which 6,710 were on type**
Notification Source:	**Safety Occurrence Report submitted to the Irish Aviation Authority (IAA) by Shannon Airport Air Traffic Control (ATC)**
Information Source:	**AAIU Field Investigation** **AAIU Report Form submitted by the Operator**

[4] **UTC**: Co-ordinated Universal Time. All times in this report are quoted in UTC unless otherwise stated; local time (at EINN) was UTC + 1 hour on the date of the occurrence.

[5] The reported undercarriage fire occurred at EINN, while the in-flight engine shutdown occurred when the aircraft was descending through FL295 and was overhead Cork on Ireland's south coast, approximately 52 NM from EINN.

SYNOPSIS

The Boeing 767 aircraft departed from Dulles International Airport (KIAD) in the United States at approximately 22:21 hrs on 6 April 2022, on a scheduled passenger flight to Zurich Airport (LSZH) in Switzerland. At approximately 04:13 hrs, when the aircraft was at Flight Level 360 and located approximately 20 nautical miles off the south coast of Ireland, the Flight Crew contacted Shannon Air Traffic Control (ATC) to declare an '*emergency*', stating that they wished to divert to Shannon Airport (EINN) as they needed to shut down an engine due to low oil pressure. ATC cleared the aircraft to EINN, where it landed at approximately 04:40 hrs with the No. 1 engine shut down.

When the aircraft was taxiing towards its parking stand, the Airport Fire and Rescue Service noticed a fire at the left-hand undercarriage and requested (via the Shannon Ground Movements Controller) the aircraft to stop. The aircraft stopped and while the fire was being extinguished, the Airport Fire and Rescue Service requested (via the Shannon Ground Movements Controller) that the aircraft be evacuated on the right-hand side. Moments later, the request was cancelled, as the fire had been extinguished. The aircraft was subsequently towed onto its parking stand and all passengers and crew disembarked the aircraft normally. No injuries were reported to the Investigation.

The low oil pressure on the No. 1 engine was subsequently found to have been due to an oil leak from the engine's No. 4 bearing scavenge line magnetic chip detector, which had been inspected as part of scheduled maintenance conducted prior to the flight. The probable cause of the brief fire at the left-hand undercarriage was heat from the brake units and the presence of lubrication grease or oil that had leaked from the No. 1 engine.

NOTIFICATION AND RESPONSE

The AAIU became aware of this occurrence later on the morning of 7 April 2022, following the submission of a Safety Occurrence Report by Shannon ATC to the IAA. The AAIU contacted the Shannon Airport Duty Manager by telephone to obtain further details. Two Inspectors of Air Accidents deployed to Shannon Airport and commenced an Investigation.

1. FACTUAL INFORMATION

1.1 History of the Flight

The Boeing 767 aircraft took-off from Dulles International Airport (KIAD) in the United States, at approximately 22:21 hrs on 6 April 2022 on a scheduled passenger flight to Zurich Airport (LSZH) in Switzerland. At approximately 02:08 hrs, when the aircraft was in the cruise at Flight Level 340[6], a climb to FL360 was commenced. Sometime later, and when the aircraft was at FL360, the Flight Crew noticed that the No. 1 engine oil quantity was decreasing. The Flight Crew reported it by satcom to their operations control centre personnel, who advised the Flight Crew to monitor the engine performance. The No. 1 engine oil quantity continued to decrease and reached zero at approximately 03:27 hrs. The No. 1 engine oil pressure started to decrease around 23 minutes later, and, at approximately 04:13 hrs, a No. 1 engine low oil pressure warning was displayed in the cockpit. At this stage, the aircraft was still at FL360 and was approximately 20 nautical miles (NM) off the south coast of Ireland. The checklist associated with this warning required the Flight Crew to shut down the No. 1 engine.

[6] **Flight Level 340 (FL340):** A three-digit representation of aircraft altitude (34,000 ft in this case) referenced to standard pressure (1013.25 hPa).

The Flight Crew contacted Shannon Air Traffic Control (ATC) to declare an '*emergency*', stating that they wished to divert to Shannon Airport (EINN) as they had '*low oil pressure and need to shut an engine down*'. ATC cleared the aircraft to EINN. The Flight Crew shut down the No. 1 engine at approximately 04:20 hrs when the aircraft was descending through FL295 and was overhead Cork on Ireland's south coast, approximately 52 NM from EINN.

The Airport Fire and Rescue Service (AFRS) at EINN deployed to monitor the landing. The aircraft landed on Runway (RWY) 24 at Shannon Airport at approximately 04:40 hrs. A 180-degree turn was performed at the end of the runway and the aircraft taxied towards the aircraft parking area under escort of the AFRS. As the aircraft turned towards its parking stand, the AFRS requested the Shannon Ground Movements Controller to ask the aircraft to stop as its '*left main bogies*[7]' were '*on fire*'. The Ground Movements Controller requested the Flight Crew to stop the aircraft advising that there was a '*fire observed on the left side, left engine*'. When the aircraft stopped, the AFRS deployed fire-retardant foam to the left undercarriage area. The AFRS subsequently reported that when foam was deployed, the visibility in the area reduced to zero due to the aircraft's Auxiliary Power Unit (APU) and right-hand engine – both of which were running – blowing foam back towards the AFRS vehicles.

The Flight Crew asked the Ground Movements Controller for clarification regarding the location of the fire. The Ground Movements Controller relayed this request to the AFRS, who confirmed that the fire was at the '*left-hand bogie*'. The Ground Movements Controller reported this to the Flight Crew, and moments later, as no acknowledgement was received, repeated the message, advising '*not the engine – the left-hand bogie*'. The Flight Crew replied, stating '*understand, that's the left brake?*', to which the Ground Movements Controller said '*affirm*'. The AFRS subsequently reported that the foam being blown back seemed to be smoke, and therefore they requested the Ground Movements Controller to ask the Flight Crew to '*evacuate that aircraft on the right-hand side*'. The Ground Movements Controller relayed this request, advising that the AFRS are '*suggesting you evacuate the aircraft on the right-hand side*'. A few seconds later, as no acknowledgement was received, the message was repeated. This was acknowledged by the Flight Crew. The Ground Movements Controller then asked the AFRS to confirm that a fire had been observed. The AFRS replied that they '*have visual on fire on the left-hand side*'. Moments later, when the visibility had improved, the AFRS asked the Ground Movements Controller to cancel the evacuation request because the fire had been extinguished. This was relayed to the Flight Crew, who acknowledged the message.

Before being informed of the fire, a brake temperature warning was generated when the aircraft was turning at the end of the runway. Following notification that the fire had been extinguished, the Flight Crew informed the Ground Movements Controller of a procedural requirement for the aircraft to remain stationary for 60 minutes while the brakes cooled. This message was relayed to the AFRS, who continued to monitor the aircraft with thermal imaging cameras. The passengers and Crew remained on board the aircraft during this time. When the 60 minutes had elapsed, and with the agreement of the AFRS, the aircraft was towed onto its parking stand, where all passengers and Crew disembarked normally.

1.2 Injuries to Persons

No injuries were reported to the Investigation.

[7] **Bogie/Bogey:** An arrangement of two or more tandem wheels. It is sometimes referred to as a '*truck*'.

1.3 Damage to Aircraft

There was no damage to the aircraft or to the No. 1 engine.

1.4 Aircraft Information

1.4.1 General

The Boeing 767-322ER is a twin-engine, long-range, wide-body aircraft, fitted with a retractable tricycle landing gear, with four wheels on each main landing gear bogie and two wheels on the nose gear. The main wheels are fitted with brake units. The brake temperatures for each brake unit can be displayed in the cockpit. The temperatures are indicated by the digits 0-9 (low-high). Values in the 5-9 range trigger a brake temperature warning light.

The aircraft fuselage features four main doors (one on each side at the front and one at each side at the rear) and four over-wing emergency exits (two on each side). Emergency escape slides are fitted to each main door and in wing-to-body panels at the rear of each wing. The aircraft is type-certified for ETOPS[8] operations.

The subject aircraft, registration N760UA, was manufactured in 1999. Its Certificate of Airworthiness was issued by the United States Federal Aviation Administration (FAA) on 30 August 1999[9]. The aircraft had operated for a total of 78,893 hours from the date of manufacture until the occurrence date. The subject aircraft was fitted with two Pratt and Whitney PW4060 engines. The No. 1 engine had operated for a total time of 108,034 hours from the date of manufacture, and 11,080 hours since last overhaul.

1.4.2 Engine Lubrication System

1.4.2.1 General

The total capacity of each engine's oil system is approximately 34 US quarts (68 US pints)[10]. The Engine Manufacturer advised that normal cockpit indication for oil quantity during engine operation is from 11 to 15.5 US quarts (22-31 US Pints) and that when the oil quantity indication in the cockpit drops to zero, nine US quarts (18 US pints) remain in the oil tank. The Digital Flight Data Recorder (DFDR) records the oil quantity in US pints.

1.4.2.2 Magnetic Chip Detectors

Aircraft engines normally incorporate Magnetic Chip Detectors (MCDs) to collect magnetic particles that may be present in an engine's oil system. When incorporated, MCDs are regularly inspected during engine maintenance. The size, quantity, and composition of any particles present can be evaluated by maintenance personnel to assess if further maintenance action is required. MCDs are also referred to as MCCs (Magnetic Chip Collectors).

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[8] **ETOPS:** Extended Twin-Engine Operation permits operation for turbine-engine-powered aircraft with two engines during which a portion of a flight is conducted beyond a specified time from an adequate airport. In order to maintain a level of safety consistent with the overall safety level achieved by modern aircraft, it is necessary for ETOPS certified aircraft to have an acceptably low risk of significant loss of power/thrust.

[9] An FAA-issued Certificate of Airworthiness remains valid as long as the aircraft meets its approved type design, is in a condition for safe operation, and maintenance, preventative maintenance, and alterations are performed in accordance with the prescribed standards.

[10] **Fluid Quantities:** This report uses US volume units. US pint = 0.473 litres (Imperial pint = 0.586 litres). 1 US quart = 2 US pints.

In the case of the subject engine type, four MCDs are fitted to the lubrication and scavenge oil pump located at the base of the engine to collect any magnetic particles present in the engine oil scavenge circuits (**Figure No. 1**). An additional MCD is located at the engine's main gearbox, and another is located at the oil tank.

Figure No. 1: Location of MCDs at the base of the engine (typical installation)

The design of the MCDs fitted to the No. 1 engine on the subject aircraft is such that when a magnetic probe is installed in its housing (valve body), it opens a spring-loaded valve and enters the oil stream (**Figure No. 2**). An o-ring (primary seal), described as a '*packing*' in the associated technical publications, and a Teflon® (secondary) seal fitted to the probe, prevent oil leakage. The grip of the probe is fitted with three locking pins, which insert into three corresponding slots in the housing. The probe is installed in the housing by pushing the probe in and rotating it clockwise until it stops rotating. The slots in the housing contain detents, which together with the force from the spring-loaded valve, are designed to lock the probe in the installed position. To indicate correct installation, three equally spaced probe alignment grooves, which are normally painted red, are located on each housing and on the body (grip) of each probe. The grooves on the grip and housing align when the probe is correctly installed. When the probe is removed from its housing for inspection purposes, the spring-loaded valve, which incorporates an o-ring, closes to prevent oil leakage from the engine.

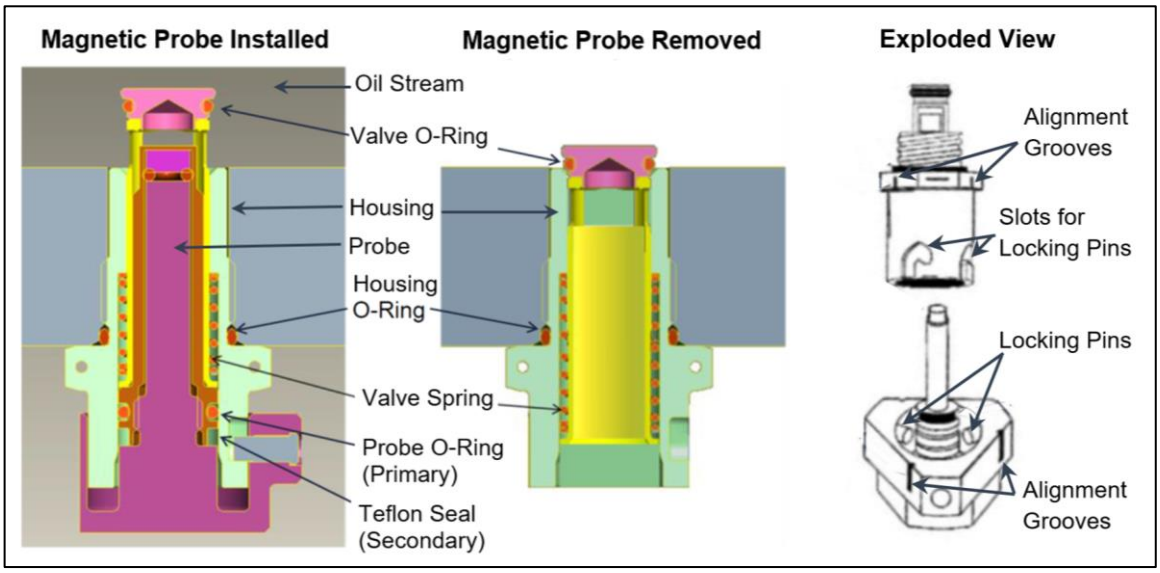

Figure No. 2: MCD design on subject engine type
(*adapted from Engine/MCD Manufacturer documentation)*

1.5 Magnetic Chip Detector Maintenance

1.5.1 MCD Maintenance Requirements, Service History and Associated Documentation

On aircraft fitted with the subject engine type, the Operator schedules an inspection of the engine MCDs to be carried out every 850 aircraft operating hours; a job card (maintenance task card) is issued to maintenance personnel to provide instructions regarding the task, and a means of recording the completion of the task. The job card, titled '*ENGINE MAGNETIC CHIP DETECTORS – INSPECT (DET[11])*', contains separate sub-tasks for the removal of the MCD probe, inspection of the probe for contamination, examination of the packing (o-ring) on the probe, and re-installation of the probe. The sub-tasks for the removal of the probe and the inspection for contamination required completion and sign-off by a mechanic, whereas the sub-tasks for the examination of the packing (o-ring) and the re-installation of the probe required completion and sign-off by a mechanic and an inspector.

The aircraft was operating on its first flight since the performance of the MCD inspection task on the No. 1 engine. The associated job card was completed on 5 April 2022 (the day before the accident flight). All sub-tasks were signed off by a mechanic at 08:34 hrs (local time, which was UTC-4 hours). The sub-tasks requiring an additional sign off by an inspector were signed off at 08:36 hrs (local time).

The engine-related maintenance procedures contained in the Aircraft Manufacturer's Aircraft Maintenance Manual (AMM) are developed from the procedures described in the Engine Manufacturer's manuals. Initially, a generic AMM is produced by the Aircraft Manufacturer, which is then customised for each operator's fleet, in consultation with that operator. AMM references in this Section relate to the Operator's customised AMM.

The Operator's job card used at the time referred to AMM task 79-21-10-206-001 as being the *'source*' document. The task in the AMM includes the suffix *'-N00*', i.e., the complete reference in the AMM is 79-21-10-206-001-N00 ('*Magnetic Chip Detector Inspection*'). The Operator's job card referred to AMM 79-21-10/401 as being an optional reference.

The Operator's job card and AMM task 79-21-10-206-001-N00 included a requirement to inspect the MCD housing '*locking mechanism (key-way)* [slots] *for wear and damage*' following the removal of the MCD probe. The Engine Manufacturer informed the Investigation that excessive slot wear had resulted in two other MCD-related occurrences. In one occurrence, the slot wear resulted in the complete liberation of the MCD, although no oil was lost in that case. In the other occurrence, the MCD was not liberated from its housing but migrated to a point which permitted oil to leak past the valve. Following these occurrences, an inspection of the slots for wear and damage was added to the AMM. No requirement was stipulated to inspect the inside of the housing for debris prior to re-inserting the MCD probe.

The Operator's job card noted that when the probe has been removed from the housing, an oil leak rate from the housing of 10 drops per minute is permitted. The Operator informed the Investigation that this was to avoid unnecessary maintenance activity that might result from '*inconsequential stray drops of oil being observed*'.

[11] **DET:** Detailed inspection.

The Operator's job card and AMM task 79-21-10-206-001-N00 instructed maintenance personnel to '*Examine the packing* [o-ring] *on the MCD probe*'. The procedure stated that if the packing '*has damage*', it was to be replaced. Neither the AMM task nor the job card referred to the presence of the Teflon® seal on the probe. Also, the image of the MCD probe and housing in Figure 601 of AMM task 79-21-10-206-001-N00 was not representative of the MCDs fitted to the subject aircraft, in that only the o-ring was shown; the Teflon® seal and the slots/locking pins are not shown. However, both the Operator's job card and the AMM task included a note stating that the '*MCD probe and the quantity of packings can be different to what is shown'* in the figure.

The sub task on the Operator's job card to '*Install the MCD probe into the applicable valve*' referred to AMM 79-21-10/401, whereas the install sub task in AMM 79-21-10-206-001-N00 referred to AMM 79-21-10-424-008-N00 ('*Magnetic Chip Detector (MCD) Installation*'). AMM task 79-21-10-424-008-N00 referred to the installation of a new packing (o-ring).

Also, AMM task 79-21-10-424-008-N00 contained several cautions that were not contained on the Operator's job card and included the following:

> '*CAUTION: MAKE SURE YOU ENGAGE THE MAGNETIC PROBE IN THE HOUSING CORRECTLY*'.

AMM 79-21-10-424-008-N00 required the end of the shaft of the MCD probe to be cleaned prior to installation because '*The oil on the shaft of the MCD probe can cause hydraulic lock*[12]*, which will not permit the installation of the MCD probe*'. The procedure stated that the probe should be installed by pushing in the probe and turning it clockwise until it stops. It then stated to '*lightly push in on the probe and verify spring pressure pushes the probe back into the locking slot*'.

AMM 79-21-10-424-008-N00 also stated to '*Make sure that the red marks on the grip are aligned with the red marks on the MCD housing*'. A note was included stating:

> '*The magnetic probe is correctly installed when you align the red marks on the probe with the red marks on the valve. This red paint in the valve and probe alignment grooves will not be maintained. If the red marks are faded or missing from the grooves, use the alignment grooves themselves to ensure correct installation alignment*'.

AMM 79-21-10-424-008-N00 also included the following instruction: '*To make sure the MCD probe is locked, pull the MCD probe*'.

There was no requirement for an engine run/leak check in AMM task 79-21-10-424-008-N00 (or AMM task 79-21-10-206-001-N00) or on the Operator's job card.

Maintenance tasks performed on ETOPS aircraft are subject to certain restrictions, such as not completing the same task on both engines during the same maintenance visit and/or ensuring that tasks on each engine are performed by different personnel. In this case, the MCD inspection task had been performed on the No. 1 engine only.

[12] **Hydraulic lock:** A restriction caused by the presence of liquid (in this case, oil), which is incompressible.

1.5.2 Maintenance Manual Differences

The Operator informed the Investigation that the FAA granted it permission to perform minor changes to the AMM and other instructions for continued airworthiness based on operational experience and engineering judgement. The Operator stated that the revision process requires (internal) technical justification and internal second approval sign-off prior to implementation.

The MCD inspection/check task in the Engine Manufacturer's Maintenance Manual included a requirement to replace the packing (o-ring) on the probe. Task 79-21-10-206-001-N00 in the Aircraft Manufacturer's generic AMM also included the requirement, whereas as outlined in **Section 1.5.1**, the Operator's AMM task 79-21-10-206-001-N00 instructed maintenance personnel to '*Examine the packing* [o-ring] *on the probe*' and if the packing '*has damage*', to replace it.

Regarding the check for the alignment of the red alignment marks, both the Engine Manufacturer's Maintenance Manual and the Aircraft Manufacturer's generic AMM note that '*the magnetic probe is correctly installed when you align the red mark on the magnetic probe with the red mark on the valve*'. This is also contained in the Operator's customised AMM; however, as outlined in **Section 1.5.1**, the Operator's customised AMM allowed for these to be missing or faded, and for the alignment grooves to be used instead.

1.6 Post-Occurrence Examination of MCD Housing and Probe

1.6.1 Inspection of No.1 Engine

When the No. 1 engine was examined at EINN following the occurrence, the MCD probe for the engine's No. 4 main bearing scavenge line was found in an upright position in the engine cowling below its housing (valve body) (**Photo No. 1**), and there was evidence of oil in the surrounding area. The Operator informed the Engine Manufacturer of the occurrence.

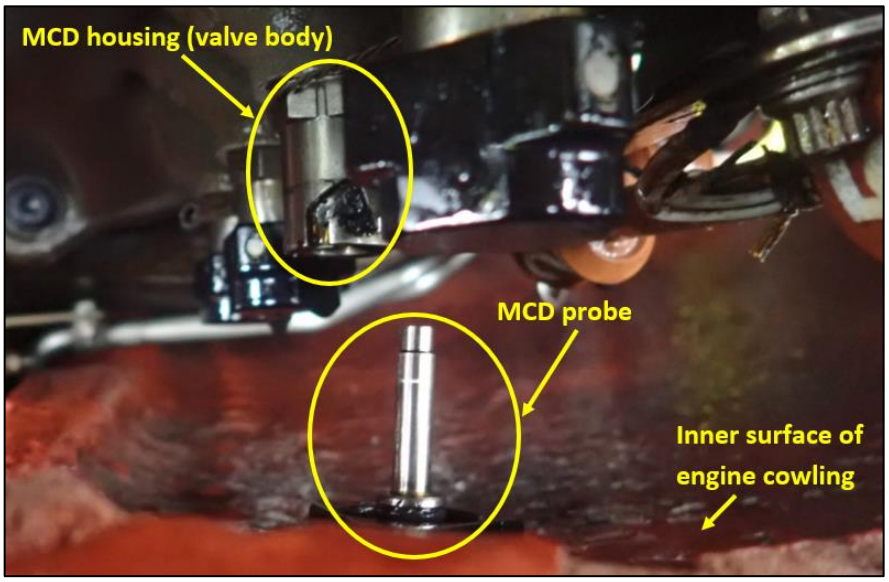

Photo No. 1: MCD for No. 4 bearing on No. 1 engine as found following occurrence

As part of the post-occurrence actions conducted by maintenance personnel in the presence of the Investigation, without re-inserting the probe, engine oil was added to the engine to determine how much oil had been lost during the occurrence. It was found that 34 US quarts were required to return the oil quantity to the normal level. Following the replenishment of the oil, there was no oil leakage from the housing. It was noted that there was no red paint visible in the alignment grooves on the housing or on the grip of the probe.

The Engine Manufacturer specified a series of further maintenance steps to be carried out on the No. 1 engine. These were carried out in the presence of the Investigation and included the following:

- A new MCD housing (valve body) and probe assembly was fitted following the removal of the occurrence housing (valve body). There was no oil leakage when the housing was removed (at this stage, the oil tank had been refilled).
- The main oil filter and all MCDs were examined for contamination. No contamination was found.
- An engine run was performed, during which the engine ran normally, and no oil leak was observed. The MCDs were re-examined, and no contamination was found.

The aircraft operated a ferry flight to Newark Airport (KEWR) in the United States, where a further inspection of the MCDs was performed. This was followed by two subsequent inspections at later dates. No contamination was found during any of these inspections.

1.6.2 Workshop Examination of Removed MCD Housing and Probe

1.6.2.1 Initial Examination

The MCD housing (valve body) and probe from the No. 1 engine's No. 4 main bearing scavenge line were shipped, in the '*as found*' condition, to the Engine Manufacturer for detailed examination and testing. An '*as received*' visual review report was prepared by the Engine Manufacturer (**Figure No. 3** refers).

The report noted the following points in relation to the MCD probe:

- All three locking pins were present.
- The o-ring (primary) seal appeared intact.
- A sliver of Teflon® (secondary) seal was found within the grip of the probe.
- There was distress on the Teflon® seal on the side opposite the liberated sliver.
- There was no red paint in the three alignment grooves.
- The magnet was functional.

The following points were noted in relation to the MCD housing:

- The o-ring on the spring-loaded valve appeared intact.
- The o-ring that provides a seal between the housing and the engine appeared intact.
- There was no red paint in the three alignment grooves.
- Debris was present within the housing.

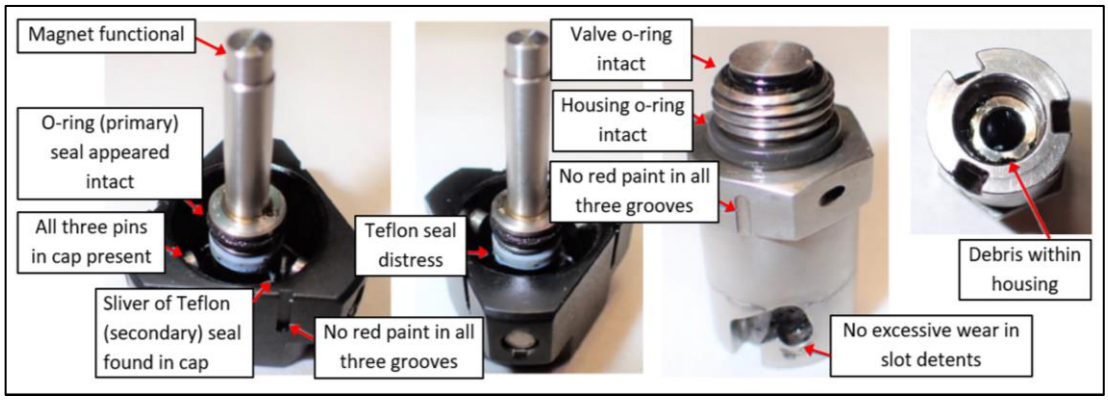

Figure No. 3: MCD probe and housing (*Adapted from Engine Manufacturer's report*)

1.6.2.2 Leak Testing

The Engine Manufacturer informed the Investigation that when the aircraft is in the cruise, the scavenge oil pressure is approximately seven pounds per square inch (psi). The Investigation requested the Engine Manufacturer to leak-check the housing prior to re-inserting the probe. The Engine Manufacturer advised that pressurised air was applied to the housing and that no leaks were evident. The probe was then installed in the housing, which was again subject to a leak check using pressurised air and no leaks were evident.

1.6.2.3 Further Examination

Several anomalies were identified on further examination by the Engine Manufacturer (**Figure No. 4**), including '*nibbling*' damage to the o-ring (primary seal) fitted to the probe, in addition to the damage to the Teflon® seal already noted. Nibbling damage was also found on the debris within the housing. The Engine Manufacturer considered that the '*nibbling*' damage on the debris in the housing '*suggests that it* [the debris] *was moving relative to the housing*'. The debris within the housing was caught between the housing and the moving portion of the spring-loaded valve. It was noted that the amount and size of the debris recovered from the housing was '*greater than the missing material from* [the] *worn o-ring*', and that the o-ring on the MCD probe and the debris were not the same material (probe o-rings are not all manufactured from the exact same material). When the valve was held in the open position for the purpose of the examination, '*burnishing* [polishing/evidence of rubbing] *and axial scratches*' were identified on the housing wall in the valve operating area, which the Engine Manufacturer considered to be '*indicative of interference between the housing and the moveable valve*'. In addition, scuff marks were found on the side of the shank of the probe.

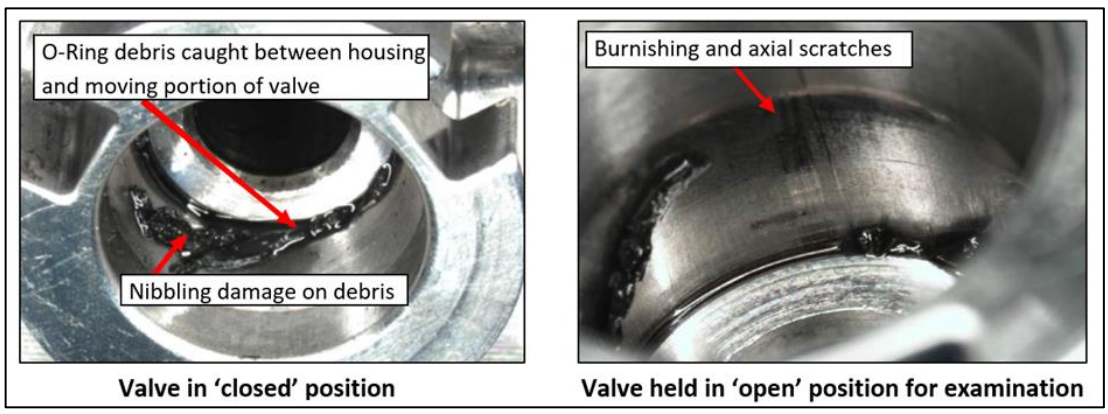

Figure No. 4: Debris within the housing, and burnishing and axial scratches (*Adapted from Engine Manufacturer's report*)

Minor wear was found in the slots in the housing, which the Engine Manufacturer noted had the potential to permit the probe to be retained in a partially installed position. However, the Manufacturer reported that when the probe was placed in this position, it was found to disengage with only slight movement.

The Engine Manufacturer carried out an X-Ray examination of the housing and probe, with no adverse findings. The Engine Manufacturer sectioned the spring-loaded valve to facilitate disassembly of the valve and further inspection. The valve o-ring was found to be in good condition with no obvious wear on the spring or the body of the valve. However, rubber debris was found to be present on the spring coils.

1.6.2.4 Engine Manufacturer's Summary

The Engine Manufacturer advised the Investigation that they were unaware of any other oil loss events following the complete liberation of an MCD. The Engine Manufacturer considered the following possible sequence of events in this occurrence, and outlined supporting evidence for each point:

- The MCD probe was installed but not locked due to lack of spring force from the self-closing valve caused by debris, or because the MCD probe locking pins were on the crests of the locking slots (i.e., not in the locked position), with the Engine Manufacturer considering the former '*most likely*'. *Supporting evidence*: Debris was embedded in housing – debris was moving relative to the housing.
- Engine vibration resulted in the MCD probe migrating and then being liberated from the housing. *Supporting evidence*: Distress on the probe's primary o-ring and elapsed time between MCD inspection and in-flight shutdown.
- Debris in the valve caused it to remain partially open and permit oil leakage, once the probe liberated. *Supporting evidence*: DFDR data shows reducing oil quantity and pressure on No. 1 engine during the event flight.

It was confirmed by the Engine Manufacturer that it was dimensionally possible for a partially installed/migrated probe to hold the valve in a partially open state, while at the same time for the probe's Teflon® seal and primary o-rings to be unseated in the housing. According to the Engine Manufacturer, prior to reaching this position, the pins in the probe are disengaged from the slot detents and the force of the valve spring has begun ejecting the probe from the valve body, and that normally, the valve is expected to close almost instantly and prevent leakage from occurring. Nevertheless, the Engine Manufacturer acknowledged that a possibility existed, although it considered it unlikely, whereby the probe may have been installed but may not have been in the locked position due to binding (interference) between the probe and valve or damaged o-rings/debris. The probe may have migrated in flight to a position where the primary o-ring and secondary Teflon® seal were unseated but that the probe was still holding the valve open. The probe could then have fully migrated on landing. The supporting evidence for this is that the valve did not leak when it was subsequently pressure tested and the probe was observed in an upright orientation when the aircraft was inspected after landing.

1.6.3 Engine Manufacturer's '*All Operators Communication*'

Subsequent to the occurrence, the Engine Manufacturer published an '*All Operators Communication*' (AOC) which described the event. The probe installation instructions and the procedure for verifying correct installation were highlighted. The AOC also highlighted the AMM requirement to inspect the slots in the housing for wear, noting that '*Excessive wear to the groove can allow oil to leak past the check valve*'. The slot inspection requirement had also been contained on the Operator's job card.

1.7 Undercarriage Fire

Following the landing at EINN, the AFRS escorted the aircraft during its taxi to the assigned parking stand. When the aircraft turned towards its parking stand, the AFRS personnel escorting the aircraft, observed a fire at the '*left-hand bogie*' and requested the aircraft to stop. When the aircraft stopped, the AFRS deployed fire-retardant foam to the area and subsequently reported that the fire had been extinguished. When the brakes on the aircraft had cooled sufficiently, the aircraft was towed onto stand.

A Closed-Circuit Television (CCTV) camera located within the airport recorded the aircraft as it approached the aircraft parking area. It was dark due to the time of day, and taxiway and airfield lighting were in use. In addition, the area was wet and the aircraft's red anti-collision lights, fitted to the top and bottom of the fuselage, were flashing on and off. These factors adversely affected the clarity of the recorded video. However, an amber-coloured flash at the aircraft's left main landing gear was visible in the video, for approximately 15 seconds, as the aircraft turned towards its parking stand.

The Flight Crew subsequently reported in the aircraft's technical logbook that they had received a Brake Temperature warning and that there was a brake temperature of '*9*' at the *'left truck/left rear wheel'* (the No. 5 position as shown in **Figure No. 5**).

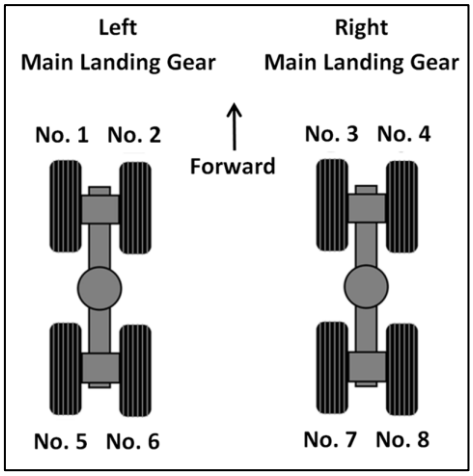

Figure No. 5: Wheel and brake unit numbering convention

The left main landing gear was inspected by the Operator's maintenance personnel in the presence of the Investigation. Excess lubrication grease was evident at several of the lubrication points and brake dust was also present; however, there was no visible evidence that a fire had occurred. Based on the reported fire and the entry in the aircraft's technical logbook, maintenance personnel replaced the No. 5 wheel and brake unit. Subsequently, following clarification from the AFRS regarding the exact location of the observed fire, maintenance personnel inspected the No. 6 main wheel and brake unit, and found no defects.

Previously, the AAIU Investigated an occurrence involving a different operator's Boeing 767 aircraft, in which an evacuation of that aircraft was carried out as a result of a main undercarriage fire following a rejected take-off[13]. In that occurrence, the fire resulted in damage to the tyres, brake units, and hydraulic lines; however, there was no identifiable cause of the fire other than heat from the brake units.

1.8 Personnel Information

The Flight Crew consisted of a Commander, a First Officer, and an International Relief Officer[14]. Each pilot held a valid ATP Certificate issued by the FAA of the USA and current first-class medical certificates. The Flight Crew's flying experience is outlined in **Table No. 1**, **No. 2**, and **No. 3** below.

Total all types:	24,500 Hours
Total on type:	6,710 Hours

Table No. 1: Commander's Flying Experience

Total all types:	4,532 Hours (with Operator)
Total on type:	3,581 Hours

Table No. 2: First Officer's Flying Experience

Total all types:	3,180 Hours (with Operator)
Total on type:	2,895 Hours

Table No. 3: International Relief Officer's Flying Experience

1.9 Meteorological Information

Met Éireann, the Irish meteorological service, was asked to provide details of the weather conditions prevailing at EINN around the time of the landing. The meteorological report stated that there was a mix of clear spells and cloudy patches, with showers in the vicinity. The surface level wind was stated to be from the north-west, at 15-20 knots (kt), gusting 20-28 kt. The wind at 2,000 ft was stated to be from the north-west at 30-35 kt. The report stated that the surface temperature was 6° Centigrade (C), the Mean Sea Level Pressure was 990 hectopascals (hPa), and the visibility was 20 kilometres (km).

While the aircraft was on the approach, ATC informed the Flight Crew that the runway surface was '*100 percent wet*'. ATC also provided regular updates to the Flight Crew regarding surface wind conditions. Approximately one and a half minutes before the aircraft landed, ATC advised that the surface wind was 310 degrees (north-westerly) at 17 kt.

[13] AAIU Report No. 2021-010.

[14] **International Relief Officer:** Additional Flight Crew member required when a flight exceeds a specified scheduled duration to facilitate crew rest breaks.

1.10 Airport Information

The aircraft landed on RWY 24 at EINN, which has a Landing Distance Available (LDA) of 3,059 metres (m).

1.11 Recorded Information

1.11.1 Air Traffic Control

Shannon ATC provided the Investigation with the recordings of the radio communications for the flight, commencing with the Flight Crew initiating the emergency radio transmission to Shannon, and including communications with the aircraft and the AFRS when the aircraft was on the ground at EINN. The recordings informed the Investigation's understanding of the occurrence and the circumstances surrounding the undercarriage fire.

1.11.2 Flight Recorders

1.11.2.1 Information Obtained

The aircraft type was fitted with a Cockpit Voice Recorder (CVR) and a DFDR. The subject aircraft was also fitted with a Quick Access Recorder (QAR), which permits access to flight data for maintenance and fleet-monitoring purposes. The DFDR records up to 25 hours of data, while the CVR records the most recent two hours from each Flight Crew Station and the most recent three hours from the cockpit Common Area Microphone (CAM).

The AAIU became aware of this occurrence following the submission of a Safety Occurrence Report by Shannon ATC later on the morning of the occurrence. Therefore, when the AAIU requested that the recorders be preserved, significant time had already elapsed. The Investigation obtained the DFDR, the CVR, and the memory card from the QAR. The flight data for the occurrence flight from the DFDR and QAR memory card was successfully downloaded. However, the CVR data from the occurrence flight had been overwritten because the CVR had not been deactivated immediately following the occurrence.

The relevant parameters from the DFDR data are contained in **Table No. 4**.

DFDR Time	Note	Time since engine start (hh:mm:ss)
21:51:20	No. 1 engine started.	00:00:00
22:20:42	Aircraft becomes airborne at KIAD.	00:29:22
02:02:18	No. 1 oil quantity starts to decrease from 34 US pints[15], having been at 34 US pints for over one hour.	04:10:58
02:05:30	No. 1 oil quantity has reduced to 32 US pints and remains at 32 US pints until DFDR time 02:08:10.	04:14:10
02:08:10	Engine high pressure compressor speed (N2) on both engines starts to increase (from 89 % to approximately 95%). Oil Pressure on No. 1 engine starts to increase from 203 to 223 psi (and then to 240 psi).	04:16:50
02:08:10	Climb commences from 34,000 ft[16]. Aircraft had been operating at 34,000 ft for over two hours.	04:16:50
02:08:10	Oil quantity fluctuates and reaches 34 US pints again at DFDR time 02:08:42 and then decreases.	04:16:50
02:11:14	Aircraft levels at 36,000 ft. Engine power decreases to approximately 89%.	04:19:54
02:13:30	No. 1 engine oil quantity steady at 29 US pints until DFDR time 02:18:00 when it starts to steadily decrease.	04:22:10
03:27:14	Oil quantity has reduced to '*0*'[17].	05:35:54
03:51:02	No. 1 oil pressure begins to decrease (from 194 psi).	05:59:42
04:03:42	No. 1 engine low oil pressure reaches 138 psi, resulting in an intermittent low oil pressure warning.	06:12:22
04:12:54	No. 1 engine low oil pressure warning (steady). Oil pressure 69psi.	06:21:34
04:20:30	No. 1 engine was shut down (29,500 ft).	06:29:10
04:40:23	Aircraft lands at EINN (nose landing gear touches down).	06:49:03
04:41:50	Brake temperature warning.	06:50:30
04:41:50	Ground speed 9 kt.	06:50:30
04:41:50	Turn to the left commenced, followed by a 180 degree turn to the right.	06:50:30

Table No. 4: Relevant DFDR parameters

As outlined in **Table No. 4**, at 02:02:18 hrs, approximately four hours and 11 minutes after the No. 1 engine was started and approximately three hours and 40 minutes into the flight, the No. 1 engine oil quantity, as recorded on the DFDR, started to decrease from 34 US pints and reached 32 US pints at 02:05:30 hrs. At 02:08:10 hrs, the engine power was increased and a climb from 34,000 ft was initiated. At the same time, the oil quantity fluctuated and reached 34 US pints again, before starting to decrease again. At 02:11:14 hrs, the aircraft levelled at 36,000 ft and the engine power decreased.

[15] The DFDR records the engine oil quantity in US pints.
[16] The DFDR records the aircraft's altitude in feet.
[17] The Engine Manufacturer advised that when the oil quantity indication reaches '*0*', there could be up to 18 US pints of oil remaining in the oil tank.

At 02:13:30 hrs, the No. 1 engine oil quantity was steady at 29 US pints and remained at this quantity until 02:18:00 hrs, before starting to decrease again. At 03:27:14 hrs, the No. 1 engine oil quantity reached '*0*'.

At 03:51:02 hrs, the No. 1 engine oil pressure began to decrease (from 194 psi). At 04:03:42 hrs, the No. 1 engine oil pressure reached 138 psi, which resulted in an intermittent low oil pressure warning. At 04:12:54 hrs, the No. 1 engine low oil pressure warning remained on steady (oil pressure 69 psi).

At 04:20:30 hrs, the No. 1 engine was shut down by the Flight Crew. The altitude at this stage was 29,500 ft. The aircraft landed at 04:40:23 hrs as indicated by the nose landing gear touching down. At 04:41:50 hrs, and at a ground speed of 9 kt, a brake temperature warning was generated. A turn to the left had commenced, which was then followed by a 180^{o} turn to the right (the aircraft performed a 180^{o} turn at the end of the runway).

1.11.2.2 Oil Loss Rate

The No. 1 engine oil loss rate, from when the DFDR recorded the oil quantity first beginning to reduce, until when the DFDR recorded zero quantity, was calculated to be approximately 12 quarts (24 US pints) per hour. The Engine Manufacturer noted that if the self-closing valve was in a fully open position, the leakage area would result in an oil loss rate 40 times greater than what was calculated for this occurrence.

1.12 Safety Actions Taken Subsequent to the Occurrence

1.12.1 Operator's Investigation

The Operator conducted its own internal investigation in relation to the occurrence, which identified that a '*maintenance technician*' (mechanic) removed and inspected all six MCD probes (as per normal procedure). The Operator's investigation report noted that the maintenance technician advised that there was no metal debris present and that the condition of the o-rings was considered '*good*'.

The report also noted that the maintenance technician asked a maintenance inspector to inspect the MCDs and verify correct installation (once completed). The report stated that when the inspector arrived, the inspector saw that the technician was busy and advised the technician that they (the inspector) *'would install the MCDs themselves*'. The inspector reported that they (the inspector) examined the MCDs for the presence of metal debris and the condition of the o-rings. The report noted that the inspector installed the MCDs (rather than just inspect them following the installation by the maintenance technician) and that from their (the inspector's) perspective, the MCDs were all '*locked and secured*' at the time of re-installation. The Operator's investigation report considered that if correctly followed, its '*dual set of eyes*' process was adequate and that in this case the procedure was not followed, and therefore no changes to the inspection process were made following this event.

The Operator's investigation report noted that subsequent to the occurrence, task 79-21-10-424-008-N00 in the Operator's AMM was revised to state the following:

> '*Make sure that the red marks on the grip are aligned with the red marks on the MCD housing.*
>
> ***Note:*** *The magnetic probe is correctly installed when you align the red marks on the probe with the red marks on the valve. The red paint in the valve and probe alignment grooves may have diminished. If so, restore using suitable paint. If material is not immediately available it is acceptable to release for up to 20 flight hours without touch-up. Use the alignment grooves themselves to ensure correct installation alignment*'.

1.12.2 Actions Taken by the Engine Manufacturer

The MCD removal, inspection and re-installation procedures contained in the AMM are developed from the procedures contained in the Engine Manufacturer's manuals. The procedure outlined in task 79-21-10-210-001 in the Engine Manufacturer's Maintenance Manual ('*Inspect The Magnetic Chip Detectors*') at the time of the occurrence, required the packing (o-ring) on the MCD probe to be replaced. The presence of the Teflon® seal was not mentioned. Also, the image of the MCD in task 79-21-10-210-001 was not representative of the MCDs fitted to the subject aircraft, and showed the o-ring but did not show the Teflon® seal. Subsequent to the occurrence, the Engine Manufacturer revised task 79-21-10-210-001 to include reference to the Teflon® seal. The procedure now states: '[For applicable Part Numbers] *Inspect the non–replaceable Teflon seal on the magnetic probe for damage and wear. Replace the magnetic chip detector assembly if there is damage or wear*'.

Additionally, an inspection requirement of '*the inner surface of the valve body for packing debris*' and a figure showing an example of debris within a valve have now been included; the procedure requires the MCD assembly to be replaced if debris is found. The revised procedure also requires an inspection to check that the red markings are present on the grip of the probe and on the housing (valve body). The image of the MCD probe has not been amended to show the presence of the Teflon® seal.

Also, as outlined in **Section 1.6.3**, subsequent to the occurrence, the Engine Manufacturer issued an '*All Operators Communication*' which described the event and highlighted the installation instructions and how correct installation is verified.

1.12.3 Aircraft Maintenance Manual Revision

The Engine Manufacturer informed the Investigation that a '*Change Request*' was issued to the Aircraft Manufacturer on 1 May 2023 to highlight the changes to the Engine Manufacturer's Maintenance Manual and facilitate the associated changes to the AMM. The Aircraft Manufacturer informed the Investigation that its AMM will be amended during the next revision cycle in April 2024. The Operator is notified of changes to the AMM through the AMM revision process.

2. ANALYSIS

2.1 In-Flight Shutdown and Emergency Landing

A loss of engine oil on the No. 1 engine necessitated an in-flight shutdown, which resulted in the declaration of '*emergency*' and a diversion to EINN. Scheduled maintenance performed before the flight included the removal, inspection, and re-installation of the MCD probes fitted to the aircraft's No. 1 engine. When the No. 1 engine was inspected at EINN following the occurrence, the MCD probe for the No. 4 bearing scavenge line was found in the engine cowling, below its housing, in an upright position. During subsequent maintenance action, a total of 34 US quarts was required to return the No. 1 engine oil quantity to the normal level, which indicated that there had effectively been a complete loss of oil from the No. 1 engine during the occurrence. The oil observed in the area surrounding the MCD housing when the engine was inspected subsequent to the occurrence, and the fact that no oil leak was observed following the installation of a new housing and probe and the completion of an engine run, indicate that the No. 4 bearing scavenge line MCD was the origin of the oil loss.

2.2 Oil Leak

The MCD housing and probe from the aircraft were shipped, undisturbed, to the Engine Manufacturer for detailed examination and testing. The Investigation requested the Engine Manufacturer to perform a leak-check of the housing prior to re-inserting the probe or conducting any testing. The Engine Manufacturer advised that pressurised air was applied to the housing without the probe fitted, and then again with the probe installed, and that no leaks were evident.

As evidenced by the Engine Manufacturer's leak test with the probe installed, the damage to the o-ring and Teflon® seal was insufficient to cause a leak with the probe in the installed position. The DFDR data indicates that the No. 1 engine oil leak commenced approximately three hours and 40 minutes after take-off and over four hours after engine start. This indicates that the probe was initially in a position in the housing that prevented oil leakage. For oil to then leak, the MCD probe would need to have migrated, either fully or to a position where its o-ring and Teflon® seal were unseated in the housing and therefore no longer providing a seal. In addition, the valve in the MCD housing would have to have been open or leaking. According to the Engine Manufacturer, a fully open valve would result in an oil loss rate 40 times greater than the calculated rate of approximately 12 quarts per hour; therefore, it is probable that the valve was only partially open during the oil leak.

As noted in the Operator's AMM procedure for checking for correct installation of the probe, spring pressure acting on the valve will cause the MCD probe to be pushed outwards. The Investigation considers it unlikely that a fully installed and correctly locked probe would migrate from its housing. If the MCD probe was correctly installed, and fully rotated in the slots in the housing, spring pressure would force the probe back into the locking slot (detent). However, if the probe was only partially installed, the spring pressure, coupled with the scavenge oil pressure and engine vibration in a running engine, could result in the migration of the MCD probe.

According to the DFDR data, the engine oil quantity started to decrease from 34 US pints to 32 US pints when the aircraft was at an altitude of 34,000 ft (FL340). The engine had been running for over four hours at that stage, and it is possible that normal engine vibration during the flight may have resulted in initial migration of the MCD probe. When the engine power was increased at 02:08 hrs approximately, and a climb from Flight Level 340 commenced, the oil pressure on the No. 1 engine increased from 203 psi to 223 psi. It is likely that the scavenge pressure and engine vibration also increased at that time. The Investigation considers it possible that these factors may have resulted in further migration of the probe, either fully, or to a position where its o-ring and Teflon® seal were unseated in the housing and therefore no longer preventing oil leakage (provided the valve was partially open).

The probe was found in an upright position subsequent to the occurrence, and had not fallen over, which may suggest that it had not been in that position for long and may indicate that the probe only fully migrated from the housing as a result of landing loads. However, the Investigation notes that the size and mass of the grip of the probe, and adhesive action from oil that had leaked into the engine cowling below the housing, would result in stability in an upright position, and therefore the probe could have been in that position for a longer period.

During maintenance inspection performed at EINN following the occurrence, oil was added to the No. 1 engine with the MCD probe not installed, and no oil leaked from the MCD housing. The MCD housing contains a spring-loaded valve, which is designed to prevent oil leakage when the probe is removed during maintenance inspection. The absence of an oil leak with the probe uninstalled does not necessarily indicate that the valve was fully closed at this stage, because the housing is installed in the engine's No. 4 bearing scavenge line, and pressurised oil is only present in this area when the engine is running. In this case, there had effectively been a complete loss of oil during the occurrence and consequently the scavenge system likely contained no oil. This is evidenced by the fact that when the housing itself was removed to permit the installation of a new housing, no oil leaked from the housing installation port.

During the Engine Manufacturer's examination of the probe and housing, minor wear was found in the slots in the housing, which the Engine Manufacturer noted had the potential to permit the probe to be retained in a partially installed position. However, when the Engine Manufacturer placed the probe in this position during testing, it was found to disengage with only slight movement. Therefore, while acknowledging that it is not possible to reproduce the exact conditions arising from the re-installation of the probe prior to the occurrence flight, the Investigation considers it unlikely that slot wear alone held the probe in a partially installed position.

The Engine Manufacturer's examination also noted that rubber debris that exhibited nibbling damage was observed to be caught between the housing and the moving portion of the spring-loaded valve. The Engine Manufacturer carried out an X-Ray examination of the housing and probe, with no adverse findings. The Engine Manufacturer sectioned the valve to permit disassembly. The sealing o-ring on the valve was found to be in good condition with no obvious wear observed on the spring or on the body of the valve; however, rubber debris was found on the valve spring coils.

The Investigation considered the possibility that hydraulic lock due to oil on the shaft of the probe, as noted in the (Operator's) AMM probe installation procedure, may have caused it to be partially installed. However, as this would probably have completely prevented installation, it was therefore considered unlikely to have been a factor.

Despite the presence of the debris on the spring coils and the debris caught between the housing and the moving portion of the spring-loaded valve, the leak test carried out by the Engine Manufacturer prior to disturbance of the housing indicates that when the probe was not installed in the housing, the valve in the housing was capable of preventing oil leakage. This may indicate that the valve had been held open by the probe itself, and not by debris. The Engine Manufacturer confirmed to the Investigation that it is dimensionally possible for the probe to be in a position where its o-ring and Teflon® seal are unseated in the housing, while at the same time for the probe to hold the valve open. It is possible that the damage to the o-ring and Teflon® seal could permit oil leakage from a probe in this position. However, the Investigation notes that pressure applied to the engine side of the housing during testing, with the probe removed, would apply a closing force on the valve, in addition to that provided by the valve spring. It is also possible that debris that may have been holding the valve open became dislodged subsequent to the oil loss or during shipping for examination/testing.

The Engine Manufacturer's examination of the housing with the valve held in the open position for the purpose of the examination found burnishing and axial scratches on the housing wall, which the Engine Manufacturer deemed to be indicative of interference between the housing and the moveable valve. Any interference could adversely affect the closing of the valve, in the event of a migrated probe. However, the Engine Manufacturer considered the most likely scenario was that the MCD probe had been in a partially installed position due to lack of spring force from the self-closing valve as a result of debris. The Engine Manufacturer suggested that engine vibration caused the partially installed MCD probe to migrate and become liberated from the housing, while the debris in the valve caused the valve to remain partially open and permit oil leakage.

2.3 Probe Examination and Installation Procedures

The Engine Manufacturer's manual and the Aircraft Manufacturer's AMM required the probe o-ring to be replaced prior to re-installation of the probe, whereas the Operator's customised AMM instructed maintenance personnel to examine the o-ring and only replace it if damage was found. The Operator informed the Investigation that the FAA granted it permission to perform minor changes to the AMM and other instructions for continued airworthiness based on operational experience and engineering judgement. The Operator's MCD inspection procedures required the examination of the probe o-ring and the re-installation of the probe to be signed off by a mechanic and an inspector. In this case, according to the Operator's investigation report, the o-ring was found to be in good condition. However, both the re-installation of the probe and the post-installation inspection were performed by a single person (an inspector); this was not in keeping with the Operator's '*dual set of eyes*' process specified for this task. The Operator's investigation report considered that if correctly followed, its '*dual set of eyes*' process was adequate and therefore no changes to the process were made by the Operator following this event.

At the time of the occurrence, the Teflon® seal was not mentioned in the Engine Manufacturer's manual and therefore was not mentioned in any other maintenance instructions (AMM/job card). Subsequent to the occurrence, the Engine Manufacturer added the following text to its Maintenance Manual: '[For applicable Part Numbers] *Inspect the non−replaceable Teflon seal on the magnetic probe for damage and wear. Replace the magnetic chip detector assembly if there is damage or wear*'. Consequently, no Safety Recommendation is made to the Engine Manufacturer in this regard.

The MCD probe installation procedure in the Operator's AMM includes a physical check to ensure correct installation by pushing '*in on the probe and verify spring pressure pushes the probe back into the locking slot*' and to pull the MCD probe to make sure it is locked. The installation procedure also includes a visual check of the alignment marks/grooves. There was no red paint in the alignment grooves on the grip of the MCD probe or on the housing. This was permitted by the Operator's AMM at the time of the occurrence. Notwithstanding that the Operator's '*dual set of eyes*' process was not followed, the lack of red markings would have adversely affected any visual inspection for correct installation and the Investigation considers it probable that the probe was not in the fully installed and locked position prior to the occurrence flight. Subsequent to the occurrence, the Operator revised its AMM to include a requirement to repaint the alignment grooves on the MCD probe and housing if missing. Therefore, no Safety Recommendation is made to the Operator in this regard.

Also, subsequent to the occurrence, an inspection requirement of '*the inner surface of the valve body for packing debris*,' and a figure showing an example of debris within a valve have been added to the Engine Manufacturer's Manual.

The Engine Manufacturer informed the Investigation that a '*Change Request*' was issued to the Aircraft Manufacturer on 1 May 2023 to highlight the changes to the Engine Manufacturer's Maintenance Manual and facilitate the associated changes to the AMM. The Aircraft Manufacturer informed the Investigation that its AMM will be amended during the next revision cycle scheduled for April 2024. The Operator is notified of changes to the AMM through the AMM revision process.

2.4 Undercarriage Fire

Approximately one minute and 30 seconds after touching down on RWY 24 at EINN, a Brake Temperature warning was generated and the Flight Crew noticed that there was a brake temperature of '*9*' at the No. 5 position. The DFDR data indicates that the ground speed at this stage was 9 kt and that the aircraft had commenced a turn (A 180-degree turn was performed at the end of the runway). It is possible that the elevated brake temperature was due to higher-than-normal braking energy as reverse thrust was only available on one engine.

When the aircraft turned towards its parking stand, the AFRS, who were escorting the aircraft following its emergency landing, observed a fire at the '*left-hand bogie*'. They requested (via the Ground Movements Controller) the aircraft to stop and deployed fire-retardant foam to the area. The AFRS reported that the foam was blown back by the APU and the still-running right-hand engine. This appeared, to the AFRS, to be smoke and therefore they requested (via the Ground Movements Controller) the aircraft to be evacuated on the right-hand side. This request was cancelled shortly afterwards, as the fire had been extinguished. The Investigation notes that an emergency evacuation, which involves the use of an aircraft's escape slides, presents its own inherent risk of injury for those involved.

Notwithstanding that a fire was reported and an amber-coloured flash at the aircraft's left main landing gear was visible for approximately 15 seconds in the airport CCTV recording, when inspected following the occurrence there was no evidence at the landing gear that a fire had occurred. However, excess lubrication grease was evident at several of the lubrication points on the undercarriage and it is possible that heat from the brake units ignited some landing gear grease or oil residue from the No 1 engine. Because the AFRS were present, they were able to quickly extinguish the fire before it resulted in any damage. The Investigation notes that another AAIU investigation into an occurrence involving a different operator's Boeing 767 aircraft, in which there was a fire at the undercarriage, did not identify a cause of the fire other than heat from the brake units.

2.5 Loss of CVR Recording

The CVR data from the occurrence flight had been overwritten because the CVR had not been deactivated immediately following the flight. However, other recordings were available to the Investigation and the loss of the CVR data did not impede the Investigation.

3. CONCLUSIONS

3.1 Findings

1. The aircraft's airworthiness certification was valid.

2. The Pilots' licences and medical certificates were valid.

3. A loss of engine oil on the No. 1 engine occurred when the aircraft was enroute from KIAD to LSZH, which necessitated an in-flight shutdown, the declaration of an '*emergency*', and a diversion to EINN.

4. During taxi, as the aircraft turned towards its parking stand, the AFRS, who were escorting the aircraft following its emergency landing, observed a fire at the left-hand undercarriage.

5. The aircraft was requested to stop and the AFRS deployed fire-retardant foam to the area.

6. The AFRS reported that the fire-retardant foam was blown back by the APU and the still-running right-hand engine and appeared to be smoke, which resulted in the AFRS requesting (via the Ground Movements Controller) the aircraft to be evacuated on the right-hand side, before the AFRS cancelled the request moments later as the fire had been extinguished.

7. When the left-hand undercarriage was inspected following the occurrence, there was no evidence that a fire had occurred.

8. Excess lubrication grease was evident at several of the lubrication points on the undercarriage and it is possible that heat from the brake units ignited some grease or oil residue from the No. 1 engine.

9. When the No. 1 engine was inspected following the occurrence, the MCD probe for the engine's No. 4 bearing scavenge line was found in an upright position, in the engine cowling, below the MCD housing.

10. There was evidence of oil in the area surrounding the MCD housing, which indicated that the MCD was the source of the oil loss.

11. During subsequent engine inspection, a total of 34 US quarts was required to return the No. 1 engine oil quantity to the normal level, which indicated that there had effectively been a complete loss of engine oil from the No. 1 engine during the occurrence.

12. A scheduled maintenance inspection of the MCDs on the subject engine, which included their removal, inspection, and re-installation, had been performed in KIAD on 5 April 2022. The aircraft was operating on its first flight since the task was performed.

13. Both the re-installation of the probe and the post-installation inspection were performed by a single person (an inspector); this was not in keeping with the Operator's '*dual set of eyes*' process specified for this task.

14. For oil to have subsequently leaked from the MCD housing, the MCD probe would need to have migrated from the housing, either fully, or to a position where its o-ring and Teflon® seal were unseated in the housing and therefore no longer providing a seal and the valve in the MCD housing would have to have been open.

15. It is dimensionally possible for a partially installed/migrated MCD probe to hold the valve in the housing in a partially open state, while at the same time for the probe's Teflon® and primary o-rings to be unseated in the housing. When the probe is in such a position, the locking pins in the grip of the probe will be almost fully disengaged from the slots in the housing.

16. The Engine Manufacturer's workshop leak testing of the MCD housing conducted prior to any disturbance found that no leaks were present with and without the probe installed.

17. There was no red paint in the alignment grooves on the grip of the MCD probe or on the MCD housing.

18. The Operator's AMM had been customised to permit MCD probe installation with the red paint faded or missing, and for the alignment grooves to be used instead.

19. Detailed examination of the MCD probe and housing carried out by the Engine Manufacturer found damage to the replaceable o-ring (primary seal) and the non-replaceable Teflon® seal fitted to MCD probe and debris within the housing.

20. The amount and size of debris within the housing was greater than the missing material from the o-ring on the probe and was not of the same material which is suggestive of o-ring damage during a previous installation of the MCD probe.

3.2 Probable Cause

Migration of the No. 4 bearing Magnetic Chip Detector probe from its housing on the oil pump assembly on the No. 1 engine, followed by a loss of oil through the valve in the Magnetic Chip Detector housing, which remained partially open, due either to debris in the valve or as a result of a partially migrated probe.

3.3 Contributory Causes

1. The MCD probe was not in the installed and locked position.

2. The Operator's MCD maintenance procedures were not followed when maintenance was performed on the MCD probe prior to the occurrence flight.

3. There was no red paint in the alignment grooves on the grip of the MCD probe or on the MCD housing; this was permitted by the Operator's MCD inspection procedures.

4. The presence of debris within the MCD housing.

5. The MCD probe's o-ring (primary seal) and Teflon® (secondary) seal were damaged.

4. SAFETY RECOMMENDATIONS

As a result of the actions taken by the aircraft Operator, the Engine Manufacturer, and the Aircraft Manufacturer following the occurrence, this Investigation does not sustain any Safety Recommendations.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

Produced by the Air Accident Investigation Unit

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