SERIOUS INCIDENT

Aircraft Type and Registration:	Bombardier DHC-8-102, SX-BIO
No & Type of Engines:	2 x Pratt & Whitney Canada PW120A turboprop engines
Year of Manufacture:	1992
Date & Time (UTC):	24 April 2010 at 0733 hrs
Location:	Bristol International Airport
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	38 years
Commander's Flying Experience:	6,300 hours (of which 1,700 were on type) Last 90 days - 3 hours Last 28 days - 3 hours
Information Source:	AAIB Field Investigation

Synopsis

After a base maintenance check at Exeter the aircraft was flown uneventfully to East Midlands to be repainted. During the return flight to Exeter the right engine suffered a significant oil leak and lost oil pressure, so the flight crew shut it down. Subsequently, the crew noticed the left engine also leaking oil, with a fluctuating oil pressure, so they initiated a diversion to Bristol, where they landed safely. The oil leaks were traced to damaged O-ring seals within the oil cooler fittings on both engines. Both oil coolers had been removed and refitted during the base maintenance check at Exeter. It was probably during re-installation that the O-ring seals were damaged. A number of factors led to this damage and to missed oil leak checks. Six Safety Recommendations are made.

History of the flight

The aircraft had been flown from Greece to Exeter to undergo a maintenance check. On 16 April 2010 the aircraft was flown from Exeter to East Midlands, where it was to be repainted. The crew that operated the aircraft observed nothing unusual on the flight but on its arrival at East Midlands, the engineer who met the aircraft observed some oil spots on the ground beneath both engine nacelles.

On 24 April 2010 the aircraft was to be flown back to Exeter. The crew for this flight were collected from their hotel at 0500 hrs and driven to the airport. The weather conditions were good and the crew were taken to the aircraft where they performed their pre-flight inspection. The engineer requested that the crew perform a ground run on both engines so that he could check the engine oil levels; he had intended to do this himself the previous day but had not been able to locate an appropriate ground power unit. The ground run was completed without event and the engineer added one quart of oil to the right engine, which brought both engines' oil levels up to the 'full minus 2' (F-2) mark, a normal refill level for these engines.

The start-up, taxi and departure were all described by the crew as normal. However, photographs taken by an aviation enthusiast at 0654 hrs show some signs of oil leaking from both engines as the aircraft taxied out (Figures 1 and 2).

Approximately 10 minutes into the flight, at FL100, flying on an ATC radar heading, the commander noticed the master warning light illuminate momentarily. A closer inspection of the aircraft's instruments revealed that the right engine oil pressure was fluctuating and decreasing. The co-pilot went into the cabin and observed what appeared to be a major oil leak coming from the right engine, with oil flowing down the right side of the aircraft fuselage. The oil pressure continued to fluctuate and fall, so the crew carried out the checklist drill for low engine oil pressure, which involved initially feathering the engine. When the oil pressure fell below a certain value, they shut the engine down.

The crew declared a PAN and requested direct vectors to Exeter. After approximately 5 minutes of flight, the crew, who were monitoring the remaining engine closely, saw the left engine oil pressure begin to fluctuate. The co-pilot again entered the cabin and, this time, observed

Figure 1

Oil leak visible on right main gear leg during taxi at East Midlands on 24 April 2010
(photograph courtesy Dave Sturges/ AirTeamImages.com)

Figure 2

Oil leak visible on left main gear leg during taxi at East Midlands on 24 April 2010
(photograph courtesy Dave Sturges/ AirTeamImages.com)

an oil leak from the left engine. The commander made the decision to divert to the nearest suitable airfield and, with ATC assistance, diverted to Bristol, which was 25 nm ahead of the aircraft. ATC asked the crew if they wished to upgrade their emergency, which the crew confirmed they did, but ATC were not made aware of the problem with the operating engine until after the aircraft had landed safely.

Aircraft examination

The aircraft was examined four hours after it landed at Bristol International Airport. Both the left and right main landing gear legs were coated in clean oil (Figures 3 and 4), as were the lower surfaces of both engine nacelles and main gear doors. The right side of the fuselage adjacent to the right engine was coated in oil streaks, whereas the left side was clean. The underside of the left and right oil coolers, which are located forward of the main gear doors (Figure 4), were heavily coated in oil but there was no oil on the nacelle undersides forward of the oil cooler positions.

The engine cowlings were removed to identify the source of the oil leaks. The left engine oil cooler is shown in Figure 5 with the lower forward cowling lowered. There was oil along the lower forward surface of the oil cooler and along the lower forward cowling hinge line. Oil was also seen slowly weeping from around the knurled nut where the inlet pipe connects to the oil cooler. When the inlet pipe was disconnected and the oil cooler removed, it was revealed that two O-ring seals were fitted inside the groove of the pipe; the smaller O-ring was split and the larger O-ring contained a cut (Figures 6 and 7). The larger O-ring was of the correct size and type for the installation, but the smaller O-ring should not have been fitted. One O-ring, of the correct size, was fitted to the outlet pipe of the oil cooler and this O-ring was undamaged.

Figure 3

Left engine nacelle and landing gear leg after landing at Bristol

Figure 4

Right engine nacelle and landing gear leg after landing at Bristol

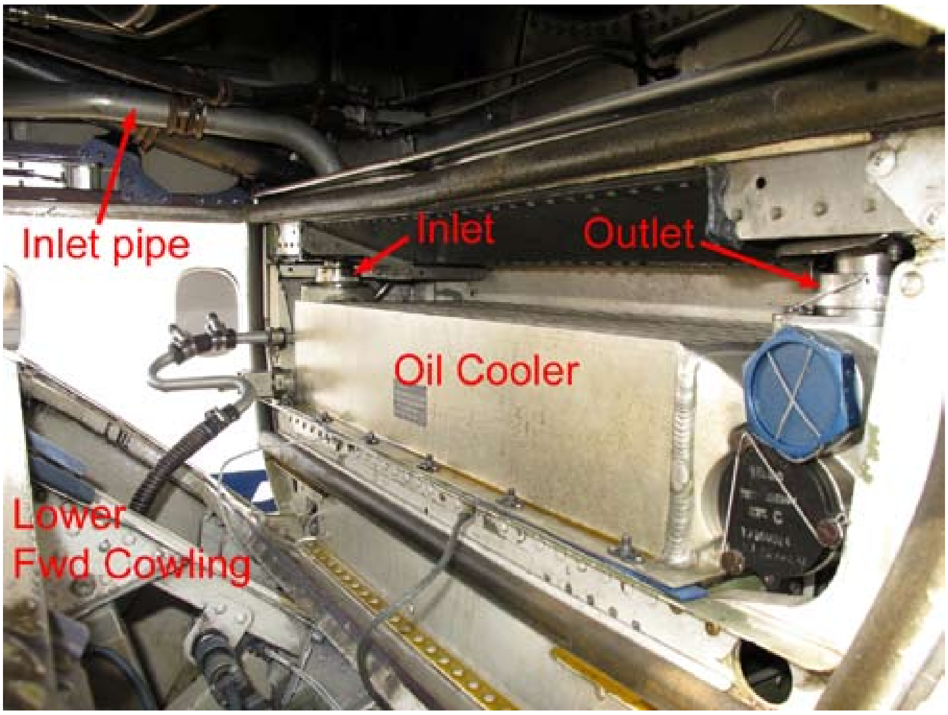

Figure 5

Left engine oil cooler with lower forward cowling lowered.
Slow oil seepage from oil cooler inlet nut

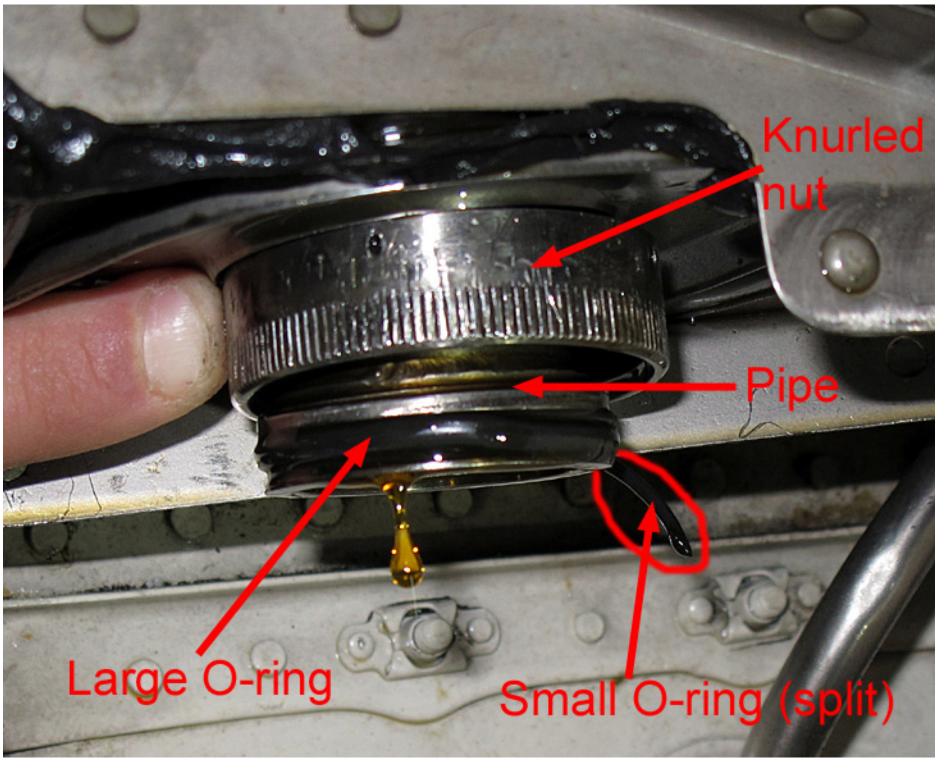

Figure 6

Left engine oil cooler inlet (inboard) pipe connector, showing large O-ring seal and small O-ring seal, which had split, part of which can be seen hanging down (highlighted in red)

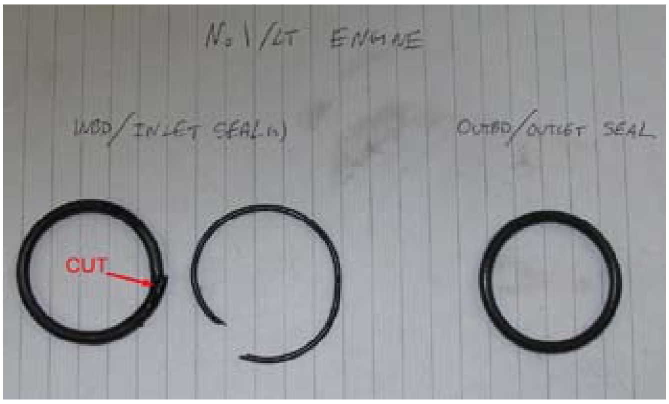

Figure 7

Left engine oil cooler inlet and outlet seals;
large inlet seal contained a cut; small inlet seal was split

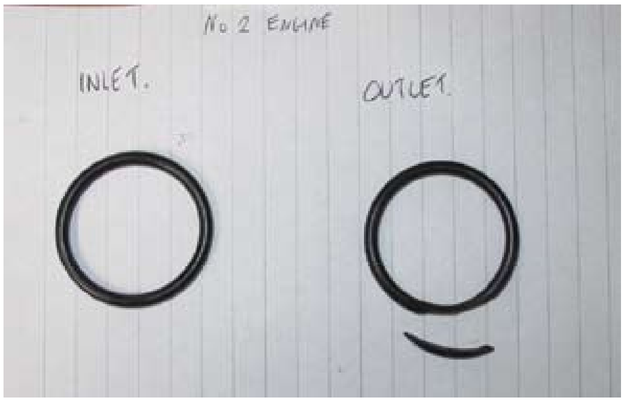

Figure 8

Right engine oil cooler inlet and outlet seals;
outlet seal had been cut; severed piece shown below it

When the right engine lower forward cowling was lowered, oil was seen along the lower forward cowling hinge line and around the oil cooler outlet pipe, but it was not noticeably weeping. This oil cooler was also removed and its inlet and outlet pipes examined. The O-ring seal on the outlet pipe had been cut and was missing a large section from its outer circumference (Figure 8). The missing section of O-ring seal was found in a side cavity beneath the oil cooler outlet. The O-ring seal on the inlet pipe was undamaged.

The circlips, which retained each knurled nut on the pipe, contained grooves where the nut had squeezed the circlip hard against the lip of the pipe (Figure 9). The knurled nuts also had score marks on their outer circumference consistent with having been tightened with a pair of grips. This was evidence that the knurled nuts on both pipes from both oil coolers had at some point been over-tightened. The maintenance manual calls for the nuts to be tightened 'by hand'.

Following the right engine oil cooler removal, it was noticed that the inlet and outlet pipes were not aligned perpendicular to the oil cooler but were canted outwards (Figure 10). This orientation of the pipes would have made it more difficult to insert the pipes into the oil cooler during installation, because some force would have been needed to align the pipes. After this incident, before the oil coolers were re-installed, the oil pipes were disconnected at their forward end to enable the pipes to be rotated to the vertical; this facilitated the insertion of the pipes into the oil cooler fittings.

A total of 13.5 litres of oil was drained from the left engine and 11.5 litres were drained from the right engine. The oil capacity of each engine was 19 litres (20 US quarts). The engine oil levels were at 'F-2' ('Full minus 2 quarts' which is equal to 17 litres), as recorded in the technical log, when the aircraft departed East Midlands Airport. Therefore, the left engine lost 3.5 litres of oil and the right engine lost 5.5 litres of oil during the flight to Bristol.

The left and right oil coolers were pressure leak tested and no leaks were found. Following rectification work, which involved installing refurbished oil coolers and new O-ring seals, no further leaks were detected. The aircraft has since completed numerous flights with no reported oil leaks.

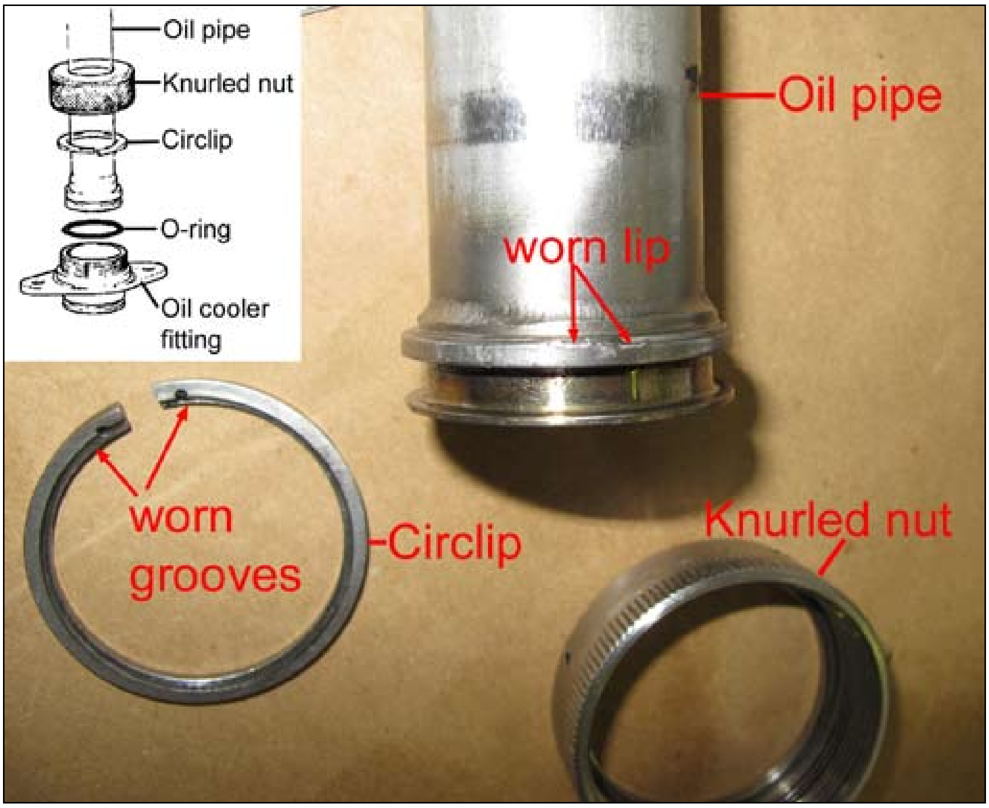

Figure 9

Worn grooves on circlip retaining knurled nut
(left oil cooler inlet pipe shown; similar wear found on the other three circlips)

Figure 10

View looking aft beneath the right engine where the oil cooler had been installed.
Note that the oil cooler inlet and outlet pipes are not orientated at 90° but are canted outwards

Maintenance history

The aircraft was based in Greece and had not flown between July 2009 and March 2010, as the previous operator of the aircraft had ceased trading. In early 2010 two new engines were fitted to the aircraft and on 18 March 2010 the aircraft was flown from Athens to Exeter Airport for a C-check[1] by a local Part-145 approved maintenance organisation (AMO). During the C-check both oil coolers were removed and refitted. On 16 April 2010 the aircraft was flown to East Midlands Airport to be re-painted and this flight took 49 minutes. One week later, on 24 April 2010, during the aircraft's return flight to Exeter, the incident and diversion to Bristol occurred. The aircraft had accumulated 29,998 hours and 38,752 cycles at the time of the incident.

A detailed investigation into the maintenance activities at both Exeter and East Midlands Airports was carried out, involving interviews of numerous technicians, engineers and managers at the AMO, in order to try and establish how the O-ring seals had become damaged and how leak checks had not detected the problem.

Oil cooler removal and re-installation

During the C-check it had been noticed that the bushings in the right and left main landing gear door pivot brackets were worn and needed to be repaired. These brackets are located in the upper forward section of the main landing gear bays, directly aft of the oil coolers. The aircraft manufacturer's Repair Drawing (RD) calls for the original bushing to be removed, the hole 'cleaned up' and then a special flanged bushing to be manufactured and installed in an interference hole. A new lined bushing is then installed into the repair bushing. The instructions in the RD do not specify if the repair can be accomplished in situ or if the bracket needs to be removed from the aircraft. A licensed aircraft engineer (LAE), a 'supervisor' grade at the AMO, initiated the work for the bushing repair tasks, but he was not sure if the bushing could be repaired in situ so he sought the advice of a workshop engineer. However, the workshop had closed for the day. In order to expedite the work, the LAE decided to have the bushings and brackets removed. He tasked two 'technician' grade unlicensed engineers to start removing the oil coolers, as he considered this was necessary to gain sufficient access to remove the brackets. One of these technicians had not completed his removal task when he went off shift, so the removal of both oil coolers was completed by the other technician, who will be referred to as Tech A. It was subsequently determined that the repair work could be done in situ, so the oil cooler removals had been unnecessary, and Tech A was then tasked with re-installing both oil coolers.

Tech A stated that he re-installed both oil coolers in accordance with the aircraft maintenance manual (AMM) instructions, section 79-20-11. He also commented that it was not an easy job as the oil cooler fits in a small space and the oil pipes were difficult to manoeuvre into position. He needed two hands to install each pipe and used a torch, held in his mouth, to illuminate the pipe and oil cooler fitting. He replaced the O-ring on each pipe with a new one, and the paperwork confirmed that four new O-rings, of the correct part number, had been used during the installation of the two oil coolers. He did not recall seeing a second smaller O-ring fitted to the left engine inlet pipe but was sure that he had not installed one. He hand-tightened the nuts first and then used a pair of soft grips to tighten the nuts further. He stated

Footnote

[1] The C-check is a heavy base maintenance check that can take several days to complete.

that he had been asked to complete both oil cooler installations before the end of his shift, which added some time pressure, but he did not consider it unusual pressure. He completed the left oil cooler installation first, and finished the right oil cooler installation at his shift-end time, 1800 hrs (1900 hrs BST).

A 'defect job card' for the left bushing repair and a separate card for the right bushing repair had been generated electronically and printed out by an LAE. The task requirements were then left blank for individuals to complete and sign off. Tech A wrote down the separate requirements for tasks to:

> *'remove oil cooler for access'*

and:

> *'refit oil cooler on completion of access requirements'*

and signed them off. These were later counter-signed by an LAE who inspected the oil cooler installations, although it was not possible to inspect the O-ring seals after they were installed. The AMM procedure for the oil cooler installation (AMM 79-20-11) calls for an engine ground run to be carried out to check for oil leaks. Tech A omitted to add the leak check task to the 'defect job card' and his supervising engineer did not notice the omission. Each task on the 'defect job card' was written by the individual who performed it, rather than all tasks being pre-planned. For example, the task written after 'refit oil cooler' was 'carry out NDT inspection of bracket post rework' and the task after that was 'carry out bush repair in situ'. Both of these tasks were written by the different people performing the task, and were out of sequence.

Post-maintenance engine ground runs at Exeter

On completion of the C-check some engine ground runs were required, to test systems and check for oil leaks. However, a leak check of the oil cooler fittings was not specifically called for. An LAE, a 'senior supervisor' grade at the AMO, was responsible for carrying out the engine ground runs and was also responsible for the overall supervision of SX-BIO's C-check. This LAE, who will be referred to as Sup A, carried out the engine ground runs towards the end of the day on 15 April 2010. He also signed off many of the tasks carried out during the check, including the oil cooler re-installation tasks.

The first engine ground run was at low power and lasted 5 minutes. The engine side cowlings were opened and no leaks were seen. The engine oil levels were checked on the sight glass; they were below the 'F-2' mark, so some oil was added to each engine to bring the levels up to the 'F-2' mark. The lower forward engine cowling, which provides access to the oil cooler, was not opened on either engine. The engines were then re-started and Sup A taxied the aircraft to a location at the airport where high power engine runs could be conducted. During this ground run the power was increased to 94% N_H[2] and 88% torque. Towards the end of the engine run, about 40 minutes after engine start, a mechanic in the rear of the aircraft noticed oil leaking down the left main landing gear leg and notified Sup A. There were no indications in the flight deck of a problem, so Sup A taxied the aircraft back to the maintenance hangar to investigate the oil leak. The left engine lower forward cowling was lowered, revealing a significant amount of oil in and around the oil cooler area. It was noticed that at the inboard/inlet oil cooler fitting there was one

Footnote

[2] N_H is the rotational speed of the high pressure turbine.

thread visible beneath the knurled nut. This reminded Sup A that the oil coolers had both been removed and re-installed. The wire locking was cut and the nut was tightened with a pair of grips. The technician who did this recalled adding one full turn to the nut. The wire locking was also cut from the outboard/outlet nut and this nut was tightened, although it only moved by a fraction of a turn. It was reported that up to 5 quarts of oil were required to top up the left engine. Most witnesses said that no oil leaks were observed from the right engine, although there were conflicting reports on whether the lower forward cowling on the right engine was opened and whether the oil cooler nuts on the right engine were tightened. One technician reported that there were traces of oil near the drain holes of the right engine, but no leaks. The oil level on the right engine was found to be high so one quart was siphoned out, although there were differing reports on whether this resulted in the level reducing to 'F-2' or 'F-1'.

Following the rectification work, a third engine run, at low power, was carried out just outside the maintenance hangar. Both engines were run up to 76% N_H and 24% torque with the propellers un-feathered. The left engine was shut down after 5 minutes of operation, while the right engine continued to run for a further 10 minutes, in order to complete some pitot-static checks. Following this engine run there were no further oil leaks reported, although according to one technician only the side cowlings were opened and not the lower forward cowling. However, according to one engineer the left lower forward cowling was lowered and he inspected the oil cooler fittings, which were dry.

Maintenance at East Midlands Airport

On 16 April 2010, the day after the engine ground runs, the aircraft departed Exeter and flew to East Midlands airport to be repainted. The flight crew did not note any engine anomalies during the flight. On arrival at East Midlands the aircraft was met by an engineer who worked for the Exeter AMO; he was 'supervisor' grade and was responsible for overseeing the repaint which was being carried out by a separate company. This engineer, who will be referred to as Sup B, noticed some oil spots on the ground beneath the nacelles of both engines and took some photographs (Figures 11 and 12); these were taken about 15 minutes after the aircraft parked on stand.

Figure 11

Oil spots on ground beneath left engine nacelle after arrival at East Midlands on 16 April 2010

Figure 12

Oil spots on ground beneath right engine nacelle after arrival at East Midlands on 16 April 2010

The aircraft was moved into a hangar and painting preparations were begun the next day, 17 April. On 18 April Sup B informed the production manager at Exeter that he had found oil leaks from both engines, but that he had not been able to open the engine cowlings to investigate the leaks due to the paint stripping work. During the ensuing days, access to the engines was limited by scaffolding but Sup B was able to access the aft section (zone 2) of the left engine and tightened an elbow joint that might have been weeping oil. Sup B reported that throughout the painting work small amounts of oil were seeping from the metalwork butt joints of both engine nacelle lower cowls – these butt joints are located on either side of the oil cooler. On 20 April Sup B took some photographs of this oil seepage. Figure 13 shows visible oil from the right engine – a similar amount of oil was visible from the left engine nacelle butt joints. On 21 and 22 April the butt joints were covered so he was unable to inspect them. On 23 April, the day before the aircraft was due to depart back to Exeter, Sup B was given full access to the engines and noticed that there was still a bit of oil seeping from the right engine butt joint but none from the left. That day, Sup A arrived from Exeter to perform the duplicate flight control inspections that were required because the flight controls had been disturbed by Sup B for balancing (required post-painting). Sup-B discussed the oil seepage with Sup A and Sup A informed him about the oil leaks they had experienced during the engine runs at Exeter and advised that the oil seepage was probably residual oil from the previous leaks. Sup A gave Sup B the impression that they had experienced oil leaks from both engines at Exeter and that these had been rectified. Sup B planned to carry

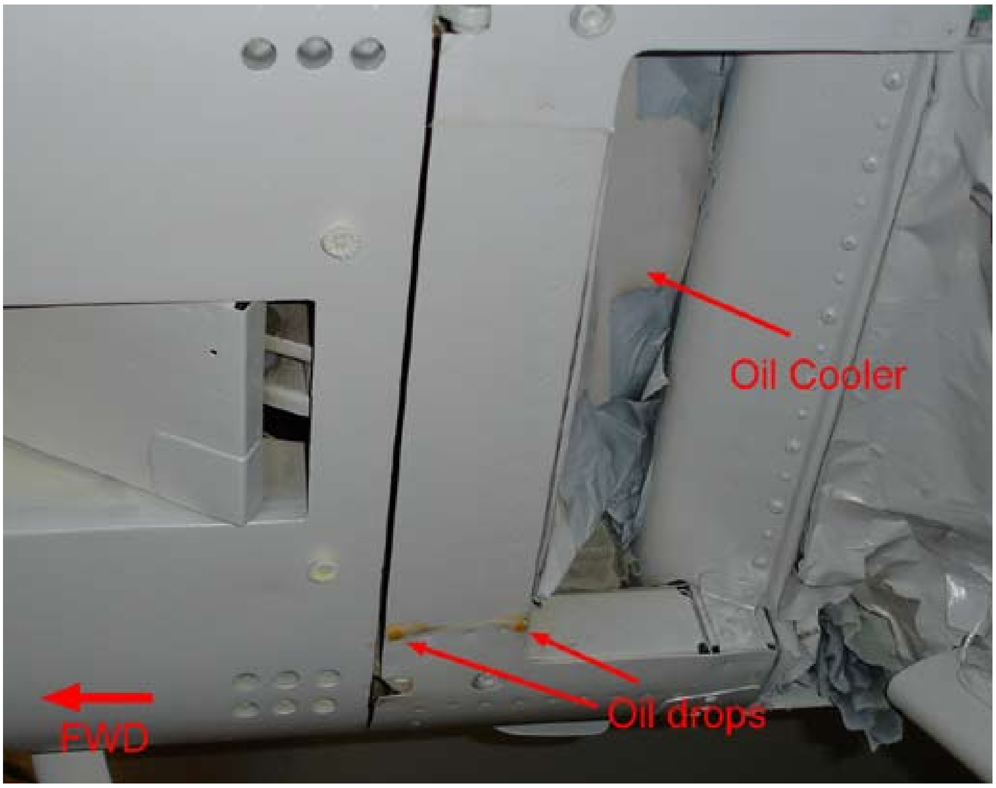

Figure 13

Oil seepage from butt joint beneath right engine oil cooler
(photograph taken on 20 April 2010 during painting at East Midlands)

out a low power engine ground run on the afternoon of 23 April to check oil levels and as a final oil leak check. However, the APU was unserviceable and a 28 volt ground power unit (GPU) was not available, so the engines could not be started. Arrangements were made for a GPU to be available the following morning prior to the aircraft's flight back to Exeter. Sup B noted that the left engine oil level was at 'F-2' and the right engine oil level at 'F-3'. However, since the engines had not been run for 8 days, these were not necessarily reliable indications.

On the morning of 24 April Sup B took some photographs of the right side of the aircraft at 0555 hrs (0655 hrs BST), about 1 hour before the aircraft's departure. The right main landing gear leg was clearly visible in the photographs and there were no traces of oil on it, or oil spots on the ground beneath the right engine. Sup B then met the flight crew and asked them to carry out a low power engine run so that he could complete a final oil level check and oil leak check. The engines were run for about 2 minutes, at flight idle with the propellers feathered (28% max torque and 74% max N_H[3]). After the engine run the indicated oil levels remained as before, so Sup B added 1 quart to the right engine to bring it up to the 'F-2' level. He did not see any oil leaks. His inspection included opening the engine side cowls but not the lower forward engine cowls[4]. The aircraft taxied out for departure at about 0653 hrs (0753 hrs BST), and at 0654 hrs and 0658 hrs respectively the photographs shown in Figures 1 and 2 were taken by an aviation enthusiast; these clearly show oil leaking down both the left and right main gear struts.

Footnote

3 Only 48 seconds of the 2-minute engine run were captured on the Flight Data Recorder (FDR). The FDR on this aircraft starts recording when the anti-collision light is turned on or 'weight-off-wheels' is detected. It is therefore likely that the anti-collision light was turned on after engine start. However, Sup B reported that the power lever was not moved beyond flight idle and the propeller remained feathered.

4 Lowering the forward engine cowling requires at least two people, and preferably three whereas, opening the side cowls is a simple one-person task.

Previous oil cooler replacements on SX-BIO

Prior to the aircraft's C-check at Exeter the right oil cooler had previously been replaced on 6 November 2005 and the left oil cooler had previously been replaced on 3 July 2009 by another AMO when the aircraft had accumulated 29,938 hours (60 flying hours before the incident on 16 April 2010). Tech A was confident that he had not installed the smaller O-ring seal on the inlet pipe to the left oil cooler but admitted that it was possible that it was already on the pipe and he had overlooked it. If that was the case then it was likely that the smaller O-ring seal had been installed on 3 July 2009 when the left oil cooler was last disturbed. The operator of SX-BIO tried to obtain information on who performed this installation, but was unable to do so because the previous operator, who had maintained the aircraft at that time, had ceased trading.

Repair procedures

The procedures for most repairs on the DHC-8-100 are contained in the aircraft manufacturer's Structural Repair Manual (SRM). Other less common repairs are detailed in individual Repair Drawings (RDs) which are also produced by the aircraft manufacturer. The manufacturer's RDs usually contain a diagram of the repair with a short instruction on how to perform the repair itself. This was the case for the pivot bracket bushing repair in the forward section of the main landing gear bay. The RD for the pivot bracket bushing repair was a stand-alone document, but at the AMO a number of frequently used RDs were collated together in a series of RD folders that were accessible to the engineers working the aircraft. The LAE who raised the 'defect job card' for the bushing repair had pulled a copy of the appropriate RD from the RD folder and had attached it to the 'defect job card'. The LAE who then actioned the 'defect job card' saw the RD but, having never undertaken this repair before, did not know what the access requirements were and judged that the oil coolers would need to be removed. The aircraft manufacturer initially stated that their RDs were a rough outline containing only detailed instructions for specific parts, and that if more detailed instructions were required, then these would normally be completed by the engineering section of the operator or maintenance organisation. The aircraft manufacturer later stated that if access to a repair required significant equipment removal, then this would be called for in an RD, with the relevant AMM reference. They also stated that the lack of an access requirement listing in this RD should have indicated to the engineer that no removals were necessary. However, one engineer at the AMO said that he was aware of a previous oil cooler removal for the same defect at another maintenance organisation in which the bracket needed to be removed and repaired in a jig due to the severity of the bushing wear.

The Head of Base Maintenance at the AMO said that normally when a repair was needed that was not covered in the SRM, the engineering planning department would contact the aircraft manufacturer to obtain an RD and the planning department would then provide instructions to the engineers on what was needed to carry out the repair. In this case the engineer already had a copy of the RD so the planning department was not involved in the repair process.

The regulations that apply to the AMO are in Annex II (Part 145) of European Commission Regulation (EC) No 2042/2003. Regulation Part 145.A.45 on 'Maintenance Data' requires organisations to establish procedures to capture any incomplete or ambiguous maintenance instructions contained in the maintenance data, and Part 145.A.45 states that the AMO can modify these instructions if they result in equivalent or improved maintenance standards. The AMO did not have a process in place for being able to provide their own instructions to supplement RDs that had been accumulated in the RD folders or to capture lessons learnt from previous repairs.

Safety Critical Maintenance Tasks

On 23 February 1995 a Boeing 737-400 (G-OBMM) lost almost all its oil from both engines in flight. The aircraft diverted and landed safely, but the AAIB investigation revealed that following a borescope inspection of both engines by the same person, both HP rotor drive covers had not been refitted, and this resulted in the loss of oil from both engines (AAIB Formal Report 3/96). Among other safety recommendations the AAIB report recommended that:

> 'The CAA, with the JAA, consider issuing advice to aircraft maintenance organisations that, where practical, work which can effect the airworthiness of an engine should not be conducted on all of the powerplant installations of an aircraft at one point in time by the same personnel' (**Safety Recommendation 96-31**).

These types of task are now referred to as 'safety critical tasks' and some of the following regulations and guidance on safety critical tasks were, in part, a result of this Safety Recommendation.

Regulation Part 145.A.65 states that:

> *'The organisation shall establish procedures agreed by the competent authority taking into*

account human factors and human performance to ensure good maintenance practices…'.

It states further that:

'With regard to aircraft line and base maintenance, the organisation shall establish procedures to minimise the risk of multiple errors and capture errors on critical systems, and to ensure that no person is required to carry out and inspect in relation to a maintenance task involving some element of disassembly/ reassembly of several components of the same type fitted to more than one system on the same aircraft during a particular maintenance check. However, when only one person is available to carry out these tasks then the organisation's work card or worksheet shall include an additional stage for re-inspection of the work by this person after completion of all the same tasks.'

In essence, the regulation requires maintenance organisations to have procedures to ensure that the same person is not carrying out the same safety critical task on two similar systems, for example on both engines of a twin-engined aircraft. However, it does allow an exception to this case if a re-inspection is carried out. In the case of the oil cooler installations, a re-inspection would not have detected that the O-ring seals were damaged. In Part 11 of CAP 562 ('*Civil Aircraft Information and Procedures*') the CAA has published Leaflet 11-21, entitled '*Safety Critical Maintenance Tasks*', to explain how it expects maintenance organisations to handle safety critical tasks. It states that:

'The CAA wishes to highlight the potential safety benefit where companies choose to apply aspects of Extended Range Twin Operations (ETOPS) maintenance philosophy to multi-system aircraft in order to avoid the possibility of simultaneous incorrect maintenance on two or more safety critical systems,…, engines and their systems being a case in point.'

The Leaflet states that:

'arrangements should be made to stagger scheduled maintenance tasks'

that are deemed safety critical and affect the same system. Where this is not practical:

'the use of separate work teams together with the accomplishment of appropriate functional checks to verify system serviceability should ensure a similar level of system integrity.'

The AMO at Exeter had implemented the intent of Leaflet 11-21 in its company procedures. It had created a '*Critical Task Checklist*' for each aircraft type that it maintained. The checklist for the DHC-8-100 stated:

'This task has been assessed as a possible risk for multiple errors on critical systems, when carried out at the same time as a similar task by the same personnel. Therefore, any similar tasks must be separated by at least one flight, or carried out by different personnel, or if this cannot be achieved, a re-inspection of the work after completion of all similar tasks should be completed and worksheets annotated accordingly.'

Among the tasks included in the critical task checklist were '*Engine Oil Filter Change*', '*Engine Oil Chip Detector Remove/ Refit*' and '*Oil Filler Cap Removal/ Refit*'. 'Engine oil cooler removal/ refit' was not on the list. There were also no tasks on the list involving disturbances of the fuel system. This list was created in October 2009, after a CAA audit in January 2009 flagged up the absence of such a list. The list was published on the company's internal internet (intranet), and the LAEs were made aware of the list during their recurrent training. Technicians and Fitters were not given the same training as the LAEs and some were not aware of the safety critical task list.

All the engineers and managers at the AMO who were interviewed during the investigation agreed that the 'oil cooler removal/ refit' task should have been flagged up as a safety critical task and that the same person should not have been tasked to refit both oil coolers. The LAE who assigned Tech A to install both oil coolers said it had not occurred to him that the task was safety critical. He said that, in hindsight, he would have identified the task as safety critical, but suggested that the list of safety critical tasks be included in each work pack as a reminder, and not just on the intranet.

The AMO has a planning department which generates a work pack for each planned maintenance input and this contained all the job cards for the required tasks. The planning department was responsible for identifying any tasks that were safety critical and annotating them as such. In the case of SX-BIO's maintenance, a 'third party' work pack was supplied by the operator of SX-BIO. The job cards in this work pack did not have 'safety critical tasks' identified on them. However, the oil cooler removal/ refit task on SX-BIO was not a planned task and therefore was not in the work pack. The oil coolers were removed because of a defect found on the main landing gear pivot door brackets, and were, therefore, part of a 'defect job card', which was raised by an LAE. The LAE who raised the 'defect job card' did not think that the oil cooler removal was necessary, but this view was not passed on to the LAE who initiated the work on the 'defect job card'. In relation to defects, the AMO's procedure on safety critical tasks (PRO TS25) states the following:

> *'Any engineer or other person raising a process sheet, task card, work request - scheduled or unscheduled (including defects) or tech log entry, in any format, should refer to the published list of critical tasks and annotate the document produced if the task involved is listed.'*

The LAE initiating the work on the 'defect job card' should have referred to the critical task list; however, the bracket repair task was not listed nor was the oil cooler removal/ refit task.

Oil cooler installation procedure

The procedure in the AMM (Revision 'Dec 20/2004') for installing the oil cooler states that the oil cooler should be positioned in the lower nacelle and its attachments aligned with the corresponding holes without inserting the bolts into the holes. It then states that the oil pipes should be connected to the oil cooler fittings and that the nuts should be run down without tightening. After securing the cooler to the nacelle with bolts and washers, it states:

> *'Complete tightening of tube assemblies (5) and (6).*
> *Pre Mod 8/0642 Torque union nuts to 1520 to 1680 pound-inches*
> *Mod 8/0642 Tighten tube assembly nuts to oil cooler fitting (20) by hand and wire lock.'*

SX-BIO had mod 8/0642 embodied which changed the assembly and nut type, and only hand tightening of the nuts was required. The following sequence of photographs in Figure 14 helps to illustrate the installation.

When the knurled nut is fully wound down, as in (4) in Figure 14, the oil pipe is free to move and can be rotated and moved up and down. The O-ring is the only barrier against oil leakage from the cooler. If the nut cannot be tightened and fully wound down by hand then this is an indication that the pipe has not been installed correctly and/or the O-ring may have been damaged. The O-ring provides the seal and no additional clamping force is provided by over-tightening the nut.

Above the oil cooler, the oil pipe passes through a pair of fire seal retainers and a clamp which serves to secure the pipe to the nacelle structure. The pipe then passes through a pair of retainers in the firewall and is attached to a flexible hose (Figure 15). The AMM procedure for the oil cooler removal requires the fire seal retainers to be disconnected, but it makes no reference to the clamp, firewall retainers nor flexible hose. According to the engineer and technician who undertook to re-install the oil coolers following the incident, in order to be able to rotate the oil pipe to the vertical position and easily manoeuvre it into the oil cooler fitting, they needed to loosen the clamp and disconnect the pipe from the flexible hose. They reported that the flexible hose was not sufficiently flexible to permit the pipe to be rotated to, and stay in, the vertical position, without disconnecting it from the pipe. Figure 10 shows that the oil pipes were not in the vertical position on the right engine installation.

Figure 14

From left to right: (1) oil cooler fitting; (2) oil pipe partially inserted – O-ring seal visible; (3) oil pipe fully inserted; (4) knurled nut fully wound down, hand tight

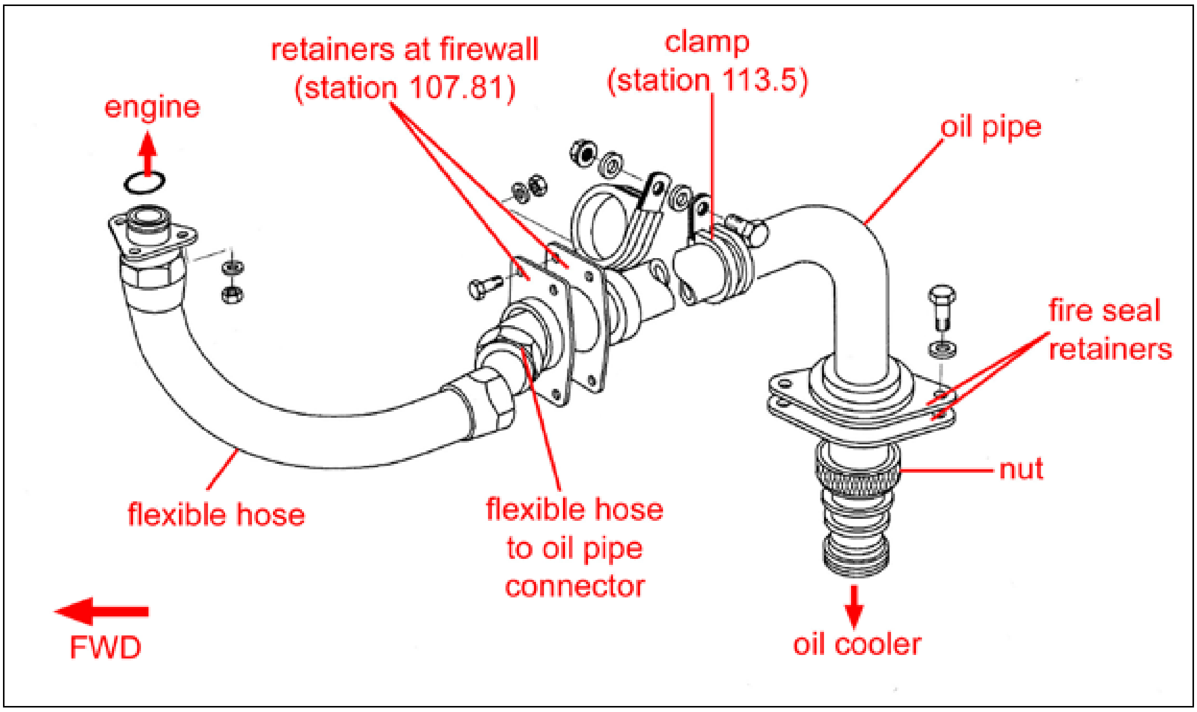

Figure 15

Oil cooler oil pipe installation on the DHC-8-100

The upper section of the oil cooler fitting (image (1) in Figure 14) has a thin wall, 1.64 mm thick, and on its inner edge it has a 30 degree chamfer which further reduces the wall thickness at its top edge, making this edge feel moderately sharp to the touch. Trying to force the pipe into the oil cooler fitting when it is not perfectly aligned could result in the sharp edge of the fitting pressing up against the O-ring seal on the pipe.

Oil leak check procedure

At the end of the oil cooler removal/installation task in the AMM (79-20-11) it states:

> *'Ground run engine (refer to Chapter 71). Check oil temperature stabilizes at approximately 80 degrees C. Check for oil leaks.'*

However, as identified earlier, this requirement was not included in the 'defect job card'. Chapter 71 contains a detailed procedure for ground running the engine, but it does not make any specific reference to an engine run procedure for oil leak checks. After starting the engine it says to unfeather the propeller, check that N_H stabilizes at 75% (power lever at FLT IDLE) and that the oil pressure is between 55 and 65 psi (green arc on gauge). A note in the AMM states that:

> *'Normal Oil Pressure is 55 to 65 psid at Nh speeds above 66% at oil temperatures between 71 Degrees and 115 Deg C.'*

The condition lever is then advanced to MAX, to perform a check of engine parameters. The engine shutdown procedure is to retard the power lever to FLT IDLE, retard the condition lever to MIN, and then to START & FEATHER for 30 seconds, to prepare the engine for the oil level check. The engine is then shut down. There is no minimum duration specified for the engine ground run in Chapter 71, and there is no requirement to move the power lever beyond FLT IDLE. The aircraft manufacturer stated that once the engine oil is up to normal operating temperature (45°C to 90°C), there will be minor fluctuations in oil pressure in transient conditions, but the oil pressure will be constant at stable power settings regardless of the power the engine is generating. The 80°C temperature listed in the oil cooler removal/ refit procedure is the temperature at which the thermostatic valve inside the oil cooler opens to divert oil into the matrix. This temperature would need to be reached to check for leaks from the cooler matrix, but not for checking leaks from the oil cooler fittings (as oil passes through the inlet and outlet fittings regardless of the position of the thermostatic valve). Once the engine run is completed, the lower forward cowling needs to be opened to check for leaks from the oil cooler fittings.

Working hours

The shift patterns for the engineers, technicians and fitters working on the aircraft at Exeter were '4 days on' followed by '4 days off', working 12 hours per day (including a half hour lunch break) from 0700 to 1900 hrs. Overtime was permitted. In the two weeks before Sup A started work on SX-BIO's C-check at Exeter he was working abroad. During the 10 days prior to his return to the UK he averaged 15.7 hours work per day with one day off in the middle (this time included 2 hours commuting between the hotel and airport). Sup A considered that he did not suffer from fatigue during this period despite the long working hours. After returning to the UK, Sup A had 2 days off and then he worked on SX-BIO for 6 days on, 2 days off, 6 days on, 1 day off, 4 days on, 3 days off, followed by 5 days on, averaging 12 hours per day (60 hours per week). Sup A said that during SX-BIO's leak checks, which were at the end of the aircraft's C-check, he felt tired and had a lot on his mind trying to get the aircraft ready for its scheduled painting slot. However, he said it was not an unusual level of tiredness and he did not consider himself fatigued.

According to '*The Working Time Regulations 1998*' and '*The Working Time (Amendment) Regulations 2003*'[5], an employer should ensure that a worker does not work in excess of an average of 48 hours per week over a 17-week period. In the 1998 regulations the air industry was excluded from this rule, but in 2003 this air industry exclusion was removed. However, the 48-hour limit does not apply if a worker has agreed with his employer, in writing, that it should not apply in his case. 97% of engineers at the AMO, including Sup A, had signed an 'opt-out' agreement so that the 48-hour limit would not apply to them. In the 17-week period leading up to the end of SX-BIO's C-check, Sup A had worked an average of 57 hours/week[6].

The WTRs also state that a worker is entitled to a rest period of 11 consecutive hours in each 24-hour period, and at least two rest periods of 24 hours each in each 14-day period (ie at least 2 days off during every 2-week period). These rest periods still apply even if the individual has signed an 'opt out' agreement. On most of the days when Sup A was working abroad he was averaging just 8.3 hours rest between shifts, significantly less than the 11 hours rest entitled under the WTR.

The AMO stated that their policy was that staff should not work more than 6 days on before a full day off, or 12 days on before 2 days off, in accordance with the WTR, although this was not a written policy. This

Footnote

5 The UK legislation enacted as a result of the EU Working Time Directive (2003/88/EC).

6 57 hours/week calculated using the WTR formula where 'annual leave hours' are included in the total average.

policy was not monitored by the AMO and relied on individuals reviewing their working hours with their managers. The AMO did not have a policy on minimum rest periods.

There are no regulations that limit the maximum hours that an individual can be asked to work in any 24-hour period, assuming it is followed by 11 hours rest. The AMO did not have a policy on the maximum hours that an engineer could work in any 24-hour period and relied on the fact that every engineer and manager had undergone human factors and human performance training and it was expected that engineers would tell their managers if they were becoming fatigued.

The Part 145 regulations do not explicitly require the AMO to monitor the working hours and the fatigue levels of their engineers. However, it does require that the planning of maintenance tasks take into account human performance limitations (145.A.47). As previously stated, Part 145.A.65(b) also requires that the AMO establishes procedures that take into account human performance to ensure good maintenance practices. Part 145.A.30(e) also requires that personnel are trained in human factors and human performance issues, and the Guidance Material for 145.A.30(e) states that this should include fatigue.

Maintenance personnel

Sup A, a 'senior supervisor' at the AMO, had worked for the organisation for 10 years. He was a 'B1' category LAE and had a type rating on the DHC-8-100. His responsibilities included being in charge of a team and deputising for management out of normal working hours. He had been the lead engineer responsible for SX-BIO's maintenance check.

Sup B, a 'supervisor' at the AMO, had worked for the organisation for almost 7 years. He was a 'B1' category LAE and had a type rating on the DHC-8-100. As a 'supervisor', he was occasionally expected to control aircraft hangar inputs and/or line shifts.

Tech A, a 'technician 2' at the AMO, had worked for the organisation for 10 years, with 7 years at Exeter. He was not an LAE and had no company approvals, but to become a 'technician 2' he would have had to demonstrate an ability to raise and complete paperwork (including 'defect job cards'), use technical manuals, possess reasonable problem-solving and troubleshooting ability, and be able to lead small groups on tasks. He had been promoted from 'fitter' grade to 'technician 2' grade in September 2008.

Analysis

The oil leaks from both engines, during the incident flight, were caused by damaged O-ring seals at the oil cooler fittings. The right engine oil leak originated from the outlet fitting of the right oil cooler, as a result of the O-ring seal on the outlet pipe being cut and losing a section during installation. The left engine oil leak originated from the inlet fitting of the left oil cooler, as a result of a cut in the main O-ring seal and a split in a smaller O-ring seal which should not have been fitted. The source of these two oil leaks was confirmed when the seals were replaced with new ones and the aircraft departed with no further reports of leaks.

Oil was already weeping slowly from both oil coolers when the aircraft arrived at East Midlands Airport and continued to do so during the ensuing week, manifesting itself in oil drops underneath the nacelle butt joints on either side of the oil coolers. However, the leaks appeared to have stopped or slowed just before the aircraft was cleared to depart. The leaks then worsened during the aircraft's taxi out, and continued to leak at a higher rate during the incident flight. The right engine lost about 5.5 litres of oil before it was shut down and the left engine lost about 3.5 litres of oil. The oil cooler fittings had not leaked at this rate during the aircraft's flight from Exeter to East Midlands and yet there was no evidence that the oil coolers had been disturbed while the aircraft was at East Midlands. It was therefore probable that either engine vibration, or the loads imposed during the landing at East Midlands, slightly shifted the position of the oil pipes such that the effect of the cuts in the O-ring seals was exacerbated. Shortly after landing, the engines were shut down and the oil pressure dropped, which would have caused any oil leak to slow. It is probable that during the 2-minute low power engine run, to check oil levels and as a final oil leak check before the aircraft departed East Midlands, the oil leak from the oil coolers would have been apparent had the lower forward cowlings been lowered and the oil coolers inspected. Two minutes was probably insufficient time for the oil to seep through and around the oil cooler and deposit itself on the main landing gear legs. However, once the aircraft started taxiing for departure, sufficient oil had made it through and a visible coating of oil on both landing gear legs was apparent. There were a number of contributory factors to this incident and these will be analysed in turn.

Repair of the main gear door pivot bracket bushings

The first contributing factor was the raising of a 'defect job card' to repair the left and right main gear door pivot bracket bushings with an attached RD which did not detail the access requirements for the repair. Had there been repair instructions which made it clear that the repair could be accomplished in situ, then the oil coolers would not have been removed and the incident to SX-BIO would not have occurred. The aircraft manufacturer stated that RDs were not meant to be detailed and it was for the maintenance organisation to write detailed instructions if necessary. The AMO did not have a process for creating repair instructions to accompany RDs, and they did not have a searchable database of common repair jobs that could be accessed by engineers. The planning department was involved when a new repair, that the AMO had not previously performed, needed to be carried out, but they were not necessarily involved when engineers obtained the RDs from the RD folder. The engineer who pulled the RD for the bushing repair knew that the repair could be done in situ but the engineer who picked up the repair task did not know this. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-014

It is recommended that Flybe Aviation Services revise their practices and procedures to ensure that their repair instructions are adequately detailed and specify the necessary access and removal requirements.

Removal and refit of the oil coolers was not identified as a safety critical task

When it was decided that both oil coolers needed to be removed from the aircraft, these tasks should have been identified as safety critical. If a person makes an error while disturbing the oil system on one engine, and then repeats the error on the other engine, the safety of flight of a twin-engined aircraft can be compromised. This was the case in the incident to the Boeing 737-400 (G-OBMM) that lost almost all its oil from both engines due to the rotor driver covers not being refitted following borescope inspections on both engines by the same person.

The AMO agreed that the oil cooler re-installation tasks should have been identified as safety critical tasks and should have been carried out by different people. The

AMO had a process in place for identifying safety critical tasks and had a safety critical task checklist for the DHC-8-100. However, not all staff were aware of this process and the oil cooler removal/refit task and other critical tasks were missing from the safety critical task checklist. To address these issues, the AMO provided a 'Safety Awareness Presentation' to all staff in May 2010, which, amongst other things, highlighted the importance of identifying safety critical tasks. They also launched a Poster Awareness Campaign, which included one poster stating '*Think Safety – Are YOU aware of Safety Critical Tasks on the aircraft you are working on?*' A reminder of the importance of identifying safety critical tasks will also feature in the company's engineer annual continuation training. The safety critical task checklist for the DHC-8-100 has also been amended to include the removal/refit of the oil cooler. A new process has also been developed for identifying safety critical tasks on third party work cards.

Incorrect re-installation of the oil coolers

Both oil coolers were re-installed incorrectly and this resulted in the O-ring seals being damaged. The contributory factors to the incorrect re-installation were:

1. The technician had not performed the task before.
2. The technician did not ask for or receive any assistance (the job was possible for one person but it would have been easier with two).
3. There was some time pressure to complete the task by the end of his shift.
4. The working space under the nacelle was small and poorly illuminated.
5. The oil pipes were not aligned vertically and would have been difficult to orientate to the vertical position as they were still attached to the flexible hoses at their forward ends (the AMM procedure did not call for them to be disconnected at their forward ends).
6. The oil cooler fitting had a sharp edge which could cut an o-ring if the oil pipe was forced into the fitting with improper alignment.

After the oil pipes were installed it should have been possible to wind the knurled nut fully down with hand pressure alone. However, the technician said that he used a pair of soft grips to tighten the nuts. The fact that the nut on the inlet fitting of the left oil cooler was found not to be fully wound down after the first series of engine ground runs (one thread was visible), indicates that the nut had probably been difficult to tighten. This should have been an indication to the technician that the pipe was not installed correctly. There was clear evidence on the nuts and the circlips inside the nuts that they had been over-tightened on more than one occasion, and this could have been due to a miss-understanding of the purpose of the nuts. They do not provide any clamping force on the O-ring seal.

In order to address a number of these issues the aircraft manufacturer has incorporated some amendments to the AMM (Revision Jan 15/2011). A note has been added to the oil cooler installation task, at the step for connecting the oil pipes ('*tube assemblies*') to the oil cooler fittings, stating:

> *'If required, loosen or remove the tube assemblies from the flexible oil hoses to provide the freedom of motion for the installation of the oil cooler.'*

Detaching these pipes at their forward ends (firewall station 107.81 in Figure 15) will make manoeuvring the pipes into the fittings easier and, therefore, should make it less likely that the seals will be damaged.

A further note has been added to the AMM (Revision Jan 15/2011) which states:

> *'If there is any difficulty in tightening the fittings, remove the pipes and check the O-ring for a defect.'*

The aircraft manufacturer had also intended to add a step stating:

> *'Make sure that the union nut on each tube assembly (5) and (6) bottoms out against the oil cooler fittings (20)'*

but this was missed out of the Jan 15/2011 revision. The manufacturer has stated that it will be added to the next revision.

It is considered that the aircraft manufacturer should also highlight the fact that correct installation of the engine oil coolers requires the knurled nuts, which secure the inlet and outlet pipes to the engine oil coolers, only to be hand-tightened. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-015

It is recommended that Bombardier Inc. amend the Aircraft Maintenance Manual for the DHC-8-100 series aircraft to emphasise the correct procedure for securing the inlet and outlet pipes to the engine oil coolers, including the method for tightening the associated knurled nuts.

Task breakdown on 'defect job cards'

The final step of the oil cooler installation procedure in the AMM called for an engine ground run and leak check of the coolers. This step was not written on the 'defect job card' and, therefore, at the end of the maintenance check when the engine ground runs were carried out, the engineer involved did not know that an inspection of the oil coolers was required. In the event, the leak from the left engine was obvious and the left oil cooler was visually inspected. However, had the leak not been so obvious then the left oil cooler may not have been inspected. It was not clear if the right oil cooler had been inspected. The omission of the leak check task from the job card was therefore a significant omission. The tasks on the job card (which was a 'defect job card' for the bushing repair) were written by a number of individuals, rather than all tasks being pre-planned. For example, the task after 'refit oil cooler' was 'carry out NDT inspection of bracket post rework' and the task after that was 'carry out bush repair in situ'. Both of these tasks were written by the different people performing the task, and were out of sequence. Tech A should have written down the 'oil cooler leak check' task after the 'refit oil cooler task', but he was only concerned with writing down his own specific tasks which only involved removing and installing the oil cooler. His supervising engineer did not notice the omission. Had a single person planned the entire job and written all the tasks required, then perhaps the leak check task would not have been missed.

The AMO has stated that it has since started a new programme of 'Documentation training' for its licensed engineers and unlicensed technicians and fitters. However, to ensure that this issue is fully addressed the following Safety Recommendation is made:

Safety Recommendation 2011-016

It is recommended that Flybe Aviation Services review their defect rectification processes to ensure that important safety checks, such as oil leak checks, are not omitted.

Engine oil leak checks at Exeter

Although there was no plan to specifically check the oil coolers for leaks, engine ground runs were required to be carried out to test systems and check for other oil leaks. During the first ground run which lasted about 5 minutes no oil leaks were observed. However, the lower forward cowlings were not removed so the oil cooler fittings were not inspected. During the second engine ground run, at higher power, the oil leak from the left engine became apparent after about 40 minutes when oil was noticed leaking down the left main landing gear leg. This leak was attributed to the nut on the left oil cooler inlet fitting not being fully wound down. This was rectified and a third engine ground run, at low power, was carried out and, reportedly, there were no more leaks. There were differing accounts as to whether the left lower forward cowling was removed after this engine run, and there were also differing accounts on what work, if any, was done on the right engine to check the right oil cooler. The engineer in charge of the engine ground runs (Sup A) had thought that all the oil cooler fittings on both sides had been tightened but no one could recall having tightened the right oil cooler fittings. One technician reported that there were traces of oil near the drain holes of the right engine, but no leaks. It was possible that these traces were due to a slight leak from the right oil cooler outlet fitting. The interviews of the relevant personnel were carried out two weeks after the events described, so poor memory recall of the events could explain the differing accounts.

In summary, it was not possible to establish if the right oil cooler fittings had been inspected.

The fact that the aircraft then completed an uneventful 49 minute flight to East Midlands, with no loss of oil pressure or significant oil quantity loss, indicated that the leaks which remained, if any, were very slow.

Maintenance work at East Midlands – oil leaks not rectified

The engineer at East Midlands (Sup B) who supervised the repaint provided the investigation with photographic evidence that there was slow oil seepage from both the left and right engine nacelles beneath the oil coolers (Figure 13). The need to start preparing the aircraft for paint stripping prevented Sup B from initially investigating these leaks and he was subsequently hampered by scaffolding surrounding the engine nacelles. The day when full access to the engines was finally provided coincided with the day that Sup A arrived to perform the duplicate control inspections. Sup A's dismissal of the reported oil seepage as being residual from the previous leaks at Exeter had the effect of alleviating Sup B's concerns about the seepage he had seen. Therefore, Sub B did not lower the forward cowlings and inspect the oil coolers. An additional factor may have been that the task of lowering the forward cowling requires at least two people, and preferably three. Opening the side cowls is a simple one handed task but this does not provide access to the oil coolers. On the morning before the aircraft departed East Midlands, Sup B requested that the pilots perform an engine run to check the oil levels and as a final leak check. No leaks were seen but, again, the lower forward cowlings were not lowered, so another opportunity to detect the source of the leaks was missed.

Had the engines been run for longer, then the leaks would probably have become apparent before the aircraft started to taxi. However, there is no minimum time period specified for operating the engine when conducting leak checks. According to the aircraft manufacturer once the oil is up to normal operating temperature the oil pressure will remain relatively constant. The engine was run for 2 minutes so it is probable that the oil was close to its operating temperature. However, that was not sufficient time for the oil leak to reach a point at which it became visible externally. Therefore, the only reliable method of detecting the leak would have been to open the lower forward cowling. It is important that the source of any oil leak, even if seemingly very minor, is correctly identified and rectified. Therefore the following Safety Recommendation is made:

Safety Recommendation 2011-017

It is recommended that Flybe Aviation Services remind all staff of the importance of investigating the source of every engine oil leak.

Working hours and fatigue risk management

In the 17-week period leading up to the end of SX-BIO's C-check, Sup A had worked an average of 57 hours/week which was 9 hours/week in excess of the Working Time Regulations (WTR). Furthermore, during the 10 days prior to SX-BIO's arrival at Exeter, Sup A had averaged 15.7 hours work per day, resulting in the 11-hour rest entitlement in the WTR being significantly curtailed. Sup A said that he did not consider himself fatigued during this period. However, he also said that during SX-BIO's leak checks he felt tired and had a lot on his mind, trying to get the aircraft ready for its scheduled painting slot, although it was not an unusual level of tiredness. There was no single factor in this serious incident that could be directly attributed to fatigue. However, the fact that an engineer had been tasked to work a 10 day period, with just one day off in the middle, averaging 15.7 hours per day, is a potential safety concern, particularly since it was not being monitored by the AMO. Insufficient sleep and rest can lead to fatigue and increase the probability of maintenance errors[7].

The AMO stated that following this incident they are now carefully monitoring working time to ensure that staff do not work more than 6 days on before a full day off, or 12 days on before 2 days off, and they are amending their staff handbook to reflect this. The revised draft staff handbook also includes a provision for 11 hours of uninterrupted rest per day, in accordance with the WTR. However, it includes a caveat that staff can be asked to start work again before their 11 hours of rest have elapsed and this extra time will be paid at the overtime rate. The WTR does not permit payment in lieu of the rest entitlement, although it does permit exceptions to the rest entitlement where '*activities involve the need for continuity of service*' or when a shift worker changes shifts. The AMO has no policy on the maximum hours that an engineer can work in any 24-hour period and relies on the fact that every engineer and manager has undergone human factors/performance training and that engineers will communicate to their managers if they are becoming at risk of fatigue. Some individuals who have undergone this training will probably be very responsible and will request time off when they feel that they need it. However, for some individuals this may not be the case, particularly when they have a strong desire to complete the job they have started and when there is a financial incentive to work longer hours. There is also evidence that people are not very

Footnote

[7] '*Human Factors Guide For Aviation Maintenance*', U.S. Department of Transportation, Federal Aviation Administration, (ISBN 0-16-042643-X).

good at detecting their reduction in performance levels as they become fatigued[8]. Therefore, the responsibility for managing fatigue should belong to the AMO and not just the individual.

The Canadian aviation regulator, Transport Canada, has published two Notices of Proposed Amendment (NPA) 2004-047 and 2004-049. These NPAs propose requirements for an AMO to manage fatigue-related risks through their Safety Management System. To support these proposed regulations, Transport Canada has published guidelines for a Fatigue Risk Management System (FRMS)[9]. This system provides a method for quantifying fatigue risk on a numerical scale (see Appendix 1) using knowledge of working hours and rest periods. It does not rely on knowledge of sleep times which is difficult information for an AMO to acquire.

The US Federal Aviation Administration (FAA) has set up a maintenance fatigue working group that is currently reviewing the need for regulatory limits on working hours for maintenance engineers. The European Aviation Safety Agency (EASA) have stated that their remit does not include the regulation of working hours; they have no legal power to mandate maximum hours limits or minimum rest periods for maintenance engineers. However, EASA stated that fatigue risk management is an issue which they will be looking at as part of their introduction of a regulatory requirement for a Safety Management System.

Part 145 states that the AMO needs to take human performance limitations into account when planning maintenance tasks and, although not specifically stated, this should include taking maintenance engineer fatigue into account. However, the advisory material (AMC) and guidance material (GM) to Part 145 do not explain how this should be accomplished. Transport Canada have provided some advice on how to accomplish this. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-018

It is recommended that the European Aviation Safety Agency expand the advisory or guidance material in Annex II (Part 145) of European Commission Regulation (EC) No. 2042/2003 on how approved maintenance organisations should manage and monitor the risk of maintenance engineer fatigue as part of their requirement to take human performance limitations into account.

Oversight of the AMO by the Civil Aviation Authority (CAA)

The CAA is required to conduct annual audits of the AMO to ensure that the AMO complies with the requirements of Part 145. At the time of writing, the last audit was carried out in June 2010. In order to ensure that the safety lessons from this investigation have been adopted by the AMO, the following Safety Recommendation is made:

Safety Recommendation 2011-019

It is recommended that the Civil Aviation Authority include the following areas in their Part 145 audits of Flybe Aviation Services: practices and procedures for detailing repair instructions, identification of safety critical tasks, planning of defect rectification and management of maintenance engineer fatigue.

Footnote

8 '*Aircrew Fatigue, Sleep Need and Circadian Rhythmicity*' by Melissa M. Mallis, Siobhan Banks and David F. Dinges, Chapter 13 in '*Human Factors in Aviation*' Second Edition, edited by Eduardo Salas and Dan Maurino (ISBN 978-0-12-374518-7).

9 These guidelines can be found at http://www.tc.gc.ca/eng/civilaviation/standards/sms-frms-menu-634.htm.

Operation of the aircraft

The crew diverted into Bristol whilst flying on one engine with an oil leak. While ATC were aware that the aircraft was flying on one engine, they were not aware that this remaining engine was also giving the crew cause for concern. Whilst in this case it did not influence the service provided by ATC, it is good practice for flight crew to keep ATC informed about any relevant developments in an emergency situation.

Conclusions

The oil leaks from both engines were caused by damaged O-ring seals at the oil cooler fittings. This damage probably occurred when both oil coolers were improperly re-installed by the same individual during base maintenance. The limited repair instructions had resulted in the unnecessary removal of the oil coolers and the re-installation of the coolers had not been identified as safety critical tasks. Following the oil cooler re-installation it was not documented that an oil leak check would be required, due to incomplete planning of the tasks on a 'defect job card'. The incorrect diagnosis that the slow oil seepage from both engine nacelles was residual oil from a previous leak led to the source of the leaks not being fully investigated at East Midlands.

Appendix 1

Fatigue Likelihood Scoring Matrix for Work Schedules

	Score 0	1	2	4	8
a) Total hours per 7 days	< 36 hours	36.1 – 43.9	44 – 47.9	48 – 54.9	55+
b) Maximum shift duration	< 8 hours	8.1 – 9.9	10 – 11.9	12 – 13.9	> 14
c) Minimum short break duration	> 16 hours	15.9 – 13	12.9 – 10	9.9 – 8	< 8
d) Maximum night work per 7 days	0 hours	0.1 – 8	8.1 – 16	16.1 – 24	> 24
e) Long break frequency	> 1 in 7 days	< 1 in 7 days	< 1 in 14 days	<1 in 21 days	< 1 in 28 days

Extract from Transport Canada's Fatigue Risk Management System, Policies and Procedures Development Guidelines (TP 14576E, April 2007)