ACCIDENT

Aircraft Type and Registration:	Raytheon 390, Premier I, G-OOMC	
No & Type of Engines:	2 Williams International FJ44-2A turbofan engines	
Year of Manufacture:	2005 (Serial no: RB-146)	
Date & Time (UTC):	12 March 2015 at 1148 hrs	
Location:	Blackpool Airport, Lancashire	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 2	Passengers - 2
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damaged beyond economic repair	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	34 years	
Commander's Flying Experience:	3,455 hours (of which 408 were on type) Last 90 days - 85 hours Last 28 days - 29 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft suffered a hydraulic system problem shortly before commencing an approach to Blackpool Airport. The hydraulic pressure fluctuated initially and there was subsequently a total hydraulic system failure, which was not recognised by the crew. The loss of hydraulic pressure resulted in the speedbrake/lift dump system and power brakes being unavailable, but the emergency braking system remained operational.

The emergency brakes, although available, were not applied during the landing and the aircraft overran the runway at about 80 kt and was extensively damaged. The occupants, who were uninjured, evacuated without assistance.

The investigation determined that, irrespective of the omission to apply the emergency brakes, the Landing Distance Available (LDA) at Blackpool was insufficient for the aircraft to land with a hydraulic failure. A fatigue crack in the port cap[1] of the left hydraulic pump had caused a hydraulic leak which eventually resulted in the total loss of the hydraulic system.

Footnote

[1] Port Cap – Aluminium alloy (7075-T73) cover plate fitted to the pump piston casing containing the suction and pressure ports.

History of the flight

The aircraft planned to fly from Avignon Airport, France to Blackpool Airport, with two flight crew and two passengers. The co-pilot performed the external checks; this included checking the fluid level in the hydraulic reservoir, as stated in the '*Pilot Checklist*'. The aircraft was refuelled to 3,000 lb and, after the passengers boarded, it departed for Blackpool. The commander was the pilot flying (PF).

The takeoff and cruise to Blackpool were uneventful. Prior to the descent the crew noted ATIS Information 'Lima', which stated: Runway 10, wind from 150° at 18 kt, visibility 9 km, FEW clouds at 2,000 ft aal, temperature 11°C, dew point 8°C, QNH 1021 hPa, runway damp over its whole length. The commander planned and briefed for the NDB approach to Runway 10, which was to be flown with the autopilot engaged.

Whilst descending through FL120, the left, followed by the right, hydraulic low pressure cautions illuminated. Upon checking the hydraulic pressure gauge, situated to the left of the commander's control column, the pressure was noted to be '*cycling up and down*', but for the majority of the time it indicated about 2,800 psi (in the green arc). During this time the hydraulic low pressure cautions went on and off irregularly, with the left caution being on more often than the right. The co-pilot then actioned the '*HYDRAULIC SYSTEM - HYDRAULIC PUMP FAILURE'* checklist. It stated that if the hydraulic pressure was a minimum of 2,800 psi, the flight could be continued[2].

Just before the aircraft reached the Blackpool NDB, the commander commented "IT'S DROPPING", but he could not recall what he was referring to. This was followed by the ROLL FAIL and SPEED BRK [BRAKE] FAIL caution messages illuminating. The co-pilot then actioned the applicable checklists. These stated that the Landing Distances Required (LDR) would increase by approximately 65% and 21%, respectively. As the ROLL FAIL LDR increase was greater than that of the SPEED BRK FAIL, the crew used an LDR increase of 65% which the co-pilot equated to 5,950 ft. Runway 10 at Blackpool has an LDA of 6,131 ft, therefore they elected to continue to Blackpool.

The ROLL FAIL checklist stated that a '*FLAPS UP*' landing was required. The co-pilot then calculated the V_{REF}[3] of 132 kt, including a 20 kt increment, as stipulated by the '*FLAPS UP, 10, OR 20 APPROACH AND LANDING*' checklist. The commander then continued with the approach.

At about 4 nm on final approach the co-pilot lowered the landing gear, in response to the commander's request. About 8 seconds later the commander said "JUST LOST IT ALL"; referring to the general state of the aircraft. This was followed almost immediately by the landing gear unsafe aural warning, as the main landing gear was not indicating down and locked. Whilst descending through 1,000 ft, at just over 3 nm from the threshold, the commander asked the co-pilot to action the '*ALTERNATE GEAR EXTENSION'* checklist.

Footnote

[2] See *Operational procedures/checklists* below for the complete checklist procedure.
[3] V_{REF} is the speed to be flown on the final approach prior to landing.

The commander then discontinued the approach by selecting ALT HOLD, increased engine thrust and selected a 500 ft/min rate of climb on the autopilot. However, a few seconds later, before the co-pilot could action the checklist, the main gear indicated down and locked. The commander disconnected the autopilot and continued the approach. The crew did not consider reviewing the '*HYDRAULIC SYSTEM - HYDRAULIC PUMP FAILURE'* checklist as they had not recognised the symptoms of loss of hydraulic pressure.

When ATC issued the aircraft its landing clearance the wind was from 140° at 17 kt. This equated to a headwind component of about 10 kt and a crosswind of about 12 kt.

As the aircraft descended through 500 ft (the Minimum Descent Altitude (MDA) for the approach) at 1.5 nm from the threshold, the commander instructed the co-pilot to advise ATC that they had a hydraulic problem and to request the RFFS to be put on standby. There was a slight delay in transmitting this request, due to another aircraft on frequency, but the request was acknowledged by ATC.

The aircraft touched down about 1,500 ft from the start of the paved surface at an airspeed of 132 kt and a groundspeed of 124 kt. When the commander applied the toe (power) brakes he felt no significant retardation. During the landing roll no attempt was made to apply the emergency brakes, as required in the event of a power brake failure. The co-pilot asked if he should try to operate the lift dump, but it failed to function, due to the lack of hydraulic pressure. At some point, while the aircraft was on the runway, the co-pilot transmitted a MAYDAY call to ATC. When an overrun appeared likely, the commander shut down the engines. The aircraft subsequently overran the end of the runway at a groundspeed of about 80 kt. The commander later commented that he was in a "state of panic" during the landing roll and was unsure whether or not he had applied the emergency brake.

As the aircraft left the paved surface the commander steered the aircraft slightly right to avoid a shallow downslope to the left of runway's extended centreline. The aircraft continued across the rough, uneven ground, during which the nose gear collapsed and the wing to fuselage attachments were severely damaged (Figure 1). Once it had come to a stop, he shut down the remaining aircraft systems. The passengers and crew, who were uninjured, vacated the aircraft via the entry/exit door and moved upwind to a safe distance. The RRFS arrived shortly thereafter.

Figure 1
G-OOMC post-accident

Recorded data

The aircraft was equipped with a 30-minute duration CVR which was removed from the aircraft and successfully replayed by the AAIB. The recording commenced as the aircraft started its descent from FL250 at 1118 hrs, prior to the hydraulic system fault indication, and ended almost immediately as the aircraft overran the runway, at 1148 hrs. (The CVR is stopped automatically if an acceleration of 6g or greater is sensed by an inertia switch).

Radar information was available from three radar heads. The radar at St Annes, located less than 1 nm to the south-east of Blackpool Airport, provided a complete record of the approach and landing, with Mode S groundspeed and airspeed data available.

The salient recorded data for the approach and landing are presented in Figure 2.

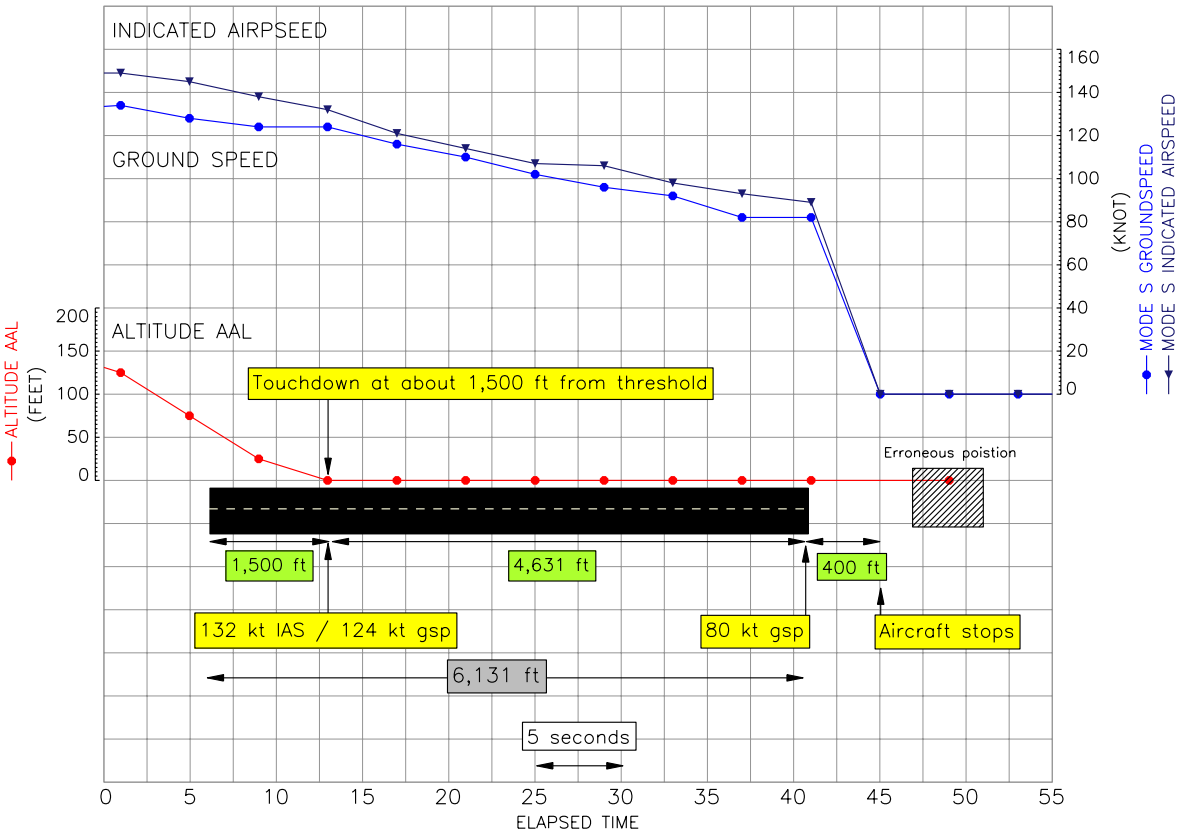

Figure 2

Salient final approach and landing data

Aircraft damage

Marks on the runway showed that the main landing gear (MLG) inboard doors remained extended throughout the landing, suffering edge abrasion damage as a result. The aircraft travelled approximately 123 m beyond the runway paved surface, during which the nose landing gear collapsed and the nosewheel detached.

Prior to coming to a halt, the left wingtip was driven into the ground, deflecting the aircraft from its path. The four wing-to-fuselage mounting forgings were damaged and, in three cases, had fractured. The wing was displaced to the right, indicated by extensive root fairing and inboard flap track damage.

Subsequent examination found evidence of a hydraulic fluid leak within the left engine nacelle, in the vicinity of the hydraulic pump. Hydraulic fluid had congealed and accumulated on the engine bleed air pipe, on surrounding pipes and surfaces, and at the bottom of the lower panel. The engine casing and components attached to the lower portion of the engine were covered in a thin film of hydraulic fluid (Figure 3). The hydraulic reservoir was empty, but a small amount of residual fluid was present in the filter housings and the bottom of the assembly. The filter blockage indicators had not 'popped' and the fluid and filters were found in a clean and uncontaminated condition.

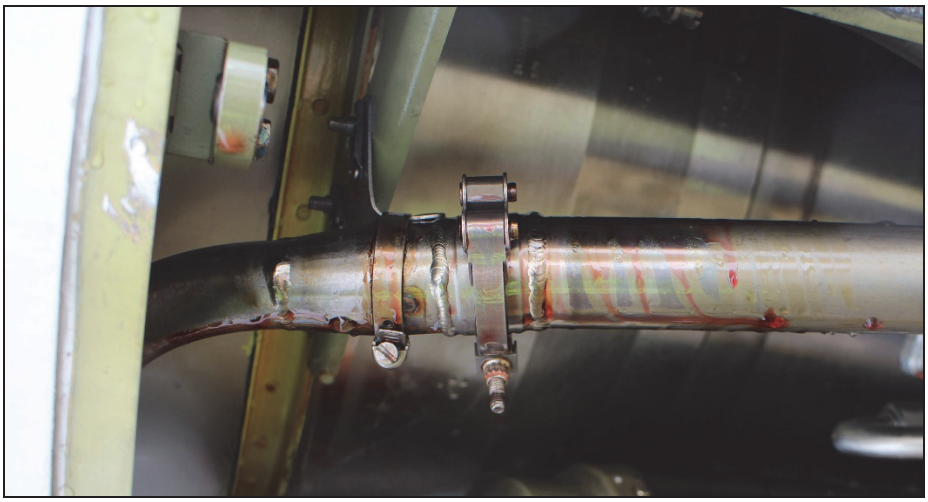

Figure 3

Hydraulic system leak spray dispersion within the left engine nacelle

Operational procedures/checklists

Premier I/IA Airplane flight Manual (AFM)

Section 3, *Emergency Procedures*, states:

> *'…Bold type indicates steps of a procedure requiring immediate action by the flight crew.'*

Premier I/IA Pilot Checklist

Page ii states:

> *'This document is an abbreviation of the checklists and procedures contained in…Section 3A (ABNORMAL PROCEDURES)…of the FAA-approved Airplane Flight Manual (AFM)…Since this is an Abbreviated Checklist, the intent of all applicable warnings has been included, most explanatory items, notes and cautions have been omitted for brevity. Consequently, users of this Abbreviated Checklist must be familiar with and operate the airplane in accordance with the official applicable AFM.'*

Page E-4 states:

> *'Certain component failures are capable of compromising multiple airplane systems. It is possible that the root failure may not be annunciated or otherwise apparent to the pilot. In these cases the pilot must respond directly to the annunciated, or otherwise identified, system failures and consult the AFM/Checklist for each corresponding individual abnormal or emergency procedure.*

Where different procedures result in conflicting aircraft configurations for safe recovery to landing, the most restrictive is to be used. ***Where different procedures identify landing distance factors to increase the required landing distance, the factors are additive*** [AAIB bold] *and are always applied to the applicable normal landing distance.'*

Page A-28 states:

'HYDRAULIC SYSTEM

HYDRAULIC PUMP FAILURE
(L OR R HYD PRESS LO ANNUNCIATOR ILLUMINATED)

1. Hydraulic Pressure ..... VERIFY 2800 PSI MINIMUM

2. Firewall Shutoff Valve Annunciators..... VERIFY ASSOCIATE WHITE L OR R H/V OPEN INDICATION

3. Flight ..... CONTINUE

…

If hydraulic pressure is below 2800 psi:[4]

9. Flaps..... UP

…

23.Landing Gear .....DN, USE ALTERNATE GEAR EXTENSION PROCEDURE

24. Flaps ..... VERIFY UP

25. Autopilot .....DISENGAGE

26. Airspeed..... VREF + 20 KIAS

27. Yaw Damp.....OFF

28. Emergency Brakes (After Touchdown) .....APPLY GRADUALLY

NOTE

Landing distance will increase approximately 133%.

Footnote

[4] The Hydraulic Pump Failure checklist, in the AFM, contains the following below this condition:
'NOTE:
The following hydraulically powered systems may not operate normally or may be inoperative: Landing Gear, Speed Brakes, Roll Spoilers, Lift Dump and Power Brakes'

Page A-24 states:

'ROLL SPOILER FAILURE
(ROLL FAIL ANNUNCIATOR ILLUMINATED)

1. Flaps ..... UP

2. Airspeed (Above 15,000 ft.).....0.64 MACH (MAX)

3. Airspeed (Below 15,000 ft.) .....NO RESTRICTION

4. Speedbrakes .....WILL NOT EXTEND

5. Lift Dump ..... INBD PANELS ONLY OPERABLE

6. Land .....FLAPS UP

7. See FLAPS UP, 10, OR 20 APPROACH AND LANDING Procedure; Tab 3, page A-8.

NOTE

Landing distance will increase approximately 65%.'

SPEEDBRAKE FAILURE
(SPEED BRK FAIL ANNUNCIATOR ILLUMINATED)

1. Airspeed. ..... NO LIMITS

2. Altitude ..... NO LIMITS

3. Speedbrakes .....WILL NOT EXTEND

4. Lift Dump .....INBD PANELS ONLY

NOTE

With SPEED BRK FAIL annunciator illuminated, avoid excessive control wheel movement with respect to roll control. Landing distance will increase approximately 21%.'

Page E-22 states:

'POWER BRAKE FAILURE

1. Emergency Brakes ..... APPLY GRADUALLY

NOTE

Landing distance will increase approximately 48%.'

Aircraft performance

Aircraft details

The following weights were established from the aircraft's flight documentation:

Dry operating mass = 8,877 lb
ZFW = 9,450 lb
Fuel remaining at Blackpool ~1,000 lb
Landing weight = 10,450 lb

LDR calculations

The aircraft manufacturer calculated that, for the aforementioned landing weight and reported atmospheric conditions, the LDR on a dry runway[5], assuming no aircraft system failures, is 2,807 ft.

The co-pilot had calculated the LDR, with no failures, to be 3,000 ft. He then applied an LDR increment of 65%. This should have equated to 4,950 ft; however, he had calculated a figure of 5,950 ft. He could not recall how he had arrived at this.

The *Hydraulic Pump Failure* checklist states that the landing distance is increased by 133%. Applying this factor, the manufacturer calculated that the LDR for the conditions and aircraft weight at the time of the accident should have been 2,807 ft + 3,733 ft = 6,540 ft.

Airport information

Runway 10 at Blackpool Airport has a magnetic bearing of 097° and an LDA of 6,131 ft.

The nominated alternate airport for the flight was Liverpool Airport, 27 nm south-south-east, with a LDA of 6,893 ft on Runway 09. Other possible alternate airports in the locality were Warton Aerodrome, 6 nm east-south-east, with an LDA of 7,736 ft on Runway 07 and Manchester Airport, 37 nm south-east, with a LDA of 8,488 ft on Runway 05L.

Decision making

An operator's Operation Manual Part A (OMA) provides generic information and standard operating procedures (SOPs) applicable to all the aircraft types flown by an operator. Operation Manual Part B (OMB) provides information and SOPs specific to an aircraft type.

The operator's OMB for the Premier I/IA did not include any guidance for its pilots on decision making. However, the operator's OMBs for their other aircraft types did include such information. This guidance included a description of the five steps to take during the decision making process. The last step is titled '*Review*'. In this section it states:

Footnote

[5] A runway is considered damp when the surface is not dry, but when the water does not give it a shiny appearance. There are no performance corrections required for a damp runway, therefore dry performance figures can be used.

> *'…A rushed decision without due consideration of situation and options is almost always THE WRONG DECISION...'*

Decision making is covered in pilots' initial and recurrent crew resource management (CRM) training syllabus and is also assessed during a pilot's six-monthly recurrent checks (Licence Proficiency Check and Operator's Proficiency Checks).

The commander was a CRM instructor and was appointed a line trainer in January 2015. The co-pilot had received decision making training in December 2014, during his initial CRM training.

Aircraft and systems description

Landing gear

The tricycle landing gear consists of oleo struts which are operated hydraulically and can be lowered under gravity in an emergency.

Wheel brakes

The mainwheels are fitted with anti-lock multiple disc hydraulic brakes, operated by toe pedals. The parking and emergency braking system operates the brakes using hydraulic pressure supplied by an accumulator. The emergency accumulator is pre-charged to 800 psi and pressurised via a non-return valve to 3,000 psi when hydraulic system pressure builds after engine start. This pressure remains until the emergency or parking brakes are used. The emergency brakes are activated using the parking brake lever, and provide reduced retardation without anti-skid protection. The emergency accumulator is of sufficient volume to provide approximately 20 brake applications.

Flying controls

The flying control system uses conventional pushrods, cables and pulleys to operate the ailerons, rudder and elevators. Three hydraulically actuated spoiler panels are mounted on each wing and aid lateral control, act as speedbrakes and provide lift dumping on the ground. The wing flaps are electrically operated.

Hydraulic system

There is a 1.6 US gallon[6] (6.04 litres) reservoir and multiple filter assembly, known as the Hydraulic Package, located in the rear equipment bay. The reservoir is a non-separated type (air over fluid) and is pressurised by engine bleed air to about 20 psi. There is a sight glass fitted to the reservoir, but for pre-flight checks there is a test switch and light in the right rear equipment bay. If the light illuminates when the button is pressed, it indicates that the reservoir contains less than 1.2 gallons and should be replenished.

Footnote

[6] Gallons used throughout this report are US gallons which equate to 3.78 litres or 6.66 imperial pints.

The system is pressurised by two pumps, producing 3,000 ± 150 psi, driven by the left and right engine accessory gearboxes. The pump output pressure lines are fitted with pulse dampers to smooth out pump fluctuations and pressurised fluid is delivered to the system via the Hydraulic Package. Hydraulic system pressure is displayed on an analogue gauge on the left side of the instrument panel in the cockpit. The system is also fitted with left and right pump output monitoring pressure switches which illuminate either a L or R HYD PRES LO caption on the cockpit annunciator panel when the corresponding hydraulic pump output pressure drops below 2,400 ± 150 psi.

Engineering findings

The left hydraulic pump and associated pipework were tested at the system working pressure. During the test a constant leak was visible in the vicinity of the pressure compensator[7] assembly chamber plug on the port cap of the pump.

Further testing was performed by the manufacturer in the US, under the supervision of the NTSB Accredited Representative. Figure 4 shows the pump under test leaking hydraulic fluid.

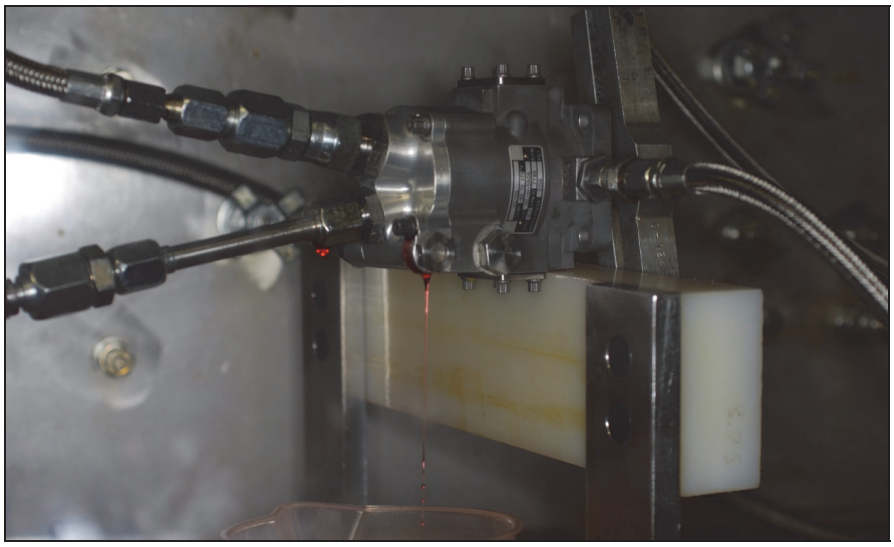

Figure 4

Hydraulic pump leaking under high pressure (3,000 psi) test
(Photo courtesy of the NTSB)

The leak was emanating from a crack surrounding a threaded hole for the compensator plug fitting in the port cap. A steady stream of hydraulic fluid leaked from the crack and 50 ml was collected over a two-minute period. The crack was enhanced by dye penetrant and is shown in Figure 5.

Footnote

[7] The compensator is a spring loaded valve device within the pump to limit pump outlet pressure to a predetermined level and adjust pump outlet flow to the level needed to maintain the set pressure.

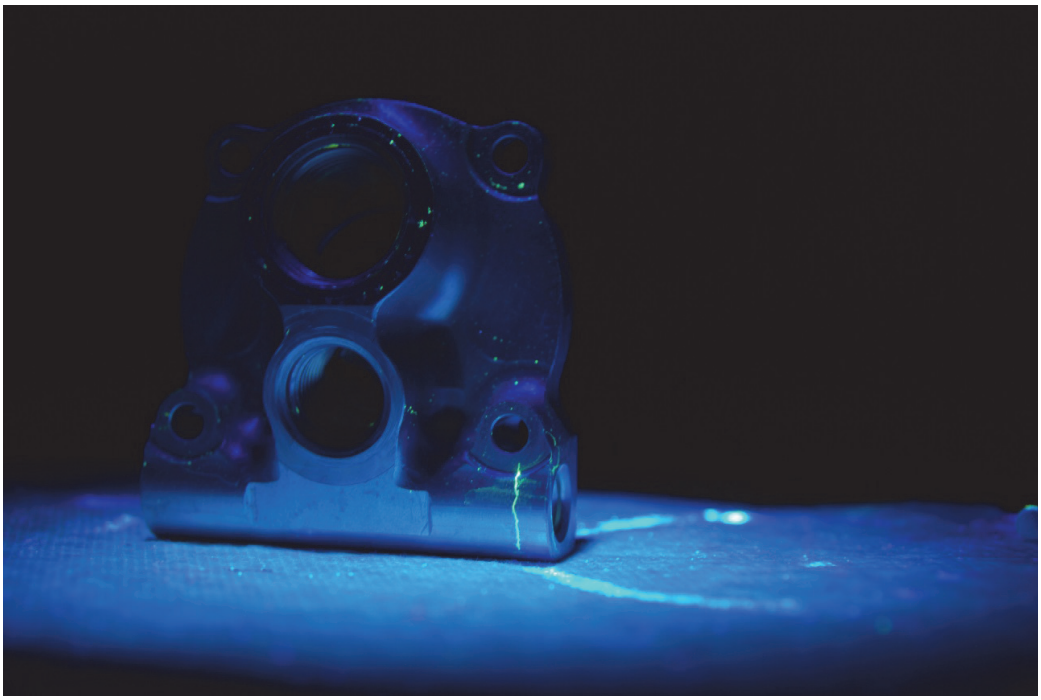

Figure 5

Crack in the port cap shown with dye penetrant under UV light
(Photo courtesy of the NTSB)

The left hydraulic pump, serial number K0365, was manufactured in May 2005 and fitted new to G-OOMC at aircraft build, in 2005. At the time of the accident it had accumulated 2,114 flying hours. On disassembly, with the exception of the crack in the port cap, the pump was found to be in good condition.

Detailed laboratory testing was carried out on the port cap structure and fracture. This showed that the port cap was of the correct material specification. Examination of the fracture area revealed multiple-origin fatigue cracking from a thread root inside the bore which had propagated to the outer surface of the port cap. The thread root, from which the crack originated, was mid-way down the bore and its trough radius was found to be 0.003 inch. There was also evidence of pitting on the thread root and adjacent surfaces.

Analysis

Conduct of the flight

Crew response

Prior to departure the co-pilot verified during the aircraft external checks that there was sufficient hydraulic fluid in the reservoir. During the descent to Blackpool the hydraulic pressure indication was observed to be fluctuating. The crew initially responded by actioning the hydraulic pump failure checklist. As the hydraulic pressure was indicating about 2,800 psi for the majority of the time, the crew elected to continue the flight, in accordance with Item 3 of the checklist.

Shortly thereafter the roll spoiler and speedbrake failure captions illuminated. The co-pilot actioned the relevant checklists, which required increments to be added to the LDR. He incorrectly calculated the LDR to be 5,950 ft, but could not recall exactly how he had arrived at this figure. Based on this figure, Blackpool appeared suitable to the crew in this situation.

The crew did not return to the hydraulic pump failure checklist because they were reportedly unaware that there had been a hydraulic system failure. The checklist items for hydraulic pressure below 2,800 psi contained the significant information that the emergency brakes would have to be applied after touchdown and the landing distance would have to be increased by approximately 133%. By not completing the hydraulic pump failure checklist, the crew were unaware of this increment and the need to use emergency brakes. If the correct increment of 133% had been applied to the crew's calculated LDR of 3,000 ft, this would have given an LDR of 6,990 ft and it would have been evident that the 6,131 ft runway at Blackpool was unsuitable.

After touchdown, the commander applied the toe brakes, but found them to be ineffective. He directed the co-pilot to deploy the lift dump system but this was inoperative due to the hydraulic failure. The emergency brake was not applied and the retardation of the aircraft was minimal, causing it to depart the runway at about 80 kt.

Crew decision making

The crew's decision to continue the flight to Blackpool was appropriate for the hydraulic indications with which they were initially presented.

Despite various indications of a serious hydraulic system malfunction as the flight progressed, the crew did not appear to fully recognise the situation and so did not return to the hydraulic pump failure checklist. Consequently, they constructed their mental model without the vital additional information contained in the rest of hydraulic pump failure checklist. This caused them to conclude, incorrectly, that Blackpool had sufficient LDA for the aircraft's condition, and they were unaware that application of the emergency brake was necessary on landing.

It is likely that, had the crew taken more time to thoroughly review the situation, they would have developed a more complete understanding of the implications of the hydraulic failure and reacted accordingly.

Engineering aspects

Loss of hydraulic pressure

The crew carried out the reservoir level check procedure in accordance with the checklist prior to the flight and found it to be correct, as indicated by the test light not illuminating. This meant that there was at least 1.2 gals (4.5 litres) of fluid within the reservoir. Evidence of hydraulic leakage was only visible within the left engine nacelle.

The crew reported fluctuating hydraulic pressure in the latter stages of the flight and intermittent L HYD PRESS LO then R HYD PRESS LO captions on the annunciator panel, the left more than the right. After they had selected the landing gear down the hydraulic pressure dropped completely. The pressure fluctuations suggest that the left pump in particular was struggling to maintain pressure due to cavitation and leakage. As the fluid in the system was gradually depleting, later shown by the fluid accumulation in the engine bay, the right hydraulic pump was also suffering cavitation, as indicated by the R HYD PRESS LO indications. When the MLG was lowered the fluid taken in by the retraction jacks, which is estimated to be at least 4 pints (2.27 litres), further reduced the volume of hydraulic fluid. This resulted in more severe pump cavitation such that the pumps were not able to produce or maintain useable hydraulic pressure. It is likely that the fluid quantity became unviable as the landing gear reached the full extent of its travel, manifesting itself in a delay in getting the gear down and locked indication and the inboard doors not being able to complete their sequence and remaining open.

The parking/emergency brake was not affected by the hydraulic system loss. Had a demand been made on the emergency brakes system during the landing it would have worked normally, albeit without anti-skid and a reduced retardation capability.

Pump port cap failure

The multiple-origin cracking found in the port cap by the laboratory testing had propagated from a thread root in the bore to the outer surface of the cap. It is not known how long the crack had been propagating for, but it is likely that the crack broke the surface of the cap relatively recently, allowing the leakage of fluid outwards under pressure from within the pump. The excessive pitting at the root of the thread is likely to have initiated the fatigue crack, with the thread root radius as a contributory factor. The load imparted into the thread by the compensator plug fitting places the thread under a constant tensile stress when the pump is operating, leading to the eventual fatigue failure.

AAIB observation

During the examination of the aircraft at the accident site items of personal property, and other items, were found beneath the cockpit flooring, having fallen through the rudder pedal recesses. The items found included a mobile phone, glasses case and a plastic mineral water bottle. These items had the potential to cause a rudder or steering control restriction.

Safety actions

A review identified two other instances of port cap failures due to a crack around the compensator plug. The records also show that the failed pump on G-OOMC (serial number K0365) was manufactured within a few weeks of the other two pumps, one of which was the next serial number (K0366).

The pump manufacturer is taking action to replace the port caps from the batch of port caps processed by the outside non-destructive testing (NDT) vendor which have excessive pitting. Service Bulletin 66179-29-486 is being issued to replace port caps with serial numbers 0057 to 0099 with port caps manufactured under the current process which do not have excessive pitting.

The AAIB highlighted the issue of loose articles beneath the cockpit floor to the aircraft manufacturer's Continued Operational Safety Department. Although they had not received any previous reports, the manufacturer has taken the safety action of adding the issue to the fleet safety monitoring list.

Since this accident, the operator of G-OOMC has removed the information on decision making from Operations Manual Part B and incorporated it into Part A of the Operations Manual.