INCIDENT

Aircraft Type and Registration:	Bombardier CRJ100ER, F-GRJO	
No & Type of Engines:	2 General Electric CF34-3A1 turbofan engines	
Year of Manufacture:	1999	
Date & Time (UTC):	17 January 2007 at 2134 hrs	
Location:	Runway 20, Southampton Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 3	Passengers - 33
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None, precautionary removal of nose landing gear for inspection	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	47 years	
Commander's Flying Experience:	7,500 hours (of which 5,000 were on type) Last 90 days - 150 hours Last 28 days - 40 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft suffered a failure of the No 3 hydraulic system when lowering the landing gear on approach. The commander took what he believed to be the necessary actions prior to landing but without apparent reference to the QRH. As a result the aircraft landed with one of the No 3 hydraulic system pumps still running and the nosewheel steering ON, contrary to instructions in the Quick Reference Handbook (QRH). This resulted in an uncommanded steering input to the right after touchdown and the aircraft departed the runway.

History of the flight

The crew reported for duty at 1625 hrs at Katowice in Poland and had completed an uneventful flight to Paris Charles de Gaulle Airport. At 2039 hrs they departed Paris for Southampton, taking off at 2049 hrs with the co-pilot acting as handling pilot. The takeoff and cruise went without incident and the aircraft was established on the ILS for Runway 20 at Southampton with the autopilot engaged. At a range of about 6.5 nm, with the aircraft descending through 2,000 feet QNH and with 20º of flap set, the co-pilot called for the landing gear to be lowered. The commander selected the gear DOWN and the landing gear lowered with the three green gear indicator lights illuminating.

The pilots reported that almost immediately a 'HYD 3 LO PRESS' caution message appeared on the Engine

Indication Control and Alerting System (EICAS) display 1. The commander selected the hydraulic synoptic page on EICAS display 2 which indicated a loss of hydraulic fluid from No 3 hydraulic system. The commander later stated that he consulted the Quick Reference Handbook (QRH) and identified the appropriate drill (Figure 1). He stated that, as the EICAS indicated there was no fluid remaining in No 3 hydraulic system, he did not switch on the hydraulic 3B pump and was unsure whether he switched off the hydraulic 3A pump, but remembered turning off the nosewheel steering.

The commander lowered the flaps to 30º and later to 45º, the normal landing configuration, and the co-pilot set the approach speed of 137 kt. They then completed the landing checks.

The co-pilot later stated that he disengaged the autopilot at about 500 ft and, late in the approach, positioned the aircraft slightly below the glideslope in an effort to touch down early. The pilots stated the aircraft appeared to touch down normally, on the centreline and in the area of the runway touchdown markings. The co-pilot applied maximum reverse thrust and started to apply the brakes. He stated there appeared to be no asymmetry in the braking or the reverse thrust and the aircraft began to decelerate. The commander recalled that the ground spoilers also deployed normally.

The co-pilot steadily applied more pressure on the brake pedals but felt that the brakes were less effective than normal. He stated that, as the aircraft decelerated below about 70 kt, the speed at which commanders normally take control, it began to veer to the right. The co-pilot released pressure on the right brake and applied full left brake and full left rudder. The commander stated that he also applied full left brake and full left rudder, as well as trying to steer using the tiller. Despite this the aircraft continued to veer to the right, crossing the mouth of Holding Point B1 (Figure 2 - aerial photograph) and departing the runway onto the grass. The pilots estimated the speed to be about 20 kts on leaving the runway, at which point the co-pilot cancelled the reverse thrust, and the aircraft came to a halt.

The commander called the cabin crew member, who confirmed there had been no injuries amongst the passengers. ATC notified the airport fire service; the pilots started the APU and kept the engines running until the fire services arrived and requested they shut down the main engines. The passengers were then disembarked, using the aircraft steps, and were transferred to the terminal by bus.

The crew later stated that, for landing performance, they considered the normal landing distance required for their landing weight of 19,740 kg was no more than about 1,000 m. They stated that they had applied the landing distance correction of 1.5 specified in the QRH to this figure, giving a 'distance required' lower than the landing distance available on Runway 20 "of about 1,800 m". They therefore continued the approach.

Weather

The following weather conditions were recorded at 2120 hrs, 14 minutes prior to the aircraft's landing:

> Wind 210º at 4 kt, visibility in excess of 10 km, FEW cloud at 3,500 feet, temperature 8ºC, dew point 5ºC and QNH 1006.

The weather conditions at 2150 hrs, 16 minutes after the aircraft landed, were:

> Wind 210º at 4 kt, visibility in excess of 10 km, temperature 8º, dew point 5ºC and QNH 1006.

CRJ SERIES Regional Jet	ABNORM 10-5
	TR RJ/98, Apr 05/07

HYD 3 LO PRESS Msg

NOTE

If during the accomplishment of a hydraulic system low pressure procedure, a second system also fails, disregard both single system failures and proceed directly to the applicable double system failure procedure.

TO PREVENT FLIGHT CONTROL UNDAMPED VIBRATION:	
ALTITUDE LIMITATION	**AIRSPEED LIMITATION**
Do not exceed 31,000 feet	Do not exceed 250 KIAS or 0.55 Mach whichever is lower

(1) HYDRAULIC 3B pump .... ON

(2) Hydraulic pressure and fluid quantity .... MONITOR

System 3 quantity readout is less than 5%, or pressure is less than 1800 psi, or pressure is rapidly decreasing:

Yes

(3) HYDRAULIC 3A and 3B pumps .... OFF

(4) HYDRAULIC page and FLIGHT CONTROLS pages .... REVIEW AFFECTED SYSTEMS

HYDRAULIC SYNOPTIC	
COMPONENT	**SYSTEM 3**
Inboard Brakes (when system 3 accumulator pressure is depleted)	INOPERATIVE
Normal Landing Gear (extension and retraction)	INOPERATIVE
Nosewheel Steering	INOPERATIVE (may result in nose wheel shimmy)
Parking Brake	INOPERATIVE

(5) Land at the nearest suitable airport.

Prior to landing:

(6) N/W STRG .... OFF

(7) LDG GEAR lever .... DN

(8) LANDING GEAR MANUAL RELEASE .... PULL TO FULL EXTENSION

QUICK REFERENCE HANDBOOK CSP A-022	HYDRAULIC SYSTEM MALFUNCTIONS

Figure 1

QRH drill

Figure 2
Holding point B1, Runway 20

Inspection of incident site

The aircraft had stopped in a grassed area 16 m to the right of Runway 20, displaced a distance of 34 m from the runway centreline. From the tyre marks it was determined that both sets of mainwheels, and the nosewheels, had left the runway at the junction with Taxiway Bravo and then entered the grassed area, with the nosewheels having travelling 61 m on the grass.

Figure 2 is an aerial photograph of the location in which the tyre marks are visible. In Figure 3 it can be seen that the marks from the nosewheels are closer to the marks of the right mainwheels than to the marks of the left mainwheels, indicating that the aircraft was 'skidding' slightly to the left. The marks from both the inboard and outboard left mainwheels were consistent with all four brakes functioning normally, and with differential braking to the left. There were heavy scrubbing marks from the two nosewheel tyres, and there was a distinct narrow line outboard of the mark, left by the tread of the left nosewheel tyre, see Figure 4. This line was consistent with the tyre chine (a circular ridge on the outboard side of the tyre designed to deflect water on wet runways) touching the runway.

The torque link, which turns the steerable portion of the nose gear and which is routinely disconnected during towing operations, was found to be connected.

In summary, the evidence from the tyres and ground marks was consistent with the aircraft veering to the right after landing, under the influence of 'nose right' steering of the nose gear, with heavy differential braking of the left mainwheels causing 'scrubbing' of the nosewheel tyres to the right.

Runway state

The runway state at 2120 hrs was described as dry along the full length. The runway surface

Figure 3

Tyre marks, F-GRJO

friction was assessed shortly after the incident. The measured surface friction values were higher than the Maintenance Planning Level[1], and were close to, and in some cases exceeded, the Design Objective Level. It was concluded that runway surface friction was not a factor in this incident.

Flight Recorders

The two solid-state flight recorders were replayed at the AAIB; both had retained a recording of the incident landing and the events immediately preceding it. Whilst recorded radio communications were in English, all conversation between the crew was conducted in French and the Bureau d'Enquetes et d'Analyses (French accident investigation authority) provided an English translation. The co-pilot was the handling pilot for the approach and landing. The commander assisted the co-pilot during the rollout.

Figure 4

Tyre marks - nosewheels

Footnote

1 As defined in CAA publication CAP 683.

The FDR recorded a number of parameters relevant to this investigation, including the brake 'pressure available' to the inboard and outboard wheel braking systems, together with discrete (ON or OFF) parameters for the presence of low hydraulic pressure on each of the aircraft's three hydraulic systems. Individual wheel brake pressures and data from the nosewheel steering system were not recorded. Pertinent parameters recorded during the approach and landing are shown in Figure 5.

The flight recorders showed that the initial approach was uneventful. At 2,000 ft amsl, with the autopilot engaged and Flap 20 selected, the aircraft intercepted the localiser from the left. It then captured and descended on the glideslope. Shortly after, at 1,830 ft amsl (1,786 ft aal), the landing gear was lowered and the inboard brake pressure available began to reduce from 3,000 psi. Outboard brake pressure available remained close to 3,000 psi. Flap 30 was selected.

Fifteen seconds elapsed before the landing gear indicated that it was locked down. Inboard brake pressure available had reduced to 2,200 psi by that time before beginning to recover slowly towards 2,300 psi. One second after the landing gear indicated 'down and locked' a No 3 hydraulic system low pressure warning was recorded on the FDR, also audible as a warning chime on the CVR. The crew selected the hydraulic page on the EICAS display just before the aircraft was cleared to land and two minutes before the aircraft touched down. The co-pilot commented that they would not have the inboard brakes and that the runway was short. The commander responded that the aircraft was not heavy and then advised the cabin attendant that they would be landing in one minute. The co-pilot further commented that they ought to analyse the situation and asked the commander if he wanted to continue the approach. The commander stated that they would continue.

Flap 45 was selected at 900 ft aal and the crew carried out the 'before landing' checklist. The co-pilot advised the commander that they would have reduced braking and no steering, and asked him if it was not better to divert to London. The commander restated to the co-pilot that they would continue with the landing and request a tow if it became necessary. The autopilot was disconnected at 325 ft aal. The aircraft touched down at 132 kt just to the left of the runway centreline[2] and the ground spoilers deployed symmetrically. The aircraft yawed 1.5° to the left and began to slow; the inner brake pressure available again began to reduce. As the aircraft was derotated and the 'weight-on-wheels' switch for the nose gear was made, the aircraft yawed to the right by 3°. Progressively increasing left rudder was applied which arrested the yaw for a period of about four seconds and reverse thrust was selected. Engine N_1 and reverser deployment parameters showed that maximum symmetrical reverse thrust was used. Six seconds after mainwheel touchdown the co-pilot stated that he had a problem and the commander offered his assistance. Recorded localiser values indicated that the aircraft was heading and tracking to the right of the runway centreline and towards the right side of the runway at that stage. Seven seconds after touchdown, with airspeed and inner brake pressure available having reduced to 97 kt and 2,000 psi respectively, the aircraft briefly yawed 2° to the left before, with full left rudder now being applied, yawing progressively to the right at a rate of 2.7º per second.

From the changes in recorded values of pitch attitude and normal acceleration, it is likely that the nose gear left the paved surface at an airspeed of about 50 kt whilst

Footnote

[2] Derived from the recording of localiser deviation.

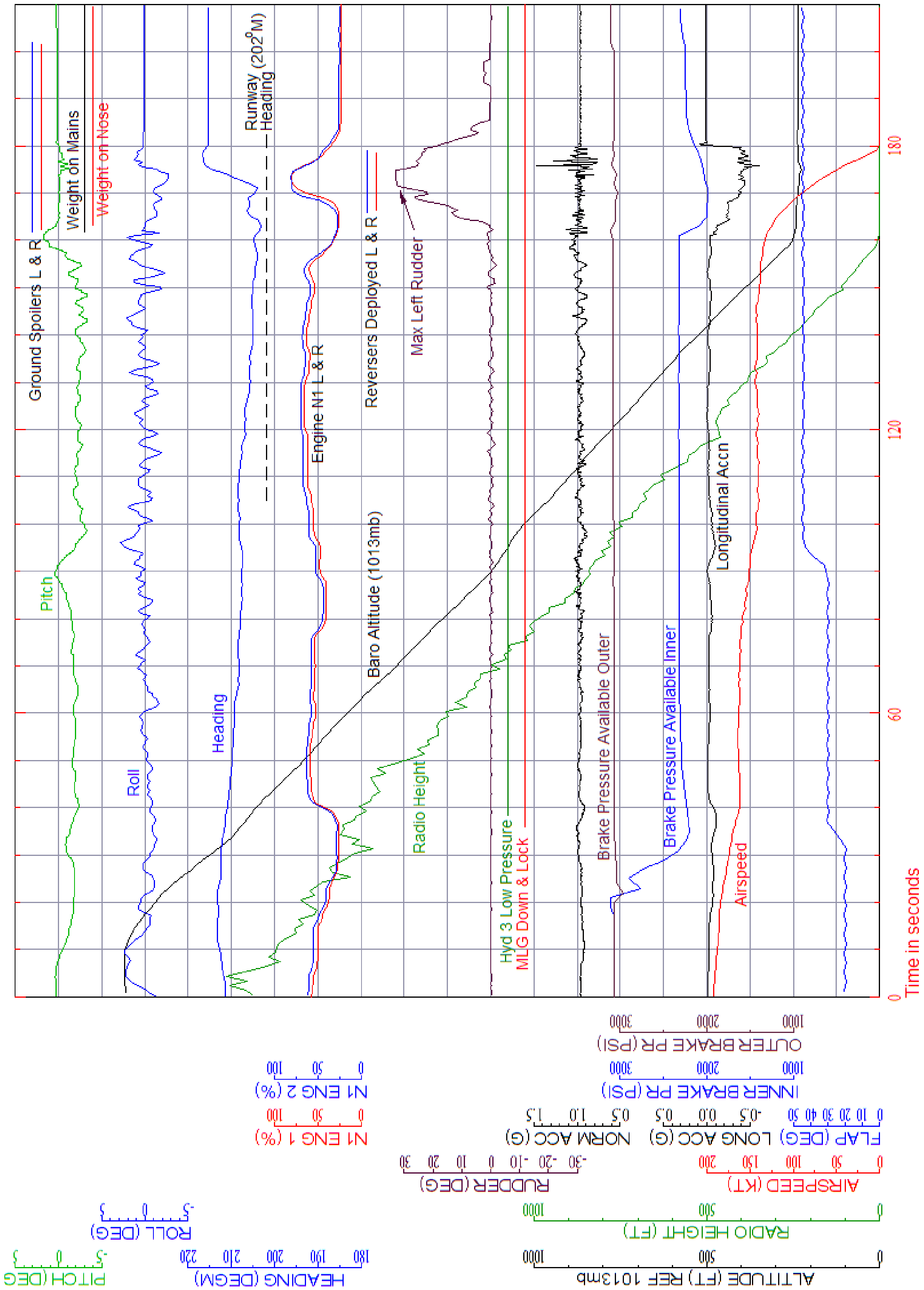


Figure 5

FDR plot, F-GRJO

the main gear followed one second later. The aircraft came to a halt on a heading of 215°M, 19 seconds after main gear touchdown. The crew advised ATC that they had had a hydraulic problem and had been unable to maintain good braking action, but that there was no fire.

The CVR showed that, during the discussions immediately after the aircraft had come to a halt, the crew debated whether they should have aborted the landing. They also referenced the checklist appropriate to a No 3 hydraulic system low pressure warning. With regard to the status of the No 3 hydraulic system, the commander commented that "*OFF OR NOT, IT DIDN'T CHANGE ANYTHING*".[3] The co-pilot then requested "*STEERING OFF, YOU CAN PUT IT OFF*". The sound of a switch selection was then recorded before the commander replied "*OFF, SO I DID NOT PUT IT...*" Further checklist discussion centred around the factoring of an increase in landing distance by 50% and advice to brake carefully and use maximum reverse thrust.

Throughout the landing roll the recorded values of longitudinal acceleration showed that the aircraft was being slowed effectively. However, in the absence of actual recorded brake pressures, it was not possible to determine whether any degradation in the inner braking system had occurred as a result of the reduced inner brake pressure available.

Aircraft information

The Bombardier CRJ is a twin-engined, 50-seat regional airliner, and over 1,000 have been built (all variants).

The main forces that decelerate the aircraft after landing are spoilers which dump lift and act as airbrakes, thrust reversers and four anti-skid brakes, one mounted on each of the four mainwheels.

Footnote

[3] English translation provided by the BEA.

There are 3 hydraulic systems on this aircraft type. The No 3 hydraulic system has two electrically-operated pumps to provide power, pump 3A and pump 3B, and these are installed in the left and right wing-to-fuselage fairings respectively. A schematic of the hydraulic system is shown in Figure 6. From this it can be seen that the only hydraulic power supply for the nose gear door, the nose gear steering, and the landing gear retraction is from No 3 hydraulic system. The inboard brakes (both left and right) are also supplied from No 3 system. Figure 6 shows that the outboard brakes are powered by No 2 hydraulic system, and the inboard brakes by No 3 hydraulic system.

Both the outboard and inboard brakes have a hydraulic accumulator. If either No 2 or No 3 hydraulic system fails, then the brakes on the failed system can be applied four or five times before the accumulator is depleted. Therefore, in the case of a failure to No 2 or No 3 hydraulic system, one set of brakes will operate normally, the other (on the failed system) will operate satisfactorily but only for four or five applications on the brake pedals, and thereafter this set of brakes will be ineffective.

There are selector switches for the hydraulic pumps on the overhead panel in the cockpit, as in Figure 7. The normal operating position for all four switches is down: Pump 1 AUTO, Pump 3A ON, Pump 3B AUTO, and Pump 2 AUTO.

Directional control on the landing roll is maintained by a combination of rudder, asymmetric brakes and nosewheel steering. The nosewheels can be turned to 70° to the left or right by using the handwheel control unit situated to the left of the left pilot's seat, or to approximately 8° to the left or right by application of the rudder pedals. It is normal operating practice for the handwheel to be used at speeds of less than 70 kt .

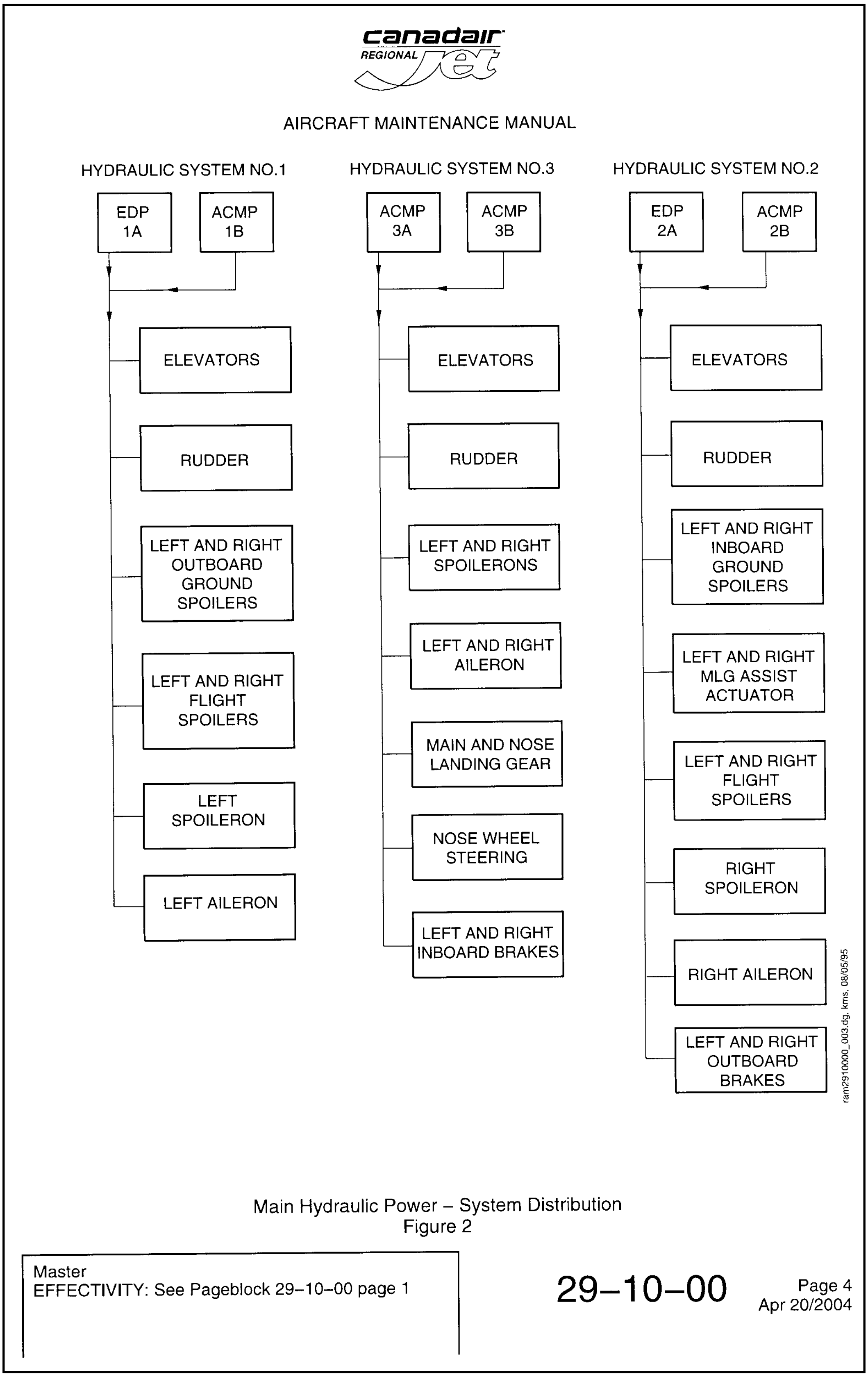


Figure 6

Hydraulic system schematic

Figure 7

Overhead panel

The CRJ has a 'steer-by-wire' Nose Wheel Steering (NWS) system. The NWS system is electrically controlled and hydraulically powered (Figure 8). If the NWS is switched off, or if the NWS Electronic Control Unit (ECU) detects a fault, the system reverts to a free-castering mode. In this mode, valves isolate the hydraulic pressure in the two steering actuators and these actuators act as dampers; the nosewheels are then free to caster. The normal hydraulic pressure is 3,000 psi. With the NWS armed, the system operates normally for No 3 system hydraulic pressures between 1,650 and 3,000 psi, and reverts to free-castering mode at a pressure below 600 psi. For pressures between 600 and 1,650 psi (with the NWS armed) the system's performance may be reduced.

Engine Indication Control and Alerting System (EICAS)

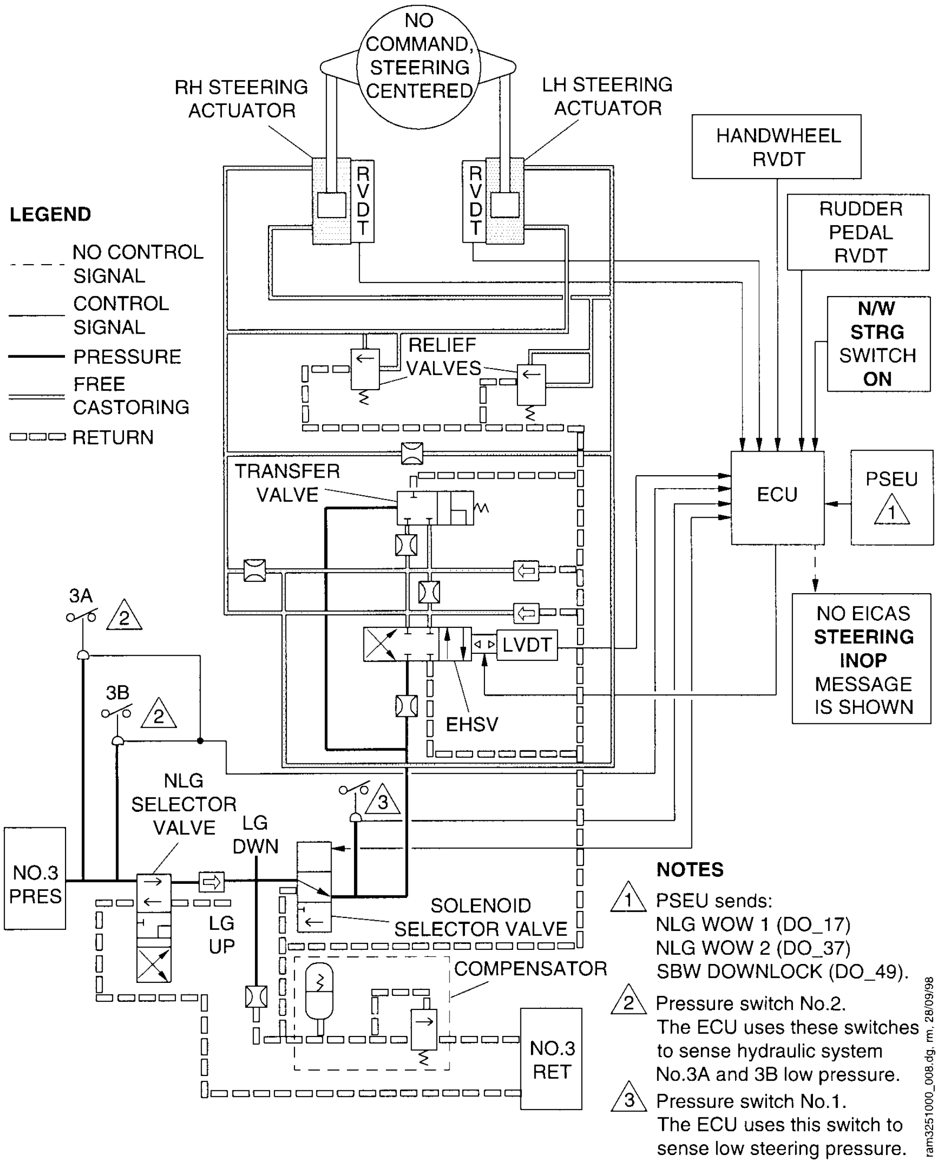
The EICAS display consists of two screens situated on the central flight deck console, which provide information to the crew on the status of the aircraft and are the means by which warning, caution and advisory messages are displayed. The system does not provide information on actions that might need to be taken by the crew should such messages appear, this information being contained in a Quick Reference Handbook (QRH).

Aircraft inspection

Following this incident at Southampton, the aircraft was inspected:

canadair REGIONAL jet

AIRCRAFT MAINTENANCE MANUAL



NWS System Hydraulic Schematic – SBW Mode with No Command Input
Figure 7 (Sheet 1 of 2)

Master
EFFECTIVITY: See Pageblock 32–51–00 page 1

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Figure 8

NWS schematic

a. The left nosewheel tyre was found to have regular transverse marks at approximately 12° to the wheel axis, and the tyre chine, which usually shows no signs of wear, had signs of heavy loading, see Figures 9 and 10. The orientation of the marks is consistent with both nosewheel tyres being highly loaded and 'scrubbed' to the right, opposing the aircraft's motion. There were no significant marks on the chine on the right nose tyre.

b. The nose gear leg and associated structure was inspected and no damage was seen.

c. With the aircraft on jacks the nose gear steering system was functioned and the rigging values were checked, with nothing abnormal being

Figure 9 (left)
Tyre chine, left nosewheel

Figure 10 (right)
Tyre tread, left nosewheel

found. The free-castering mode was checked, firstly with the hydraulics ON (at the normal 3,000 psi) and the steering OFF, and secondly with the steering ON and the hydraulics OFF. In both cases the upper link could be rotated by hand, indicating that the nose gear system has reverted to free-castering mode as expected.

d. There was a leak at the outlet of hydraulic pump 3A at the elbow joint. An 'O' ring had ruptured and the failure appeared consistent with a rapid loss of fluid. A locking wire was missing between the pump and the elbow fitting and either this, or the incorrect installation of the 'O' ring, appeared to be the cause of the failure.

e. There was a leak at the flexible outlet hose on pump 3B. This leak was confirmed by raising the system pressure until a leak was detected, with a slow and constant loss of fluid. No loose fittings or damage could be found, although the locking wire between the pump and elbow fitting was missing (as on pump 3A). The short length of outlet hose was aligned in a gentle 'S' shape, and this may have induced extra, and unnecessary, tension in the installation.

f. Apart from heavy contamination of mud and grass, nothing abnormal was found with the tyres and brakes on both main gears.

g. The fans and intakes of both engines were found contaminated by mud. More detailed inspection revealed no damage to either compressor, and subsequent engine runs confirmed that the performance of the engines was not significantly degraded.

Further engineering investigation - nosewheel steering

Most of the components of the nose gear steering system, including the nose leg and the steering Electronic Control Unit, were removed from the aircraft for further examination. The components were inspected individually and used to recreate on a rig, as far as practicable, the nose gear steering system that was on F-GRJO.

The individual inspections of the components revealed nothing significant. However, the rig test revealed that, if the pressure was between 650 and 1,650 psi when the 'weight-on-wheels' switch was activated, then the nosewheel steered slowly to the right at a rate of about 1° per second. The torque was typically 3,000 lbf-in, which is almost an order of magnitude less that that for normal operation. Above 1,650 psi the steering system would steer normally; below 650 psi the system went into free-castering mode. The drift required that the steering system be switched ON, and for hydraulic power to be provided, effectively requiring either pump 3A or 3B (or both) to be ON. Such a drift would occur for all aircraft with this NWS system, the direction of the drift depending on the particular aircraft.

The 3A and 3B hydraulic pumps were sent for inspection. There were no significant defects and no signs of overheating.

Various design cases for the nosewheel steering were discussed with the nose gear manufacturer. This included an assessment of how much steering torque was available for a given hydraulic system pressure, as well as how much torque would be required for a given nosewheel angle. The discussion concluded that, with hydraulic pressures in the range of 650 to 1,650 psi, there was sufficient torque to steer the nosewheel to at least 4°.

Further engineering investigation - hydraulic leaks

The Maintenance Manual was reviewed with the manufacturer and the operator. The review concluded that the wording in the procedures for installation and removal of the hydraulic pump could be improved to ensure that pumps are correctly installed and fittings correctly wirelocked. The operator noted that, as a result of their internal investigation, they issued an internal technical bulletin to cover 'O' ring installation, hydraulic pump wirelocking and installation of hydraulic hoses. For their part, the manufacturer made minor changes in the maintenance manual.

Further engineering investigation - possibility of adverse rudder effectiveness

The aircraft manufacturer considered the possibility that the jet efflux from the thrust reversers, passing over a rudder surface fully deflected to the left, had an effect on aircraft directional control. They concluded that there was a possibility of some reduction in rudder effectiveness at lower airspeeds but not of a reversal of the rudder's control effect. To support this, the manufacturer referred to wind tunnel and 'on-aircraft' tests conducted in 1994 and 1995.

Analysis

During this investigation, rig testing clearly demonstrated a scenario in which the nosewheels would slowly steer in one direction without any command input. For this to occur, the pressure in the No 3 hydraulic system needed to be in the range of 650 to 1,650 psi, and the Nose Wheel Steering to be ON, with the 'weight-on-wheels' switch activated after the nosewheel touchdown. The pressure could be in this range after a hydraulic leak and with one, or both, of the No 3 system pumps being ON. Importantly, this particular nose gear steered to the right, which agreed with the direction the aircraft veered, the tyre marks on the runway, and damage to the left nose gear tyre chine.

The commander recalled referring to the QRH. He believed he had not switched on the hydraulic 3B pump and was unsure if he had switched off the hydraulic 3A pump. He also believed he had turned OFF the nosewheel steering.

Evidence from the CVR indicated that no reference was made by the crew to the QRH whilst airborne. It provided evidence that the Nose Wheel Steering was in the ON position for the approach, that it was not switched OFF whilst airborne, in response to the hydraulic failure, and that it remained ON for the ground roll. In addition, the CVR provided evidence that the switches for the hydraulic pumps 3A and 3B remained in the ON and AUTO positions respectively throughout the approach and ground roll.

The QRH drill (Figure 1) would, in this case, have required that the hydraulic 3A pump, the hydraulic 3B pump and the nosewheel steering all be switched OFF. In addition it required the re-calculation of the landing distance required. Comments by the co-pilot that they should divert to London suggest he was concerned about the landing distance available. Whilst there was, in fact, sufficient landing distance available, the CVR gave no indication that such a calculation was carried out by the crew prior to landing.

The crew became alerted to the hydraulic failure at a late stage in the approach, a little over two minutes prior to touchdown. It is likely that the commander believed he had sufficient knowledge of the system, reinforced by the information provided to him by the EICAS, to be able to continue the landing safely without having to action the items in the QRH.

Whilst this incident would not have occurred had the QRH been followed (ie the NWS and hydraulic pumps 3A and 3B had been switched off) there remains the possibility that, in another case, a hydraulic failure could occur just before touchdown. In such a case it would be unreasonable to expect a crew to take the appropriate actions quickly enough to prevent a similar lack of controllability on the ground. The following Safety Recommendation is therefore made:

Safety Recommendation 2007-101

It is recommended that Bombardier Aerospace review this design of nose gear steering system, in the CRJ100 and other company products, to prevent uncommanded nose gear steering following a hydraulic failure.