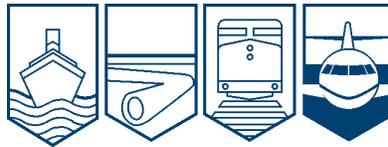


Transportation Safety Board
of Canada



Bureau de la sécurité des transports
du Canada

**AVIATION INVESTIGATION REPORT
A11Q0052**



RUNWAY EXCURSION

**TRI MARINE MANAGEMENT COMPANY LLC
BOMBARDIER BD100-1A10, N818RC
IQALUIT, NUNAVUT
12 MARCH 2011**

Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Aviation Investigation Report

Runway Excursion

Tri Marine Management Company LLC
Bombardier BD100-1A10, N818RC
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12 March 2011

Report Number A11Q0052

Summary

The Bombardier BD100-1A10 (serial number 20165, registration N818RC), operated by Tri Marine Management Company LLC, departed Long Beach airport (Daugherty Field), California, for Iqaluit, Nunavut, with 2 crew members and 1 passenger on board. The aircraft landed in Iqaluit at approximately 2100 Eastern Daylight Time. Upon contact of the nose wheel on Runway 35, directional control was lost and aircraft steering was ineffective. The aircraft exited the right side of the runway approximately 4300 feet from the threshold. The aircraft travelled 400 feet over frozen ground and stopped approximately 100 feet from the edge of the runway in a snow bank. There were no injuries, and aircraft damage was limited to the nose and main landing gear, which was subsequently replaced. There was no post-event fire and no evacuation was necessary. The emergency locator transmitter did not activate during the runway excursion.

Ce rapport est également disponible en français.

Factual Information

History of the Flight

The flight departed Long Beach (Daugherty Field) (KLGB), California, en route to Milan (LIML), Italy, with a planned fuel stop in Iqaluit (CYFB), Nunavut. The flight time to Iqaluit was 5 hours and 36 minutes at a cruise altitude of 41 000 feet. The flight en route was uneventful; the outside temperature at the cruising altitude was approximately -60°C.

The first officer was the pilot flying. An instrument landing system/distance measuring equipment (ILS/DME) approach to Runway 35 at Iqaluit was carried out with the autopilot on. The reported surface winds were within the aircraft limitations for a right crosswind with a light tailwind component. A reference speed (V_{REF}) of 114 knots was calculated. The before-landing checklist items were completed 3 miles prior to the final approach fix. The autopilot was disconnected, and the aircraft crossed the threshold at a speed of about 118 knots.

The aircraft touched down approximately 10 feet to the right of the centreline at 2100:02.¹ Once the nose wheel contacted the runway, the aircraft veered to the right. The crew applied full left rudder and left brake while selecting left nose steering with the tiller. Thrust reversers were also selected, but the aircraft continued to pull to the right. The aircraft departed the runway 4300 feet from the threshold and came to rest in packed snow 100 feet from the runway edge lights. The nose landing gear (NLG) came to rest in snow reaching the top of the wheel height, and the main landing gear (MLG) came to rest in snow reaching half the wheel height.

Crew Information

Records indicate that both pilots were certified and qualified for the flight in accordance with existing regulations. The captain held a valid United States airline transport pilot licence (ATPL) with an instrument rating certificate. The captain had accumulated 10 660 flight hours, of which 879 hours were on type, and had flown 6 hours in the previous 24-hour period, including the occurrence flight. The captain's last flight review was completed on 23 January 2011.

The first officer held a valid United States ATPL with an instrument rating certificate. The first officer had accumulated 10 095 flight hours, of which 672 hours were on type, and had flown 6 hours in the previous 24-hour period, including the occurrence flight. The first officer's last flight review was completed on 23 February 2011.

Fatigue was not considered a contributing factor in this accident.

Weather and Runway Conditions

The aviation routine weather report (METAR) for CYFB at 2100 indicated the following: wind 080° true (T) at 4 knots, visibility 10 statute miles (sm) with light snow, broken cloud at 11 000 feet above ground level (agl), overcast cloud at 20 000 feet agl, temperature -29°C, dew point -35°C, and altimeter setting 30.23 inches of mercury. The runway condition was 90% bare

¹ All times are Eastern Daylight Time (Coordinated Universal Time minus 4 hours).

and dry with 10% ice. The winds at time of landing were reported by the flight service specialist to be 120° magnetic (M) at 3 knots.

Flight Recorders

The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR); both were recovered. The FDR provided useful information to the investigation team. The CVR data however had been overwritten due to the fact that the circuit breaker was not pulled after the event. If cockpit voice recordings are not available to an investigation, this may preclude the identification and communication of safety deficiencies to advance transportation safety.

The FDR was a solid-state L3 Communications model FA2100.² It was received in good condition and contained about 204 hours of data and over 500 parameters. The data showed that the initial touchdown occurred at 2059:59.3 and was a soft landing on the left main gear, followed by a control wheel input to the right. The nose wheel contacted the ground at 2100:02, followed by the application of thrust reversers. A master caution warning occurred at the same time as the recorded magnetic heading showed a direction change to the right.

As the aircraft started to pull to the right, left control wheel and left rudder pedal inputs were applied to counteract the right veer, but without success. A 16° heading change to the right occurred, during which lateral acceleration reached 0.3g. Brake pressure was applied at 2100:10, 2 seconds before the aircraft left the runway surface. Twelve seconds after the initial touchdown, the aircraft exited the runway surface at a speed less than 60 knots and came to a full stop at 2100:16.4.

Aircraft

The Bombardier BD100-1A10 is commercially known as the Challenger 300 and entered commercial service in January 2004. The landing gear system is manufactured by Messier-Bugatti-Dowty (MBD) (Toronto, Ontario).

Records indicate that N818RC was certified, equipped, and maintained in accordance with existing regulations and approved procedures. The aircraft had accumulated 1062 hours since new.³ The last inspection was completed on 27 June 2010. There were no anomalies noted in the logbook prior to this accident.

Aircraft Damage

Skid marks left by the nose-wheel tires on the runway showed that the nose gear was incorrectly orientated with the direction of aircraft travel. The aircraft was retrieved from the snow bank on 16 March 2011. An extensive inspection of the aircraft was conducted and focused especially on the landing gear system, tires, and brakes. The left nose-wheel tire had detached from the rim and was deflated; the right thrust reverser door was packed with snow and slightly open. There was no other visible damage to the airplane. The FDR was analyzed to determine the serviceability and the airworthiness of the aircraft, more specifically of the

² Part number 2100-2043-00, serial number 00044761

³ The aircraft was built in 2007.

landing gear system. Due to the lateral acceleration gravitational load factor ⁴ that the aircraft encountered during the runway excursion, MBD engineering recommended that the operator replace all the landing gears. The work was completed before the aircraft departed Iqaluit.

Previous Nose-Wheel Steering Incidents involving N818RC

N818RC was involved in 2 previous events related to the nose-wheel steering (NWS):

- In Singapore, on 29 January 2010, the NWS failed after landing. The rotary variable transducer (RVT) was found defective; 1 of the RVT coils was found open. When such a failure occurs, the system will continue to operate by free casting, meaning that the aircraft steering can only be achieved by applying differential braking. The investigation revealed a manufacturing defect caused by honing-oil residue (with corrosive properties) in the windings. A Bombardier service bulletin (number 100-32-18) was released in January 2010 to recall defective units.
- On 10 January 2011, a NWS failure occurred after the aircraft landed at Washington Dulles International Airport, Virginia. The investigation revealed that a valve coil was found open, which prevented the valve from allowing hydraulic fluid to reach the steering selector valve (SSV) and arm the system. When such a failure occurs, the system will continue to operate by free casting.

Following the second event, the SSV was replaced by a repaired unit with a previous operation time of approximately 500 hours. This replacement SSV had also experienced a NWS failure. Other than a 2400 hours operational test requirement, there are no prescribed operation time limits, nor are there any specific inspection requirements. The teardown and failure analysis report for the previous incident stated that the cause of the NWS failure was related to a tendency to hesitate and not run smoothly. Because the part was not under the warranty period, it was not subject to an inbound evaluation by the vendor before being installed on N818RC.

Cold-Soak Tests in Iqaluit

Before the cold-soak test, the aircraft was in a heated hangar. The NWS was armed and tested with rudder pedals deflected 7° to the left and right and the system operated normally. In order to reproduce the temperature conditions present during the landing event, the aircraft was moved outside overnight on 19 March 2011 and cold-soaked for a period of 11 hours to verify the NWS operation.

On 20 March 2011, the auxiliary power unit was started, electrical and hydraulic power was applied to the aircraft, and the NWS torque link was disconnected prior to selecting the NWS to ON. The outside temperature was at -17°C. ⁵ Once the NWS was selected ON, the steering collar moved to the right approximately 15° with no steering command from the cockpit. This was followed by a NWS failure message from the engine indication and crew alerting system (EICAS). The NWS collar was moved by hand to center (zero), and the NWS was selected ON for a second time. With no steering command, the steering collar moved 15° to the right again,

⁴ Gravitational load (g load) exerted on the landing gear at the time of the runway excursion

⁵ The outside temperature was 12°C warmer than the temperature on the day of the occurrence.

followed by a NWS failure message from the EICAS. Fault codes 7, 1, and 3⁶ were displayed on the steering control unit (SCU) after the NWS failure message was posted on the EICAS. The cold-soak check indicated a steering failure similar to the accident scenario. However, additional cold-soak checks carried out during the investigation could not duplicate a similar condition.

Description of the Nose-Wheel Steering System

The NWS system is electrically controlled and hydraulically operated. The nose wheel can be turned 65° left or right from centre using the hand wheel (tiller). The nose wheel can also be turned 7° left or right from centre with a left or right rudder pedal input. These actions send an electrical signal to the SCU. The SCU, through the steering manifold, sends hydraulic pressure to the steering actuator. The steering actuator turns the steering collar and torque links, which turn the NLG axle. The steering-control system is also used to decrease vibration from the nose wheel when the aircraft is operated on the ground.

An RVT sends position feedback to the SCU. The SCU stops the steering action when the desired steering angle has been reached. A NWS pushbutton annunciator (PBA), located on the centre pedestal, arms or disarms the NWS system.

For the steering system to operate, the following 4 conditions must be met:

- NLG is down and locked;
- NLG is in a weight-on-wheel (WOW) condition;
- no system faults are found by the SCU;
- NWS is ON.

When these 4 conditions are met, the SCU energizes the SSV, and hydraulic pressure is sent to the steering bypass valve. The SCU will keep the nose wheel in the centre position until it receives a turn signal. When the hand wheel (tiller) or rudder pedals are operated, the SCU receives a turn signal. The SCU will then calculate the position error, which corresponds to the hand wheel plus the rudder pedals, minus the feedback. The position error signal is sent through the servo amplifier to the torque motor coils of the pressurized electro hydraulic servo valve (EHSV).

The EHSV changes the signal into a movement of the spool, which sends hydraulic pressure to the correct side of the steering actuator piston. The actuator then turns the nose wheel to the correct position. The SCU maintains an electrical current through the EHSV coils until the feedback RVT decreases the position error to zero. The zero position error moves the EHSV spool to the neutral position, and the steering actuator movement is stopped. When the hand wheel or rudder pedals are moved to cancel the initial turn signal, a new position error occurs. The SCU again sends a signal to the EHSV coils until the actuator moves the nose wheel to cancel the position error.

The steering actuator is a hydraulically-operated rack that is installed on the NLG shock strut. The steering actuator is part of the rack-and-pinion steering mechanism. It has 1 cylinder,

⁶ Fault code 7 refers to rigging, code 3 refers to an electro hydraulic servo valve (EHSV) fault or associated wiring, and code 1 is a fault isolated to the steering control unit (SCU).

2 pistons and 1 rack. For steering operation, hydraulic fluid will flow into 1 of the 2 ends of the cylinder and push 1 of the pistons. The piston will then push the rack. The rack has teeth that engage with the teeth on the steering body assembly pinion. This will transmit movement to the nose wheel through the torque links and axle.

The steering control system schematic is presented in Appendix B.

Engine Indication and Crew Alerting System

The SCU sends malfunction signals to the data concentrator unit (DCU), which causes messages to appear on the EICAS. Whenever a malfunction with the NWS is signaled to the system, an EICAS message will appear (Table 1).

Table 1. Engine indication and crew alerting system (EICAS) messages relating to the nose-wheel steering (NWS)

EICAS message	Level and color of message
NWS FAIL	CAUTION (amber)
NWS LIMIT EXCEEDED	CAUTION (amber)
NWS FAULT	ADVISORY (cyan)
NWS OFF	STATUS (white)

During the event and before shutting down the engines, the crew did not notice any messages on the EICAS. When electrical power was restored on the aircraft after the event, there was no NWS message on the EICAS. This can be explained by the fact that the amber message disappears if the NWS pushbutton is turned OFF. Since the NWS pushbutton was selected OFF as part of the shutdown checklist, this action would extinguish the caution message on the EICAS. However, the FDR registered a master caution warning approximately 2 seconds after the nose wheel touched down. It could not be determined which EICAS message triggered the master caution warning.

Hydraulic System Description

The Challenger 300 has a left and a right hydraulic system that are independent from each other, as well as an auxiliary system that is tied to the right hydraulic system. The hydraulic system normally operates at 3000 pounds per square inch (psi) and uses fire-resistant phosphate ester that meets requirement SAE AS 1241.⁷ Hydraulic fluid transfer can only occur between the left and right hydraulic systems through the brake shuttle valve during parking brake operations. The NWS actuator is controlled by the left hydraulic system (Appendix A). The left hydraulic system contains a reservoir for the storage of hydraulic fluid; its volume is 13 quarts or 12.3 liters. Two non-cleanable-type filter elements are provided, which retain 100% of all

⁷ This specification establishes the requirements for physical and chemical properties, as well as the minimum tests to evaluate suitability, of phosphate ester hydraulic fluids used in aircraft systems where fire resistance is required.

contaminants larger than 15 microns on the pressure side, and contaminants larger than 5 microns on the return side. The hydraulic supply pressure line from the direct-current motor-drive pumps (DCMP) and the pressure switch of the NWS system do not have a filter.

Steering Selector Valve Description

The SSV is controlled by the SCU. When the valve is de-energized, the hydraulic pressure is routed to the left hydraulic system return line. When the valve is energized, the hydraulic pressure is routed to the EHSV from the left hydraulic system supply line. The SSV is spring-loaded to close when electrical power is removed. If the valve fails to close, free caster steering with the use of asymmetrical braking is not achievable as the EHSV remains pressurized, preventing its bypass valve from switching to bypass mode. In this accident, the SSV did not close⁸ to allow the EHSV to go into bypass mode and permit free caster steering with the use of asymmetrical braking (Appendix B).

The unit involved in this accident was manufactured in April 2006 and was previously returned to Pneudraulics Inc. in March 2009 with a report of failure after 500 hours of operation by a different operator. The test performed at that time found that the insulation resistance of the solenoid did not meet requirements, and that the operation of the unit was sticky, meaning intermittent hesitation.

Steering Manifold Assembly Description

The steering manifold assembly is installed on the aft side of the NLG. It has an internal bypass valve and an external EHSV. The steering manifold is controlled by the SCU and sends hydraulic pressure to 1 of the 2 steering actuators in 1 of 2 directions to turn the nose wheel left or right (Appendix B).

The bypass valve is a two-position sliding-spool valve and is operated with left hydraulic pressure. When there is no hydraulic pressure, the bypass valve spring will close the valve. The bypass valve opens or closes the steering actuator cylinder ports to give free or pressurized flow. Hydraulic pressure moves the bypass valves, which lets pressure go to 1 of the 2 steering actuator cylinders. With hydraulic pressure removed, the bypass valve spring moves the bypass valve to the free-flow position. This connects the cylinder ports with the hydraulic system return line to let the nose wheel turn freely.

The EHSV is a two-stage, four-way, flow-control valve. It is controlled and monitored by the SCU. The EHSV receives signals from the SCU and sends hydraulic pressure to one side or the other of the bypass valve. The EHSV has 2 coils, a dry-torque motor and a linear variable differential transducer (LVDT) to sense the valve position. The servo valve has a second-stage spool-and-sleeve valve with a mechanical feedback spring between the spool and the first-stage jet pipe. The LVDT, connected to the second-stage spool, sends an electrical signal to the SCU to show the spool position. This electrical signal is used by the SCU to monitor the EHSV operation.

⁸ The steering selector valve (SSV) should close within 0.08 second, in accordance with the design logic requirement. In this occurrence, the SSV remained open for the duration of the runway excursion.

Tests and Teardown of the Nose Landing Gear System, Including Steering Selector Valve and Steering Manifold

On 02 May 2011, under Transportation Safety Board of Canada (TSB) supervision, the NLG was removed from its shipping box, documented and photographed at the manufacturer's facility in Ajax, Ontario; no external defects were noted. Hydraulic fluid samples from the steering actuator were taken and submitted to the MBD laboratory department for analysis.

A hydraulic line was connected to the steering actuator and routed through the freezer box for quick connection to the hydraulic power supply. The complete NLG shock strut was subjected to a cold soak overnight at a temperature of -40°C.

A download of the SCU was also carried out in its entirety. The downloaded information contained data from the accident on 12 March 2011 and from both cold-soak tests carried out by the investigation team in Iqaluit on 20 March 2011 (results in section below).

On 03 May 2011, the NWS was tested, and a slight movement was noted at the steering collar, which would result mainly from the steering centering. To simulate a steering fault, the electrical power was turned off at the SSV. An attempt was made to rotate the steering collar, but for approximately 15 seconds, the collar could not be moved as it should. This process was repeated several times; however, the 15° right-lock seen during this occurrence could not be repeated. The gear was re-installed in the cold chamber for an additional 2 hours; this time, the steering collar was free to move, unlike the initial test. No conclusion could be drawn from the initial steering-collar lock-up.

The SSV was replaced with another serviceable part, and the NLG was re-installed in the cold-soak chamber at a temperature of -65°C for the night. The next morning, an attempt was made to rotate the steering collar, but for approximately 2 seconds, the collar could not be moved. After 2 seconds, the collar moved freely. This process was repeated several times, but the 15° right-lock seen during this occurrence could not be repeated.

A report describing the assessment and testing of the NLG was prepared by MBD, with the support of the vendors of the SSV (Pneudraulics) and of the steering manifold (IN-LHC).

A report was provided to the TSB by MBD and contains a report from the vendor of the SSV, Pneudraulics Inc. Report number ESR00562-4 concludes that gross particulate contamination originating from the aircraft's hydraulic system was the direct cause of the intermittent operation of the SSV. This contamination was also likely the cause of the valve's failure to release pressure at the time of the occurrence. The Pneudraulics Inc. report also states that the condition of the sub-components was consistent with this conclusion. The report notes that the root cause of the contamination was undetermined. To address the hydraulic fluid contamination in the aircraft hydraulic system, the aircraft was flown to the Bombardier Service Center in Tucson, Arizona, in July 2011 for work to be completed. The hydraulic fluid in the left, right, and auxiliary hydraulic systems were sent out for testing. All tests were normal.

The MBD report also contains a report (number SAV3-374) from the vendor of the steering manifold assembly, IN-LHC. During the testing and disassembly in June 2011 at IN-LHC in France, the unit operated within the requirements of the acceptance test procedure (ATP) at

both cold and normal temperatures. The cold-soak test was conducted at the extreme of the equipment test limits, at a temperature of -54°C. At room temperature, the unit operated in the regular tolerances of the procedure. Evidence of corrosion on the magnets, of scratches, and of fluid contamination were detected. This report concludes that, although evidence of fluid contamination was found, this only had a minor impact on the performance of the unit in testing. In addition, the SAV3-374 report outlined the hypothesis that the pollution of the hydraulic fluid (confirmed by the measurement of particles inside the fluid of the manifold), combined with the low temperature (higher viscosity of the fluid, frozen water), could explain the deviation of the servo valve.

The MBD report concludes:

During all the investigations and testing carried out at Messier-Bugatti-Dowty and at suppliers (IN-LHC & Pneudraulics Inc.) only on the first steering test at cold temperature was there an anomaly where a delay in the release of pressure in the system was noted. All further testing could not repeat any anomaly. Also the anomaly noted during the field test in Iqaluit with the steering pulling was not repeatable. On detail examination of all the returned components no damage or defects were noted at Messier-Bugatti-Dowty. There were minor defects/wear marks noted in the steering selector valve as noted in appendix III during the supplier investigation. In the view of Messier-Bugatti-Dowty and both suppliers involved in this investigation the only common issue noted was the contamination of the aircraft hydraulic fluid.

Steering Control Unit Non-Volatile Memory Download Information

Following the analysis by MBD engineering of the SCU fault log entries of the non-volatile memory download, it was established that the un-commanded NWS action to the right could have been caused by 2 different parts that failed within milliseconds of each other. The EHSV⁹ did not respond to commanded current, and the SSV didn't close, which prevented the NWS system from free casting (Appendix B).

Results of Fluid Sample Taken from the Hydraulic System

Hydraulic fluid contamination can be defined as the presence of any substance or foreign material in fluid that is capable of adversely affecting system performance and reliability. Regular monitoring and maintenance following accepted hydraulic-fluid contamination procedures provides maximum operating system performance and service life, and increased safety.

According to MBD, tests carried out on the fluid samples were limited due to the insufficient quantity of each sample. Samples were tested for water content in accordance with specification contained in ASTM D1744. Water-testing results were all acceptable, except in 1 case (left-hand pressure filter), where the test failed specification. The water content was on the high side of the specification, with a marginal pass. Contamination found in the L/H return filter contained

⁹ The EHSV is part of the steering manifold assembly (part number 1227100-01, serial number LHC-0204), which is manufactured by IN-LHC, a division of Zodiac Aerospace in France.

particles predominately composed of Teflon of sizes varying from 60 to 120 microns, and water in the L/H pressure filter. A note in the fluid analysis report from MBD states that a minimum sample volume of 100 ml was required to perform all tests. The sample volume provided to the MBD fluid laboratory was 75 ml in the return filter, and 40 ml in the pressure filter.

Bombardier In-Service Records

Bombardier in-service records indicate that there are steering system failures in the field that are related to cold temperature and moisture. In 2011, 13 EHSVs were returned to the supplier because of steering failures, and were found to have contamination, insulation with low resistance, and evidence of wetness in the electrical portion of the component. Water content and cold weather have been identified as factors present in this event as well.

Challenger 300 Hydraulic System Certification Requirements

The National Aerospace Standard (NAS) 1638 is a cleanliness standard developed for aerospace components and includes fluid cleanliness classes. Each class is defined in terms of the maximum allowable particle count for a designated particle size range. Class 00 is the cleanest fluid, and class 12 is the dirtiest fluid. The Challenger 300 certification requirements specify that the phosphate-ester-based hydraulic fluid in the hydraulic system should be filtered in accordance with NAS 1638,¹⁰ using a class 9 fluid cleanliness standard. Report NT5530449 shows that during the qualification of the EHSV in endurance testing, a class 2 to 5 fluid cleanliness was used instead of a class 9 fluid. In the case of the SSV, report SQTR-4200-3 shows that class 6 fluids or better were used for endurance testing. This means that both certification tests were made using cleaner standard fluid, which differs from the certification requirements.

TSB Laboratory Reports

The following TSB Laboratory report was completed:

- LP025/2011 Flight Data Recorder Analysis

This report is available from the TSB on request.

¹⁰ National Aerospace Standard (NAS) 1638 is a particulate contamination coding system used in the fluid power industry.

Analysis

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. After the nose wheel touchdown, the experienced and qualified crew encountered an un-commanded right turn of the nose-wheel steering (NWS). Despite the crew's attempt to correct, the aircraft exited the runway. There is no indication that either the runway surface or weather conditions (other than cold temperatures) could have played a role in the occurrence. The analysis will therefore focus on the un-commanded heading deviation and the NWS failure.

The un-commanded right deflection of the nose wheel was duplicated during cold-soak tests in Iqaluit, Nunavut. Once the NWS pushbutton was selected ON, the NWS system went 15° to the right without commands; this scenario is similar to the occurrence event. The results of respective testing and teardown carried out at Messier-Bugatti-Dowty (MBD), Pneudraulics Inc. and IN-LHC concluded that contamination was a common issue and likely contributed to the failure of the steering selector valve (SSV). These tests could not determine what caused the ineffective operation of the electro hydraulic servo valve (EHSV).

Combined with contamination, the exposure time to the cold outside air temperature at altitude and the cold temperature in Iqaluit (CYFB) the day of the occurrence most likely played a role in this occurrence. The aircraft was exposed for a long period of time at a temperature of -60°C. In 2011, 13 EHSVs were found with contamination, insulation with low resistance, and proof of wetness. In this event, the EHSV disassembly in June 2011 revealed corrosion on the magnets, marks, and scratches on several parts, as well as fluid contamination.

There is neither a prescribed time limit for the operation of the SSV and the steering manifold assembly, nor any specific inspection requirements. However, a 2400 hours operational test is required on the SSV. The SSV, when installed on the occurrence aircraft, had previously accumulated 500 hours of operation within approximately a three-year period. The aircraft itself had accumulated 1062 hours in approximately 4 years. Based on this, it can be concluded that the SSV could be in operation for several years before being subjected to the 2400 hours operational test. Without specific inspection requirements, maintenance personnel are not provided with the opportunity to detect any internal damage or any type of contamination such as water and corrosion within the components, unless the SSV fails the 2400 hours operational test, which can take years before it is performed. If aircraft components have a lengthy time limit of operation without an accompanying periodic maintenance schedule, and component service history is not regularly reviewed, there is an increased risk of an unexpected component failure.

The presence of water in hydraulic fluid can have wide-ranging effects on system components, such as surface corrosion, which in turn can cause a valve to stick. The EHSV was found with internal corrosion, but this could not be explained. The EHSV did not respond to steering commands, and the steering control unit (SCU) logic commanded the SSV to close. The SSV did not close, and this condition prevented the NWS system from free casting with the steering pointing to the right.

During the certification process of the SSV and steering manifold, cleaner hydraulic fluid was used instead of a class 9 fluid, as prescribed in the certification document. The SSV and steering

manifold were not tested using dirty fluid, often corresponding to normal aircraft operation. The effects of using class 9 hydraulic oil in the Challenger 300 SSV and steering manifold were not established during the certification process. The impact that a fluid dirtier than a class 5 fluid cleanliness level could have on the operation of the NWS is unknown. The use of these valves in certain weather conditions, plus the presence of contamination, may increase the risk of failure and of a runway excursion.

During this event, the crew was unable to avoid the runway excursion. Unlike the 2 preceding events, the system did not operate by free casting, which would have helped the crew to keep the airplane on the runway. According to MBD, the failure of the SSV within milliseconds of the EHSV's failure to operate caused the NWS to shut down, preventing the free casting and ultimately any possible reaction by the crew to counter the un-commanded veer to the right.

Findings

Findings as to Causes and Contributing Factors

1. On touchdown, the nose wheel veered to the right, and the crew's attempt to control the uncommanded veer was not successful.
2. The electro hydraulic servo valve did not respond to steering commands, and the steering control unit logic commanded the steering selector valve to close. The steering selector valve did not close, and this condition prevented the nose-wheel steering system from free casting with the steering pointing to the right.
3. The electro hydraulic servo valve likely failed due to contamination, internal corrosion and exposure to cold temperatures.

Findings as to Risk

1. If aircraft components have a lengthy time limit of operation without an accompanying periodic maintenance schedule, and component service history is not regularly reviewed, there is an increased risk of an unexpected component failure.
2. If cockpit voice recordings are not available to an investigation, this may preclude the identification and communication of safety deficiencies to advance transportation safety.

Other Findings

1. Based on Messier-Bugatti-Dowty's recommendation, the landing gear was replaced due to the lateral acceleration gravitational load (g load) exceedance, even though there was no visible structural damage to the airplane.

Safety Action

Safety Action Taken

Bombardier conducted a series of tests to determine if moisture ingress from the ambient atmosphere can affect the electro hydraulic servo valve (EHSV) operation, and if hydraulic fluid contamination with moisture and particles can affect the EHSV and the steering selector valve operation. Bombardier is also in the process of issuing a service bulletin to require a one-time check of the EHSV electrical servo motor and the application of sealants around the EHSV connector and bolts to prevent ingress of moisture to the servo motor.

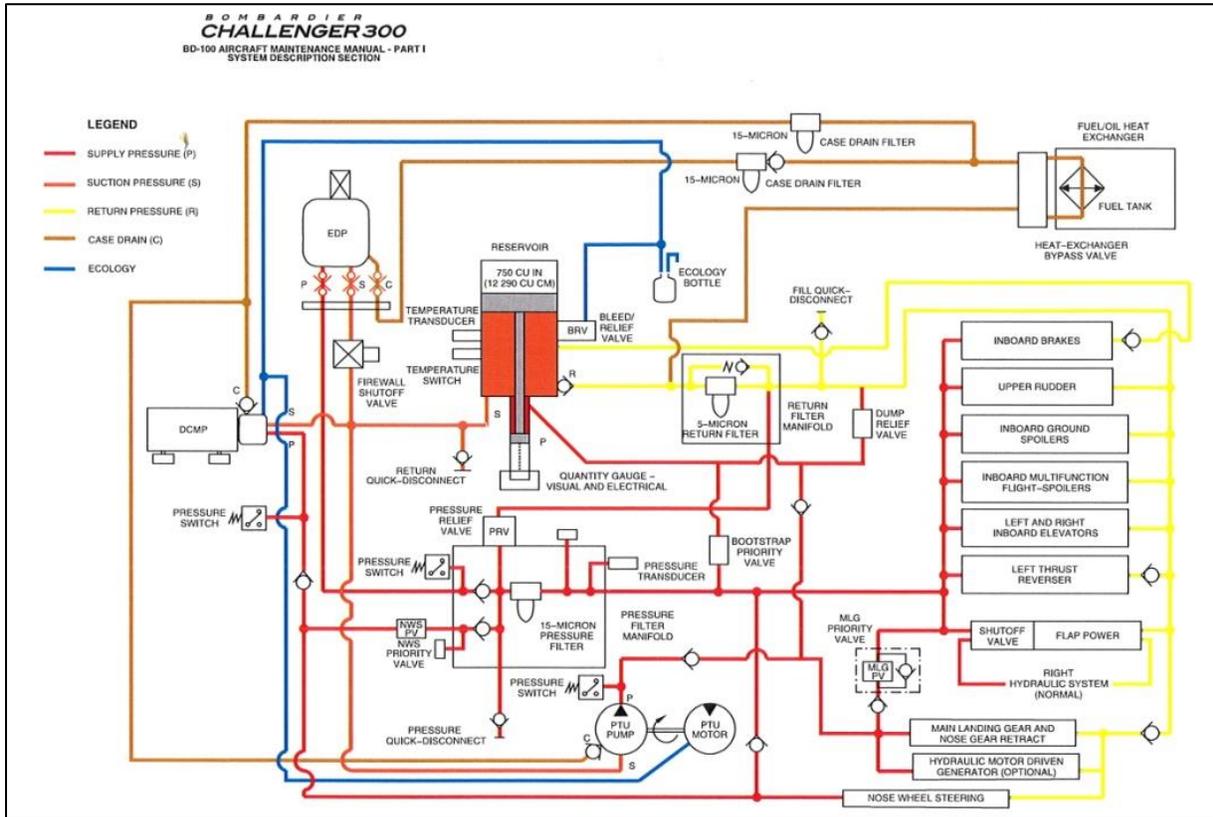
Bombardier has introduced a new EHSV configuration that has an o-ring seal between the connector and the valve cap to seal from moisture ingress.

This report concludes the Transportation Safety Board's investigation into this occurrence. The Board authorized the release of this report on 18 December 2013. It was officially released on 08 January 2014.

Visit the Transportation Safety Board's website (www.bst-tsb.gc.ca) for information about the Transportation Safety Board and its products and services. You will also find the Watchlist, which identifies the transportation safety issues that pose the greatest risk to Canadians. In each case, the TSB has found that actions taken to date are inadequate, and that industry and regulators need to take additional concrete measures to eliminate the risks.

Appendices

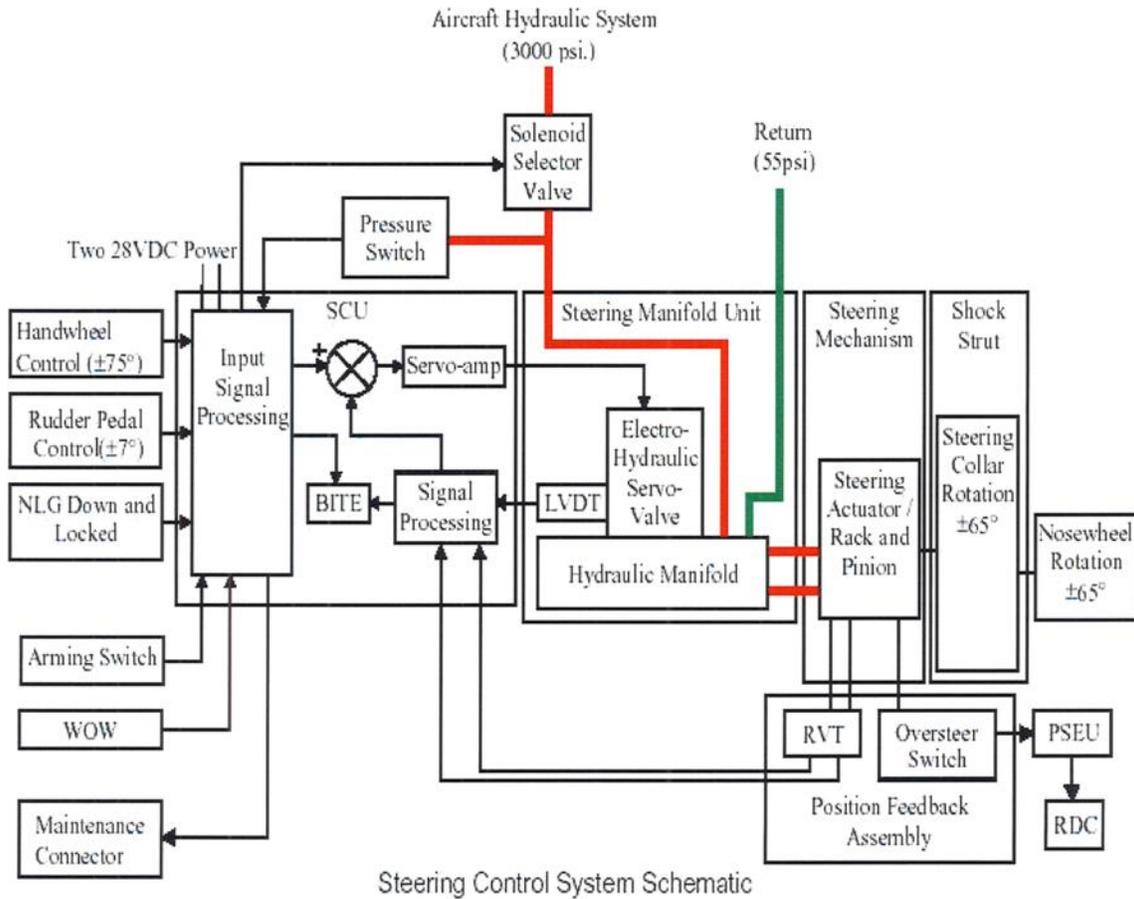
Appendix A: Left Hydraulic System



Source: Bombardier Challenger 300 BD-100 Aircraft Maintenance Manual – Part 1, System Description section. Bombardier Aerospace: 14 July 2010

Appendix B: Nose-Wheel Steering System Operation

Nose Wheel Steering System Operation



Source: Bombardier Challenger 300 BD-100 Aircraft Maintenance Manual – Part 1, System Description section. Bombardier Aerospace: 14 July 2010

Note: The solenoid selector valve is called the steering selector valve in this report.