NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

4-17-2012

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: CEN11IA379

A. INCIDENT:

Location:	General Mitchell Airport (MKE), Milwaukee, Wisconsin
Date:	June 6, 2011
Time:	About 2132 Central Daylight Time (CDT)
Aircraft:	Bombardier CL600-2B19
Registration:	N866AS
Serial Number:	7517
Operator:	SkyWest Airlines

B. SYSTEMS GROUP:

Chairman:	Mike Hauf National Transportation Safety Board Washington, D.C.
Member:	Eric West Federal Aviation Administration
Member:	Del Belyea SkyWest Airlines
Member:	Manon Cotnoir Bombardier
Member:	Bogdan Pantelimon Messier-Dowty
Member:	Nigel Petch Messier-Dowty

C. SUMMARY:

On June 6, 2011, about 2132 Central Daylight Time (CDT), N866AS, a Bombardier CL-600-2B19, operated as Skywest Airlines flight 4443, landed with the right main landing gear retracted on runway 19R at the General Mitchell International Airport (MKE), Milwaukee, Wisconsin (figure 1). The 2 pilots, 1 flight attendant, and 41 passengers reported no injuries. All of the airplane occupants evacuated the airplane via the main cabin door. The scheduled domestic passenger flight was conducted under the provisions of 14 Code of Federal Regulations Part 121. Visual meteorological conditions prevailed and an activated instrument flight rules flight plan was on file.

The Systems group was formed after the on-scene phase of the investigation, which was conducted at the General Mitchell Airport (MKE), Milwaukee, Wisconsin, during the period of June 6 - 10, 2011.

Figure 1 Airplane N866AS after landing in Milwaukee

D. DETAILS OF THE INVESTIGATION:

D.1 Recovery Operation:

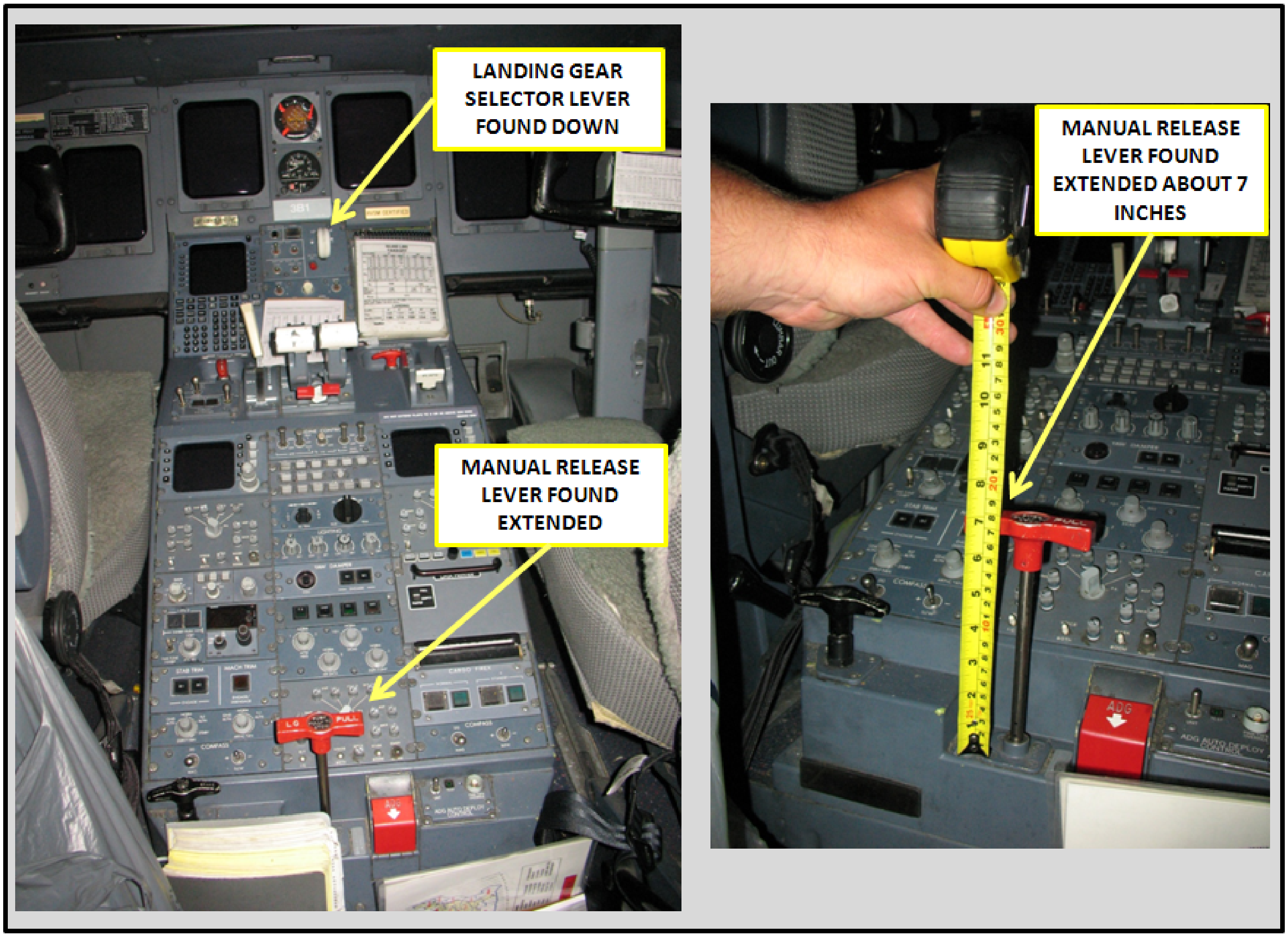
A general visual inspection of the airplane, before it was recovered from the runway, revealed that the right main landing gear (MLG) remained within its wheel well. The nose landing gear (NLG) and left MLG were in their down and locked position. Because of this configuration, the outboard end of the right wing and its trailing edge flaps were resting on the ground.

The aircraft was lifted using airbags that were positioned beneath the right wing and the tail. Once the proper height was achieved, a jack was placed under the right wing to support the aircraft. A visual inspection of the landing gear revealed that the right MLG remained within its respective wheel well and its door was flush with the aircraft fairing (figure 2).

Figure 2 View showing the position of the main landing gear

An inspection of the cockpit revealed that the landing gear manual release handle remained extended approximately 7 inches (figure 3). A SkyWest Airlines maintenance technician pulled up on the handle[1] resulting in the handle moving approximately 3 additional inches to its fully extended position of 10 inches. The additional handle displacement resulted in the right MLG extending out of its wheel well. When the maintenance technician released the handle from its fully extended position, the handle automatically began to slowly retract causing the right MLG to stop extending. The handle had to be re-pulled and manually held in its fully extended position for the right MLG to extend to its down and locked position. A slight push on the right MLG was required to bring the gear down to the down and locked position.

Figure 3 View of the cockpit showing the position of the manual release handle



[1] When the handle was pulled all hydraulic pressure was OFF.

D.2 Airplane Information:

The Bombardier Canadair Regional Jet (CRJ) CL-600-2B19 is a twin-engine turbo jet. It is certified under the bilateral certification treaty with Canada in effect since 1971. The CRJ-100 (also known as the CRJ-200 and CL-600-2B19) is included in FAA Type Certification A21AE; it was certified January 21, 1993. The incident transport-category airplane, serial number 7517, was manufactured on June 15, 2001. The airplane was configured with 53 seats; 50 of which were passenger seats located in the main cabin. At the time of the incident, the airplane had 24,969.4 flight hours and 20,132 flight cycles.

D.3 Maintenance Information:

A review of the SkyWest Airlines maintenance records revealed that on April 9, 2011 and on May 2, 2011, a non-routine write-up was generated due to a "Gear Disagree" message displayed on the Engine Indication and Crew Alerting System (EICAS). Refer to Table 1 for a list of the two non-routine write-ups and the corrective actions that were accomplished by SkyWest Airlines.

Table 1 Maintenance actions

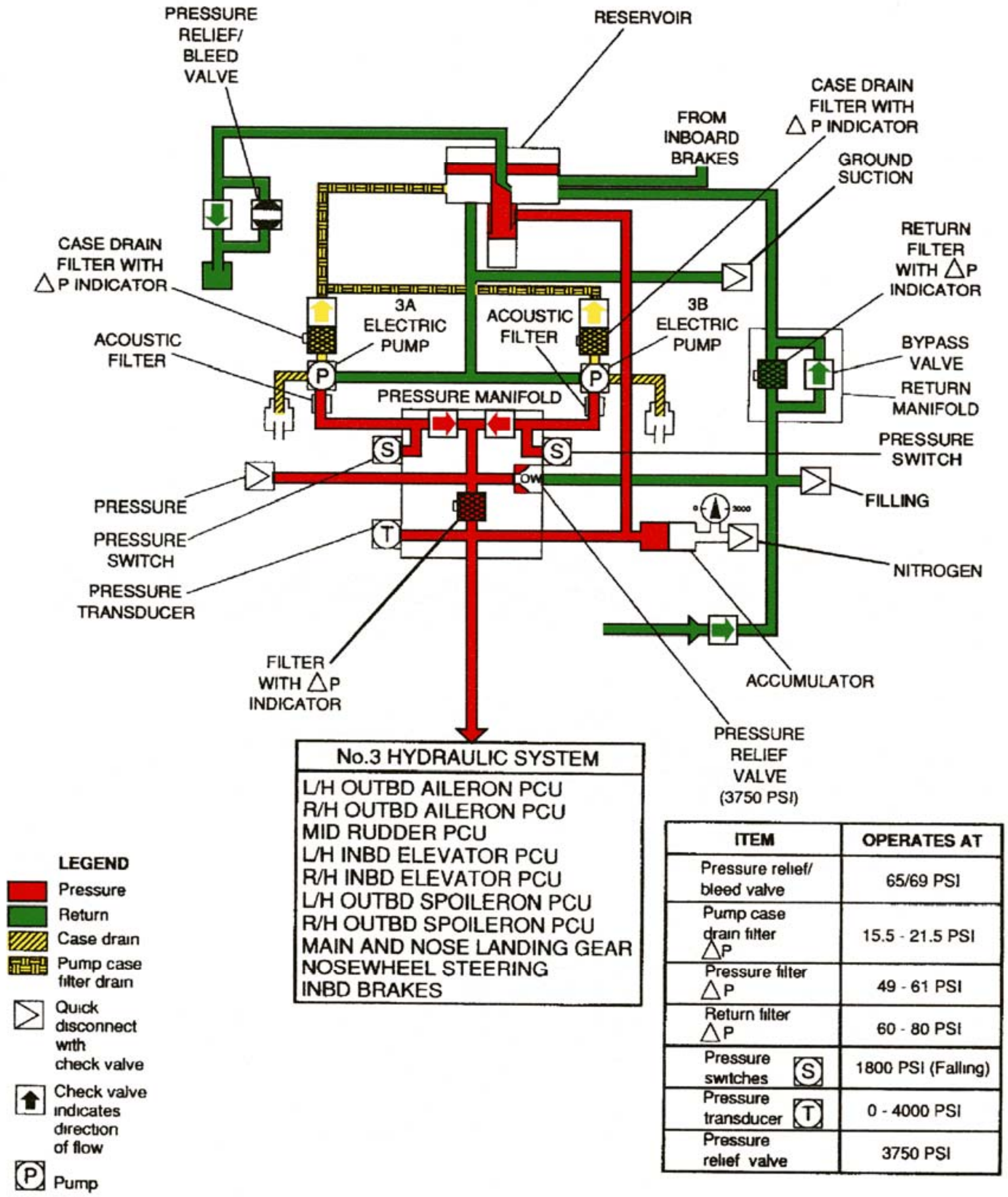
Date	Non-routine Write-Up	Corrective Action
4/09/2011	Gear disagree message: The right MLG did not extend for 3-4 minutes after selection.	Removed and replaced the MLG priority valve. Off - (P/N 4619-3, S/N 1472B) On - (P/N 4619-3, S/N2092B)
5/02/2011	After selecting the landing gear to down, the crew received a gear disagree message. On go-around, the right MLG came down and they received the down and locked indication.	Removed and replaced the right MLG sidestay actuator. Off - (P/N 17008-115, S/N 00854) On - (P/N 17008-115, S/N 01618)

D.4 Hydraulic System Number 3:

D.4.1 Description:

The Number 3 hydraulic system (Figure 4) is an independent hydraulic system that supplies the landing gear system, braking system and certain flight control systems with hydraulic pressure. This hydraulic system comprises two alternating current motor pumps, identified as ACMP 3A and ACMP 3B, to generate hydraulic power (3000 psi), a pressure manifold, and a return manifold. Pressure generation comes primarily from ACMP 3A, but because the system number 3 accumulator had been removed from the airplane in accordance with the requirements of FAA Airworthiness Directive 2010-22-012, ACMP 3B is also ON at all times during the flight.

Figure 4 Schematic of Hydraulic System Number 3



ITEM	OPERATES AT
Pressure relief/ bleed valve	65/69 PSI
Pump case drain filter △P	15.5 - 21.5 PSI
Pressure filter △P	49 - 61 PSI
Return filter △P	60 - 80 PSI
Pressure switches (S)	1800 PSI (Falling)
Pressure transducer (T)	0 - 4000 PSI
Pressure relief valve	3750 PSI

A pilot can control the operation of the ACMPs at the HYDRAULIC panel, which is located in the flight compartment. ACMP 3A is controlled by a two position toggle switch with selections of OFF or ON and ACMP 3B is controlled by a three position toggle switch with selections of OFF, ON or AUTO. When operating, the Number 3A and 3B ACMPs supply outlet pressure to the Number 3 hydraulic system pressure manifold.

The pressure manifold contains two inlet ports; one port for ACMP 3A pressure and one port for ACMP 3B pressure. The manifold also contains an external pressure switch, a filter bowl containing a 15 micron filter element, and a differential pressure indicator. The purpose of the differential pressure indicator (red button) is to provide a visual indication of a clogged or contaminated filter element. When a differential pressure of 49 to 61 psi is detected across the filter element, the red button extends 0.19 inches out of the manifold. At the pressure manifold, the fluid pressure is monitored by a pressure switch for low pressure indications (one switch for each pump).

A pressure transducer, located downstream of the pressure manifold filter, sends system number 3 pressure indications to the EICAS. From the pressure manifold, hydraulic system pressure is sent to the aircraft systems that use hydraulic fluid pressure. System pressure is also sent to the reservoir to maintain a head pressure of 55 psi, which makes sure that the suction lines of the ACMPs get positive pressure.

The return manifold contains a bypass valve, filter bowl with a 5 micron filter element, and a differential pressure indicator. A differential pressure indicator (red button) located on top of the case drain filter assembly, gives a visual indication of a clogged or contaminated filter element. The red button extends 0.19 inch when actuated by a pressure differential of more than 15.5 to 21.5 psi across the filter element.

D.4.2 Investigative Findings – Hydraulic System Number 3:

D.4.2.1 System Filters and Fluid Samples:

A review of SkyWest Airlines' maintenance program revealed that they perform a check of the filter differential pressure indicators (pressure, return and case drain filters) during each "A" check. An "A" check is a light inspection focusing on systems and their respective components. There are five "A" check intervals: A, 2A, 3A, 4A and 5A. Whenever a number precedes the letter, the interval for that task/inspection is the multiple of the "A" check interval (500 Flight Hours). The last "A" check was an "A6" check completed on April 16, 2011.

All filter elements are replaced at each "C" check. A "C" Check is a comprehensive inspection of installations with maximum access to components and systems in various zones. In addition, qualitative and quantitative checks are performed on the components / systems to detect deterioration in the performance of the components / systems. There are 4 "C" Check intervals: C, 2C, 3C, and 4C. Whenever a number precedes the letter, the interval for that task/inspection is the multiple of the "C" Check interval 5000 Flight Hours. The last "C" check was a "1C" check completed on February 8, 2011.

On June 8, 2010, while the airplane was in a hangar at MKE and prior to the number 3 hydraulic system being flushed, SkyWest Airlines removed the pressure filter and the return filter from this hydraulic system. The two filters were shipped directly to the NTSB Materials Laboratory for metallurgical examination. Reference NTSB Materials Laboratory Factual Report number 12-001 and the Computed Tomography Specialist's Factual Report contained within in the Safety Board's public docket for this incident.

After the removal and replacement of the pressure and return filters, SkyWest Airlines flushed and retained the hydraulic fluid from the number 3 hydraulic system. The retained fluid was shipped to the Wright-Patterson Air Force Base AFPET laboratory for a fluid analysis. SkyWest Airlines then acquired hydraulic fluid samples from the following components and sent them to the Wright-Patterson Air Force Base AFPET laboratory for a fluid analysis:

1. 3B Return Service connection.
2. Right MLG side stay actuator (extend side).
3. Right MLG side stay actuator (retract side).
4. Number 3 hydraulic system reservoir.
5. Left MLG side stay actuator (extend side).
6. Left MLG side stay actuator (retract side).
7. Number 3 hydraulic system Pressure manifold.

SkyWest Airlines once again flushed and retained the hydraulic fluid from the number 3 hydraulic system and sent the retained fluid to the Wright-Patterson Air Force Base AFPET laboratory for a fluid analysis. The Number 3 hydraulic system pressure and return filters were removed again and sent directly to the NTSB Materials Laboratory for metallurgical examination. Reference NTSB Materials Laboratory Factual Report number 12-001 contained within in the Safety Board's public docket for incident number CEN11IA379.

D.4.2.2 Hydraulic System 3 Pumps:

At the request of the NTSB, on June 9, 2010, a SkyWest Airlines maintenance technician removed the two alternating current motor pumps, identified as ACMP 3A (P/N 848847, S/N MX641429) and ACMP 3B (P/N 848847, S/N MX637374) from the airplane and provided them to the NTSB for further investigation. The NTSB shipped both pumps to Eaton Aerospace, located in Jackson, Mississippi for examination.

Examination of the pumps was conducted during the period of November 2-3, 2011 at Eaton Aerospace. In attendance were representatives from the NTSB, the Federal Aviation Administration (FAA), Bombardier, Eaton Aerospace and SkyWest Airlines.

D.4.2.2.1 ACMP-3B MX637374:

According to Bombardier, MX637374 was installed in position 3B on N866AS at the time of delivery from the factory in 2001.

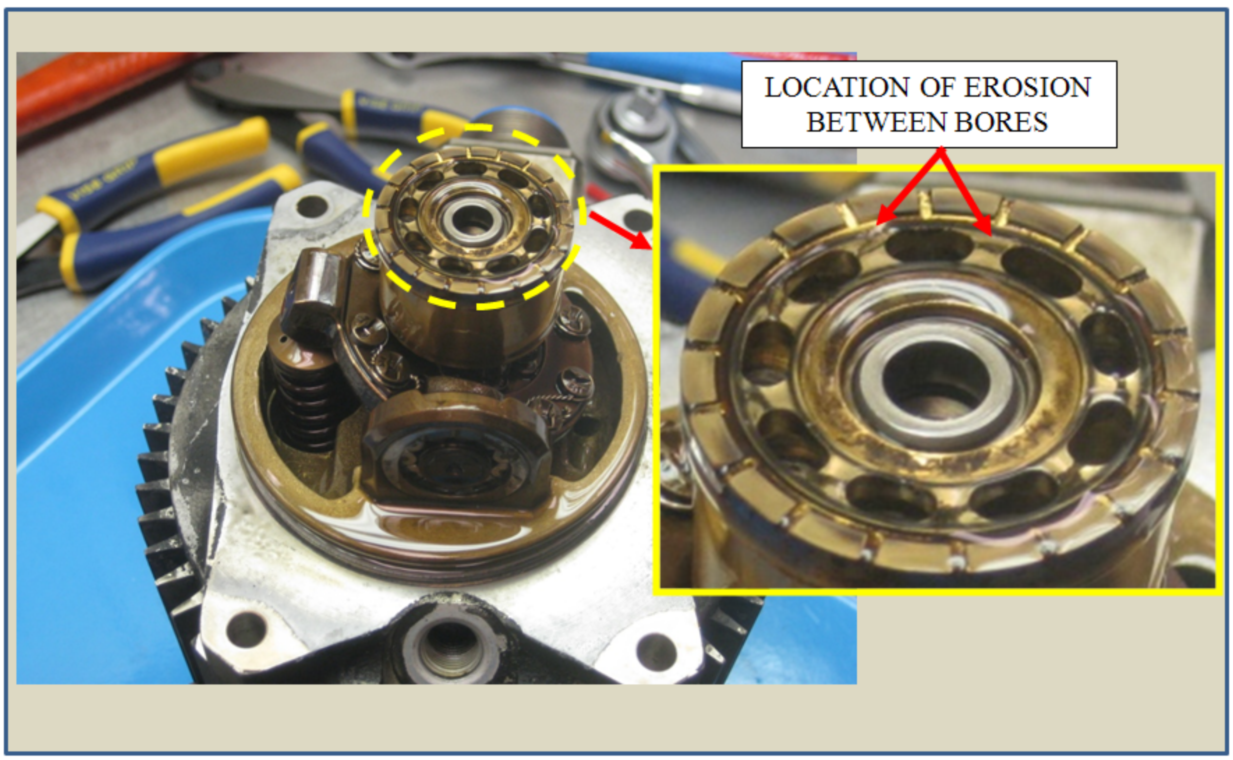
Functional testing was performed on the pump using Eaton Aerospace's Component Maintenance Manual (CMM) 29-10-45, Revision 3, and dated March 30, 2011. Once installed onto the test bench, the pumps output pressure was checked and found to be 2,933 psi which was less than the CMM pressure requirement of 3,000 ± 25 psi. In order to proceed with the functional testing, the pump's compensator was adjusted to increase the pump's output pressure to 3,014 psi. After this adjustment, the pump passed all test requirements (refer to table 2).

Table 2 Results of Pump Performance Testing

	Test Limits & Results		
Tests	Minimum	Maximum	Actual
Zero Flow Pressure Setting	2,975 psi	3025 psi	3,014 psi
Electrical phase Unbalance		2.0 amps	0.2 amps
Full Flow Delivery	3.7 gpm		3.83 gpm
Case Flow at Full Flow		0.4 gpm	0.2 gpm
Case Pressure	55 psi	65 psi	61 psi

Following the functional testing, the motor pump was disassembled and inspected. The inspection found that, other than the cylinder block and the compensator, all components were in good condition. When the compensator was removed from the pump, its respective spool assembly was difficult to remove; it felt as if it was sticking within its sleeve. Inspection of the sleeve identified that "coking" was present within the sleeve. According to Eaton, the fact that the compensator could be adjusted during the testing indicates that the "sticking" did not affect the operation of the pump. Visual examination of the surface of the cylinder block revealed circumferential erosion between the bores (figure 5).

Figure 5 View of the cylinder block from pump ACMP-3B MX637374



D.4.2.2.2 ACMP-3A MX641429:

MX641429 was originally installed on aircraft N435SW in 2001. It was removed from N435SW on March 31 2008 due to a maintenance write-up stating that the "pressure maxes out at 1,600 psi". Examination of the pump, by Niacc-Avitech Technologies, revealed that there was insufficient clearance between the piston shoes and the shoe bearing plate. The pump was repaired then installed on N866AS on May 3, 2008. Total airframe time on N866AS on that date shows as 18069.9 flight hours with 14516 cycles.

Functional testing was performed on the pump using Eaton Aerospace's Component Maintenance Manual (CMM) 29-10-45, Revision 3, and dated March 30, 2011. Once installed onto the test bench, the initial output pressure was checked and found to be 2,944 psi which was less than the CMM pressure requirement of 3,000 ± 25 psi. In order to proceed with the functional testing, the pump's compensator was adjusted to increase the pump's output pressure to 3,015 psi. Functional testing found that the pump was unable to meet the minimum requirement for full outlet flow delivery and exceeded the maximum requirement for case flow (reference table 3).

Table 3 Results of Pump Performance Testing

	Test Limits & Results		
Tests	Minimum	Maximum	Actual
Zero Flow Pressure Setting	2,975 psi	3025 psi	3,015
Electrical phase Unbalance	-----	2.0 amps	0.3 amps
Full Outlet Flow Delivery	3.7 gpm		**2.94 gpm (Failed)**
Case Flow at Full Flow	-----	0.4 gpm	**0.97 gpm (Failed)**
Case Pressure	55 psi	65 psi	60.8 psi

Following the functional testing, the motor pump was disassembled and inspected. The inspection found that, other than the cylinder block, all components were in good condition. Visual examination of the surface of the cylinder block revealed circumferential erosion between the bores similar to the erosion identified on pump ACMP-3B MX637374.

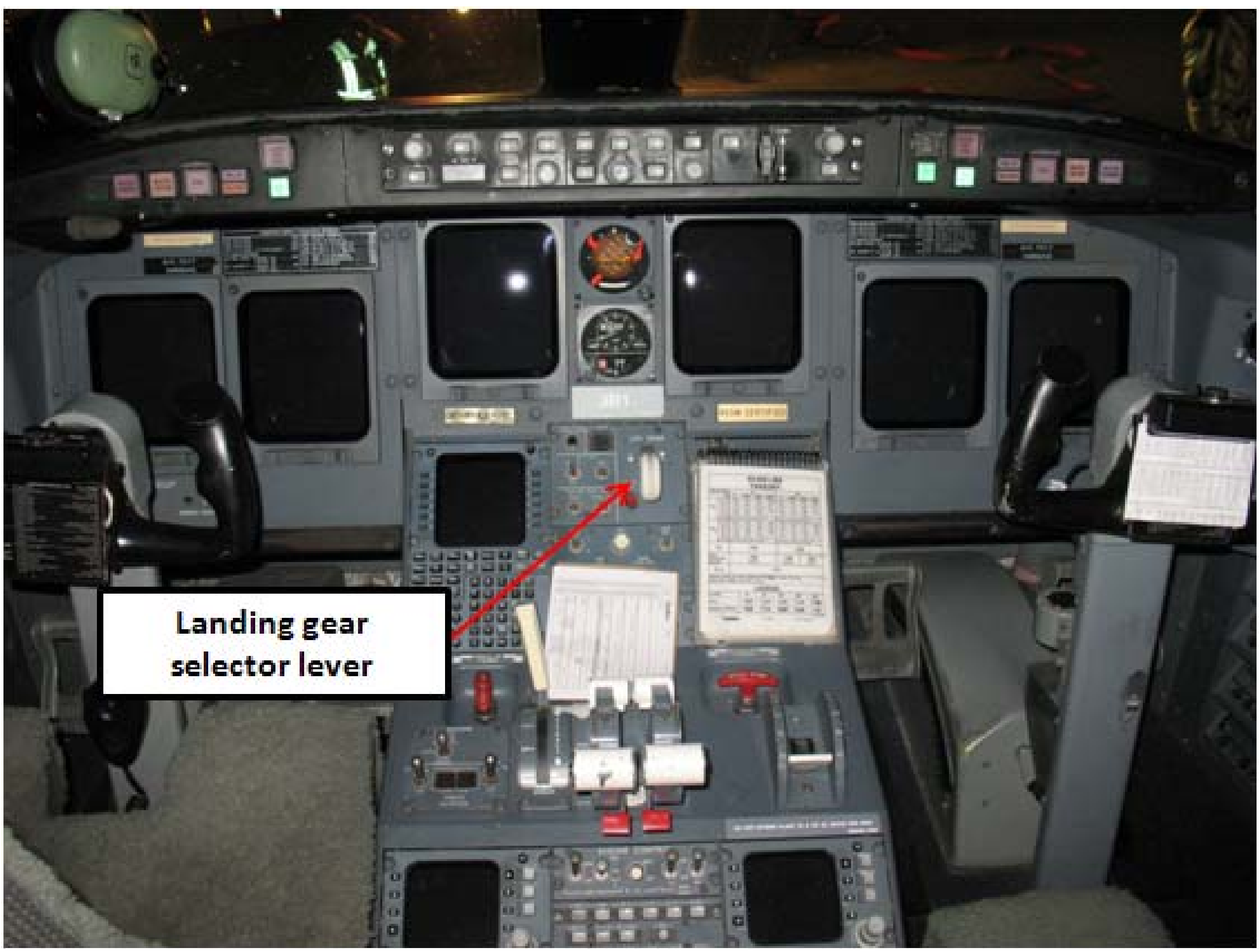
D.5 Landing Gear Control System Description:

The airplane is equipped with a tricycle–type landing gear system that comprises two main landing gear (MLG) assemblies mounted on the inboard part of each wing, and a nose gear assembly mounted directly below the flight compartment. Both MLG retract inward into recesses in the wing and center fuselage, and the nose landing gear (NLG) retracts forward. The landing gear system, operated by a selector lever, is electrically controlled by a proximity sensor electronic unit (PSEU) and hydraulically operated by the Number 3 hydraulic system. The MLG system comprises a selector valve, run-around and bypass valve, a left and right MLG sidestay actuator and uplock mechanism. The NLG system comprises a selector valve, extension/retraction actuator, uplock assembly, downlock, nose selector valve, and priority valve, bypass valves, restrictors, and check valves.

The NLG system is equipped with three doors used to prevent damage to the system components within the wheel well and increase aerodynamic efficiency when the landing gear is in the retracted position. Two of the doors are operated hydraulically and hinged horizontally along the nose landing gear bay; they are independent of the NLG. The remaining door is located aft of the other NLG doors and hinged perpendicular, mechanically attached to the NLG. During extension, the forward doors open before the NLG is released from the uplock. The nose gear assembly will then extend, simultaneously opening the rear door. Upon reaching full extension (when the NLG is down and locked), the forward doors close and remain in that configuration until a retraction command is selected.

The cockpit is equipped with a landing gear control panel, which is located beneath the EICAS displays on the center pedestal (figure 6). A landing gear selector lever is installed in the control panel. When the selector lever is manipulated, an electrical command is sent to the PSEU to extend or retract the landing gear. Both MLG are extended in the outboard direction by the MLG sidestay actuator and are hydro/mechanically locked in place for landing. They are retracted by the MLG side stay actuator in the inboard direction and locked in the MLG wheel wells during flight by their respective uplock mechanism.

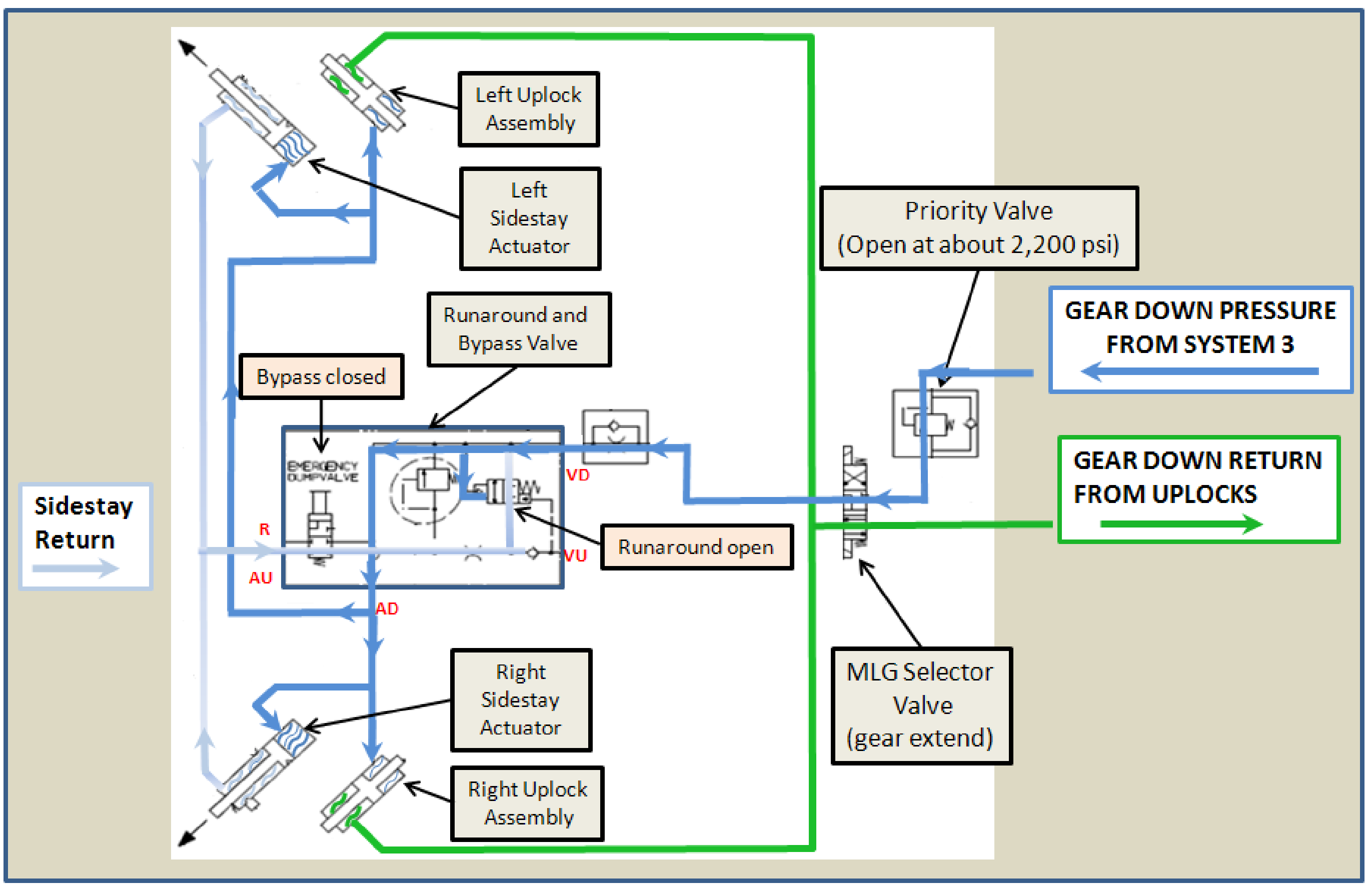
Figure 6 View of the cockpit from an exemplar aircraft showing the landing gear lever



D.5.1 Main Landing Gear Operation – Normal:

Normal landing gear extension is commanded by placing the landing gear selector lever to the gear down position. In this position, the selector lever module sends an electrical extension command to the proximity sensor system and provides electrical signals to command the MLG and the NLG selector valves to their gear down position. When the MLG selector valve transitions to its gear down position, the valve is designed to allow system 3 hydraulic fluid, from the priority valve, to be ported, via the run-around and bypass valve, simultaneously to the uplock assembly and the extend side of the sidestay actuator for each MLG. The hydraulic pressure causes each uplock assembly to unlatch and release the MLG assembly. When unlatched, an uplock sensor (on the uplock mechanism) provides an input to the PSEU, which in turn signals the data concentrator units (DCUs) to generate an amber 'IN TRANSIT' gear indication on the EICAS display for each of the gear. When hydraulic pressure is supplied to the extend side of the gear actuators (sidestay), the actuator extends causing each MLG to extend to its full down and locked position; the extension rate is controlled by a restrictor in the actuator up line. Refer to figure 7 for a schematic of the landing gear system configured to extend the MLG.

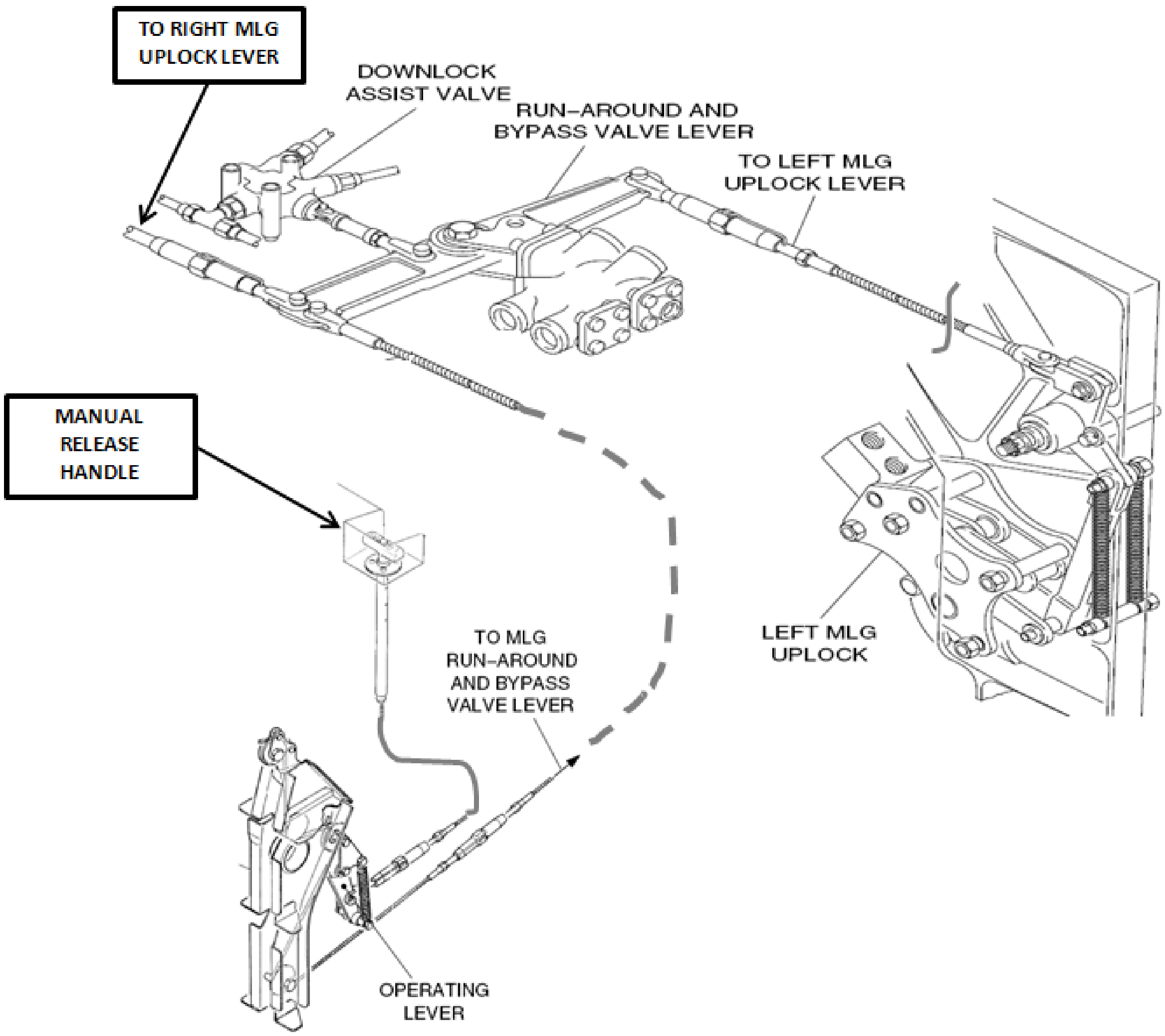
Figure 7 Schematic of the main landing gear system configured to extend the gear



D.5.2 Landing Gear Operation – Alternate Release:

The landing gear alternate release system provides the flight crew with another means to extend the landing gear in the event that an electrical or hydraulic failure within the landing gear system prevents the landing gear from being extended normally. The alternate extension system is controlled by the vertical movement of a T-shaped manual release handle. Refer to figure 8 for a schematic of the system. To extend the landing gear manually, a flight crew member must pull up on the manual release handle. Movement of the handle is transmitted by a cable circuit to the NLG uplock release mechanism and to the MLG release mechanism.

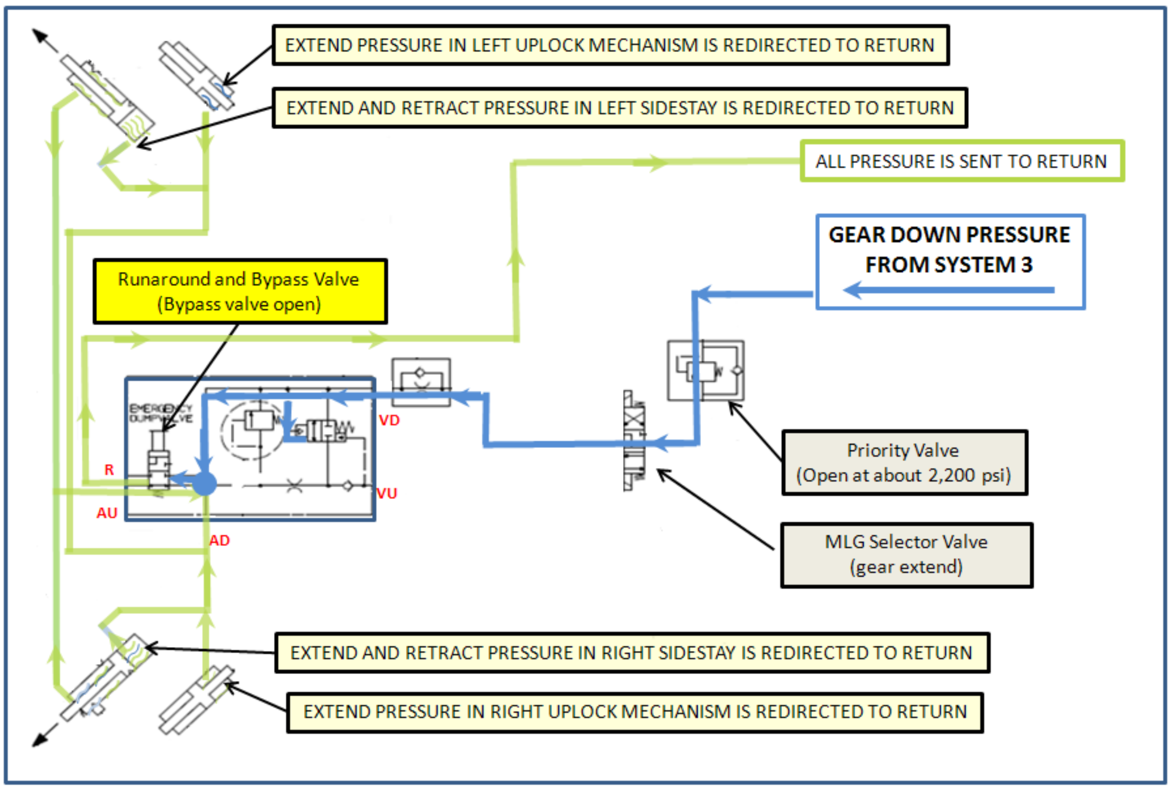
Figure 8 Schematic of the gear alternate extension system



For the NLG system, the mechanisms activates the NLG door bypass valve and the NLG bypass valve and releases the NLG uplock and nose door lock. For the MLG system, rotation of the interconnect lever results in three actions: 1) the displacement is transmitted by two cables to the release levers on the left and the right uplock mechanism to unlock the uplock mechanism permitting the gear to extend by gravity and 2) re-positions the runaround and bypass valve into bypass mode and 3) positions the assist valve to pressurize the assist actuator.

In bypass mode, the valve connects the extend pressure from the selector valve and both extend and retract pressure from the sidestay actuators and the extend pressure of the uplock assembly to an independent return line. The extend pressure of the uplock assembly is sent to the return line via the selector valve and check valves. The removal of all hydraulic pressure from the uplock mechanisms and sidestay actuators allows the gear to free-fall regardless of the position of the MLG selector valve. The activation of the downlock assist selector valve results in the valve porting hydraulic system Number 2 pressure to the MLG downlock assist actuators to assure down locking of the main gears after free-falling. Refer to figure 9 for a schematic of the landing gear system showing the flow of hydraulic fluid after the manual release handle is pulled.

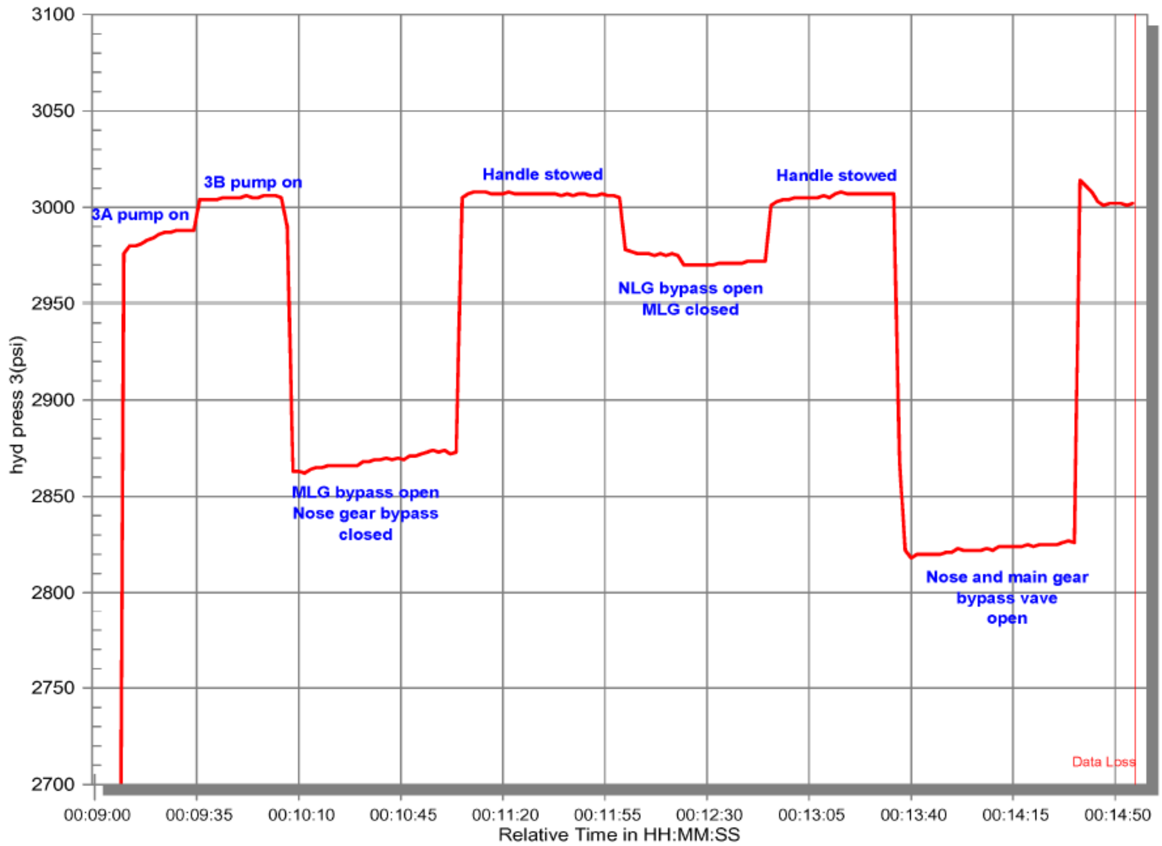
Figure 9 Schematic of landing gear system after manual release pulled



D.5.3 MLG & NLG Manual Bypass Valve Pressure Drop Test:

On August 4, 2011, SkyWest Airlines conducted a test on the landing gear system to determine the pressure drop in system 3 when the MLG and NLG bypass valves are commanded to bypass mode. They also performed this test for each valve separately (figure 10).

Figure 10 Plot showing the pressure drops due to the landing gear system bypass valves



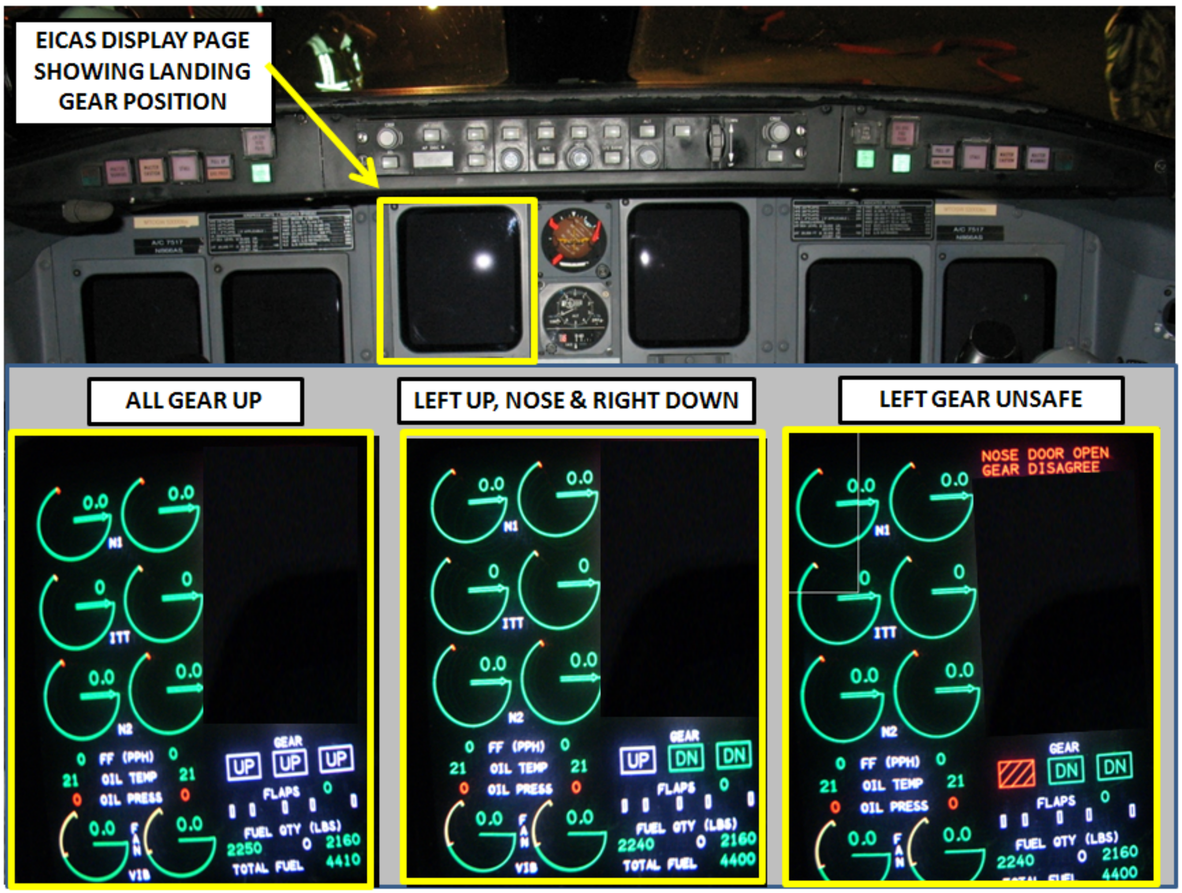
D.5.4 Landing Gear Indication and Warning:

The landing gear indication system provides the status of each landing gear position (down, intransit, or up) on the landing gear display area on the EICAS primary page. The primary page contains three rectangles that will change color depending on the position of the landing gear. Refer to figure 11 for a schematic of the EICAS primary page. When a gear assembly is “up and locked”, its respective rectangle will be colored white and display “UP”. When the indication system detects that a gear assembly is not “up and locked” or “down and locked”, its respective rectangle will transition to amber and when a gear assembly is “down and locked”, its respective rectangle will be colored green and display “DN”. If any landing gear remains in transit for longer than 28 seconds, the amber intransit indication of that affected gear will change to red (gear unsafe). Simultaneously a red ‘GEAR DISAGREE’ message will be displayed, accompanied by a ‘GEAR DISAGREE’ aural warning message.

When any landing gear assembly remains in its up and locked position for longer than 6 seconds after the landing gear has been commanded down, this will result in a landing gear disagree aural warning being annunciated along with an EICAS red gear disagree warning message. This warning will also be annunciated when any landing gear assembly remains in its downlock position for longer than 6 seconds when the landing gear has been commanded up.

If the landing gear selector lever remains "UP" during the manual extension, the EICAS immediately displays a "GEAR DISAGREE" message and the master warning illuminates and the corresponding cancellable voice message sounds.

Figure 11 Landing gear displays on EICAS



The landing gear indication and warning system comprises a proximity sensing electronic unit (PSEU) and multiple proximity sensors and switches located within the control system. The PSEU logic analyzes inputs from these various proximity sensors and switches to determine the status of the landing gear and doors. The resulting output is sent via the ARINC 429 bus to the EICAS system (primary page) and master caution/warning panel on the glare shield.

A proximity sensor is installed on the exterior surface of each landing gear uplock assembly and detects when its respective gear assembly is in the up and locked position. The target for this sensor is attached to the uplock lever and not to the latch. Testing found that the uplock lever can be moved (by the uplock actuator or the manual release system) to a position that indicates the gear is not up and locked (target FAR), but the latch assembly has not released its respective gear assembly.

Two proximity sensors are mounted externally on each MLG sidestay actuator. These sensors are placed 90 degrees offset and provide a means of detecting a main landing gear downlock position and are referred to as downlock sensors Number 1 and 2.

D.6 Investigative Findings:

D.6.1 Landing Gear System Sequence of Events from the Flight Data Recorder:

During the event landing, the flight crew initially attempted to extend the landing gear using the landing gear selector lever. According to the flight data recorder data, at gear down selection, the MLG discrete's "gear uplock-left" and "gear uplock-right" transitioned from "up and locked" to "not up and locked". After approximately 8 seconds, the left MLG discrete "gear downlock-left" indicated "down and locked". After approximately 112 seconds, the right MLG discrete "gear downlock-right" indicated "down and locked". The nose landing gear (NLG) discrete "gear uplock-nose" transitioned from "up and locked" to "not up and locked" about 4 seconds after gear down selection and required about 9 seconds to reach down and locked.

Approximately 150 seconds after initial gear down selection, the landing gear was selected to up. The MLG discrete's "gear downlock-right" and "gear downlock-left" transitioned from "down and locked" to "not down and locked". Within approximately 14 seconds, the MLG discrete's "gear uplock-left" and "gear uplock-right" transitioned from "not up and locked" to "up and locked". The NLG required about 10 seconds to transition to up and locked. All gear remained up and locked for about 38 seconds at which time it was selected down a second time.

According to the flight data recorder data, at gear down selection, the MLG discrete's "gear uplock-left" and "gear uplock-right" transitioned from "up and locked" to "not up and locked" and after 2 seconds, the NLG discrete "gear uplock-nose" transitioned from "up and locked" to "not up and locked". Within about 10 seconds, the NLG transitioned to "down and locked" while both MLG remained indication "not up and locked". The landing gear was selected to up again.

After attempting to extend the landing gear several times using the selector lever and, at least once, using the gear alternate extension handle, the flight crew was able to fully extend the left MLG along with the nose gear. However, the EICAS continued to indicate that the right MLG remained "in-transit"

D.6.2 Landing Gear System Actuation in Milwaukee:

On June 9, 2010 testing was conducted on the landing gear control system while the airplane was on jacks in the hangar at MKE. In an attempt to duplicate the event condition (right MLG remaining not down and locked when commanded down), the landing gear was extended and retracted multiple times by cycling the landing gear selector lever. For this test, the Number 3A and 3B hydraulic pumps, along with the Number 2 hydraulic ACMP pump, were operating. When the landing gear selector lever was moved from up to down, both MLG were observed to move to their down and locked position within approximately 13 seconds. The landing gear system was cycled an additional 20 times and no anomalies with the system were noted.

Because the flight data recorder data indicated that the flight crews action of pulling the landing gear manual release handle during the descent failed to extend the right MLG, a test of this system was conducted. SkyWest Airlines aircraft maintenance manual (AMM) 32-34-00, titled "manual release system, landing gear – adjustment/test" dated May 10, 2009 contains a procedure to measure and record the actual travel of the manual release handle, the force that is required to release the landing gear, and also the NLG extension times. The procedure specifies the following requirements:

1. The force required to release the landing gear must be between 25 and 46 pounds.
2. The actual travel dimension of the manual release handle must be a maximum of 7.75 inches to release the landing gear.
3. The NLG extension time must be a maximum of 14 seconds.
4. The MLG extension time must be a maximum of 21 seconds.

A test of the landing gear alternate release system was conducted with hydraulic system number 3 "ON" and with the landing gear selector lever positioned to "UP". The alternate system was cycled three times and the following observations were noted:

1. A maximum force of 56- 60 pounds was required to pull the handle to its fully extended position of 10 inches.
2. When the force to hold the handle in its fully extended position was removed, the handle would not remain locked in its fully extended position, it retracted to a position between 6.5 and 8.0 inches.
3. On two of the alternate gear extension tests, all three of the gear extended to their full down and locked position when the handle was pulled.
4. On one of the alternate gear extension tests, both MLG fully extended, however, the NLG did not extend when the handle was pulled. Troubleshooting found that the manual release handle had not been fully extended and therefore was not allowing the NLG bypass valve to go into its bypass mode. When applying a slight load to the NLG assembly a resistance was felt and it could not be moved to its down and locked position. In order to get the NLG to fully extend, the manual release handle had to be pulled and maintained at its fully extended position.

At the request of the NTSB, on June 9, 2010, a SkyWest Airlines maintenance technician removed the manual release landing gear handle assembly from the airplane and provided it to the NTSB for further investigation.

D.6.3 Landing Gear Manual Release Handle Examination:

The NTSB sent the handle having part number 2605890-001 and serial number 533 to AeroControlex, located in South Euclid, Ohio for examination.

Examination of the handle was conducted on September 27, 2011 at AeroControlex. In attendance were representatives from the NTSB, the Federal Aviation Administration (FAA), Bombardier, AeroControlex and SkyWest Airlines.

Functional testing found that the locking mechanism contained within the handle assembly failed to maintain the handle in its fully extended position (10 inches) when a retract load of 75 ± 2.5 lbs was applied to the assembly as specified in the test procedure[2]. When this load was applied, the handle fully retracted. Additional testing found that when a load of 25 pounds was applied to the handle, the handle began to slowly retract from its fully extended position. Once the handle reached a position of 6.71 inches, it stopped retracting and remained in this position.

Disassembly of the handle assembly did not find any mechanical discrepancies with the assembly, but did reveal that its inner housing and outer slider appeared to have an oily material coating of unknown origin. A sample of this material was sent to the NTSB materials laboratory and identified as a lubricant. The design of the handle assembly does not call for lubricants to be applied to the handle assembly.

D.6.4 MLG Selector Valve:

The landing gear system was equipped with a MLG selector valve, part number 750005000, serial number 0734; it was manufactured by Tactair Fluid Controls in August 2000. The valve was last overhauled by Tactair's repair station in May of 2008 and was overhauled, recertified to ATP 1ATP750005000 and returned to service.

The MLG selector valve is a four-way, three position, solenoid-operated valve that has two solenoids, solenoid A and solenoid B. The selector valve is designed to direct hydraulic pressure to the left and right MLG sidestay actuator down ports when solenoid A is energized and to the up port of the left and right MLG sidestay actuator when solenoid B is energized. The selector valve is installed on the lower surface of the hydraulic beam in the MLG wheel bay and is controlled by the PSEU.

On August 10, 2011 Tactair Fluid Controls conducted an examination of the selector valve at their facility located in Liverpool, New York. The examinations were conducted under the supervision of the Federal Aviation Administration and witnessed by representatives from SkyWest Airlines, Tactair and Bombardier.

A sample of fluid was obtained from the valve before any functional tests were conducted on the unit. The sample was observed to be clean and no evidence of residual fluid contamination or excessive foreign particles was identified.

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[2] AeroControlex test procedure TP 29-0058, titled "Investigation Test Plan for the Landing Gear Handle Assembly, Manual release".

Functional testing was conducted on the selector valve per acceptance test procedure (ATP) ATP750005000. The valve passed all tests and no discrepancies were identified that would have prevented the valve from operating when commanded.

In addition to the ATP tests, the temperature of solenoids "A" and "B" were recorded prior to, and immediately following hydraulic testing. Prior to the testing the temperature of solenoids "A" and "B" was measured and found to be 70 degrees F. After the testing the temperature of solenoids "A" and "B" was measured and found to be 100 degrees F.

The selector valve was disassembled and no anomalies were noted.

D.6.5 Landing Gear Sidestay Actuator:

D.6.5.1 Description:

Each MLG was equipped with a sidestay actuator that hydraulically extends or retracts its respective gear assembly. The sidestay actuator includes a piston, cylinder, restrictor, and an internal locking mechanism. The cylinder body contains two hydraulic ports (port A and port B): one for fluid to extend the actuator piston, and the other used to port fluid from the retract port (on the opposite side of the cylinder). When the gear is commanded to extend, the actuator receives hydraulic pressure (about 3,000 psi) at its extend port. This pressure reacts against the piston head resulting in the piston rod extending. The rate of extension is controlled primarily by the retract line restrictor in Port B.

D.6.5.2 Investigative Findings:

Both sidestay actuators remained connected to the airplane at their respective attachment locations. The actuator installed on the left MLG was identified as P/N 17008-109, S/N 00205 and the actuator installed on the right MLG was identified as P/N 17008-115, S/N 01618. Visual inspection of the actuators and their associated components (hydraulic connections) revealed that all components were intact, undamaged and remained connected to their respective parts via attachment hardware. Neither actuator exhibited evidence of unusual wear, binding, or foreign object damage.

According to SkyWest's maintenance records, the left sidestay actuator was installed on the airplane on July 23, 2010, and the right sidestay actuator was installed on the airplane on May 2, 2011.

The actuators were removed from the airplane and shipped to GE Aviation Systems LLC, located in Yakima, Washington, for examination.

During the period of October 4-5, 2011, GE Aviation examined and disassembled the actuators at their facility located in Yakima, Washington. The examinations were conducted under the supervision of the Federal Aviation Administration and witnessed by representatives from SkyWest Airlines, Messier-Dowty, and Bombardier.

D.6.5.3 Examination/Disassembly of the Left MLG Actuator:

The actuator was received in its fully extended position. A general visual inspection of the actuator revealed no abnormalities. Prior to conducting any functional testing, hydraulic fluid was drained from the unit by compressing the actuator's piston. The fluid sample was provided to the Herguth Laboratories and GE (Yakima) for evaluation (reference table 3).

Table 3 Results of Fluid Analysis from the left MLG actuator

Test	Requirement	Actual
Particle Count	NAS1638 Class 9 or better[3]	NAS1638 Class 7
Viscosity at 40º C	12.5 cST (minimum)	7.42 cST
Acid/Base #	1.5 mg KOH/g (maximum)	0.08 mg KOH/g
Water Content	0.10% to 0.30%[2]	0.23%
Clorinated Solvent	200 ppm (maximum)[2]	12 ppm

Functional testing of the actuator did not reveal any anomalies or defects; all functional tests performed were acceptable. Disassembly and inspection of the actuator's components did not reveal any discrepancies.

D.6.5.4 Examination/Disassembly of the Right MLG Actuator:

The actuator was received in its fully extended position. A general visual inspection of the actuator revealed no abnormalities. Prior to conducting any functional testing, hydraulic fluid was drained from the unit by compressing the actuators piston. The fluid sample was provided to the Herguth Laboratories and GE (Yakima) for evaluation (reference table 4).

Table 4 Results of Fluid Analysis from the right MLG actuator

Test	Requirement	Actual
Particle Count	NAS1638 Class 9 or better[4]	NAS1638 Class 7
Viscosity at 40º C	12.5 cST (minimum)	7.44 cST
Acid/Base #	1.5 mg KOH/g (maximum)	0.07 mg KOH/g
Water Content	0.10% to 0.30%[2]	0.24%
Clorinated Solvent	200 ppm (maximum)[2]	12 ppm

Functional testing of the actuator did not reveal any anomalies or defects; all functional tests performed were acceptable.

The right sidestay actuator, S/N 01618, was repaired at a third party repair station. As a result of these repair activities, several inconsistencies were encountered during the

[3] Canadair AMM 29-10-00 May 10/2010 In-Service Limits
[4] Canadair AMM 29-10-00 May 10/2010 In-Service Limits

disassembly of the actuator. These inconsistencies did not cause any functional issues with the actuator, but are included below for reference.

1. Switch lever, P/N 17217-2, was found slightly bent localized to the piston side of the spherical ball.
2. Jam nut, P/N 17243-2 was found not adequately torque and improperly sealed.
3. Target guide, P/N 17254-2, was found not staked.
4. Indicator housing, P/N 17021-4, ventilation/drain was blocked with sealant.
5. Harness assembly clamp locations were incorrect.
6. Harness assembly 17300-143 proximity switch was found assembled at 1.125 turns. It should have been assembled at 0.5 – 0.75 turns.

D.6.6 Landing Gear Up-Lock Assembly:

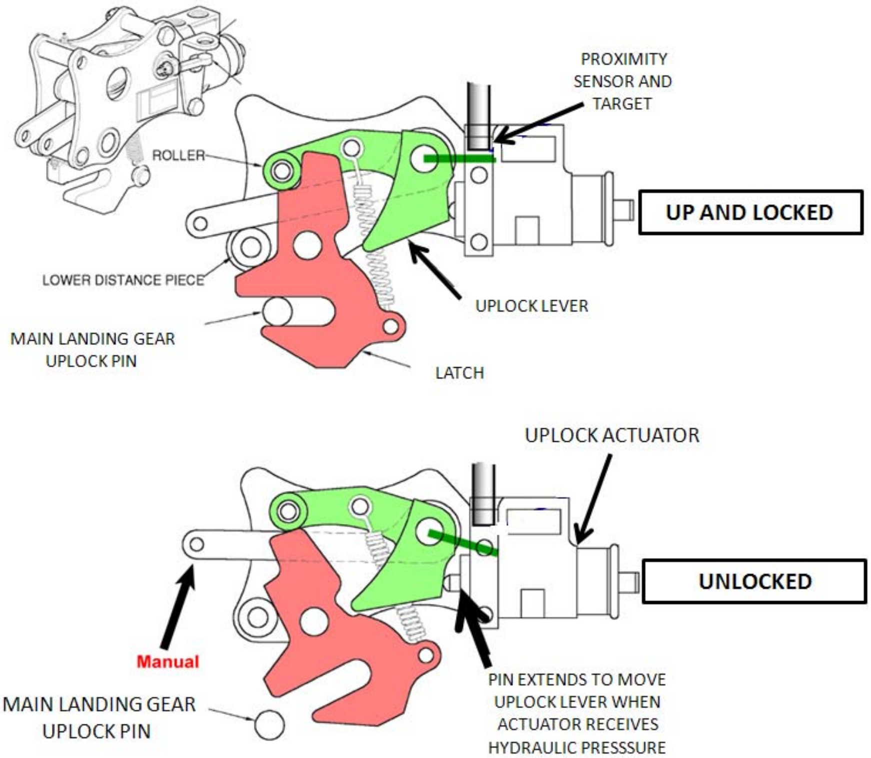
D.6.6.1 Description:

Both MLG are equipped with an uplock assembly (Figure 12) that locks each MLG in the up and locked position. The uplock assembly consists of a latch, an uplock lever, an actuator, and a manual release lever all installed between two side plates. The uplock lever assembly incorporates a roller that engages the upper shoulder of the latch to secure the gear assembly in the up and locked position. A proximity sensor is installed on the exterior surface of the uplock assembly and detects when the gear is up and locked.

In the normal mode of operation, each MLG is hydraulically released from its respective uplock assembly by the actuation of a hydraulic uplock release actuator. Each actuator has two ports, the piston head port and the rod end port. During MLG extension, the piston head port receives hydraulic pressure causing the piston to extend and move the uplock lever to release the latch assembly.

Through a manual gear extension system, there is a provision to unlock the MLG uplock assembly for emergency gear extension. This application enables the uplock to disengage from the mechanical uplock position and allow the MLG to extend by free fall method.

Figure 12 Schematic of the Uplock Assembly



D.6.6.2 Investigative Findings:

Both the right and the left MLG uplock assemblies remained connected to the airplane at their respective attachment locations. The right uplock mechanism, supplied by Messier-Dowty, was identified as P/N 17051-101 and S/N NGL/0877/00 (figure 13) and the left uplock mechanism, supplied by Messier-Dowty, was identified as P/N 17051-101 and S/N NGL/1182/01 (figure 14).

Visual inspection of the right uplock assembly at the working area of the latch (i.e. the hook where it is contacted by the uplock pin) revealed wear marks on its upper surface and wear marks and a dent on the lower surface. Visual inspection of the hook on left uplock assembly revealed contact marks on its upper surface. According to Messier Dowty, these marks are minor and consistent with normal in-service wear patterns

The airplane assembly instructions specify that the rigging gap between the root of an uplock hook and the edge of the MLG uplock pin should be a distance between 0.730 to 0.910 inches. To take this measurement, modeling clay was placed in the right uplock mechanism's hook while it was in the unlocked position. The MLG was then retracted allowing the uplock roller to displace a portion of the clay in the uplock hook. The MLG was then extended and the length of the remaining clay in the hook was measured. The remaining clay is equivalent to the gap between the uplock pin and the root of the uplock hook. The measured gap for the right uplock assembly hook was found to be 0.750 inches.

Figure 13 Right Main Landing Gear Uplock Assembly

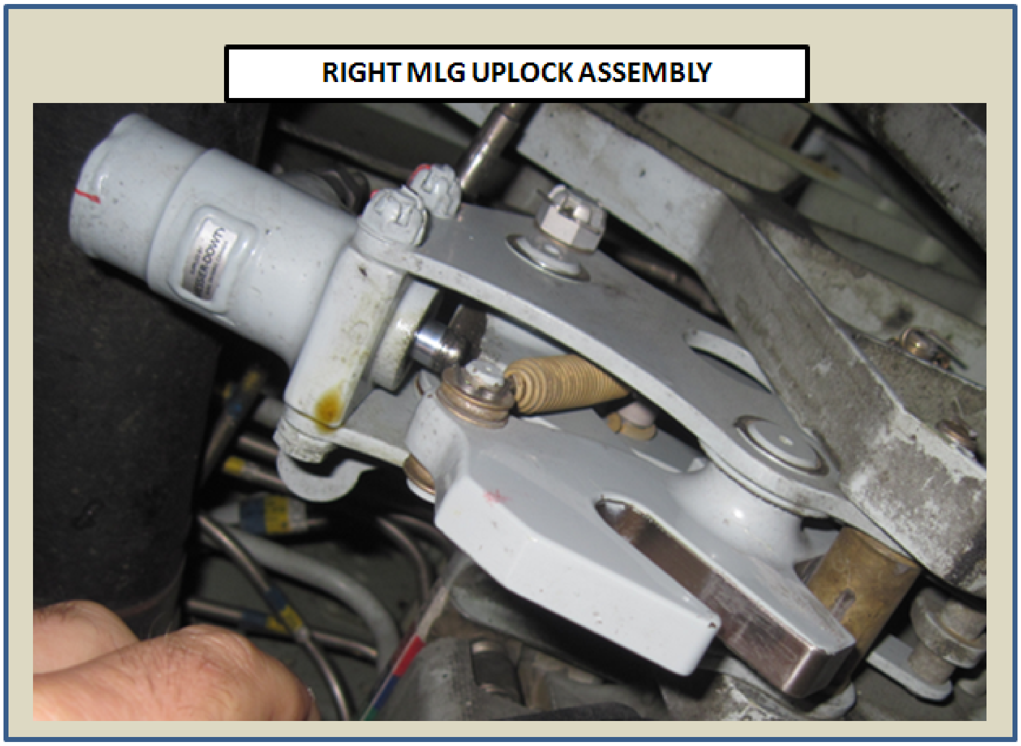
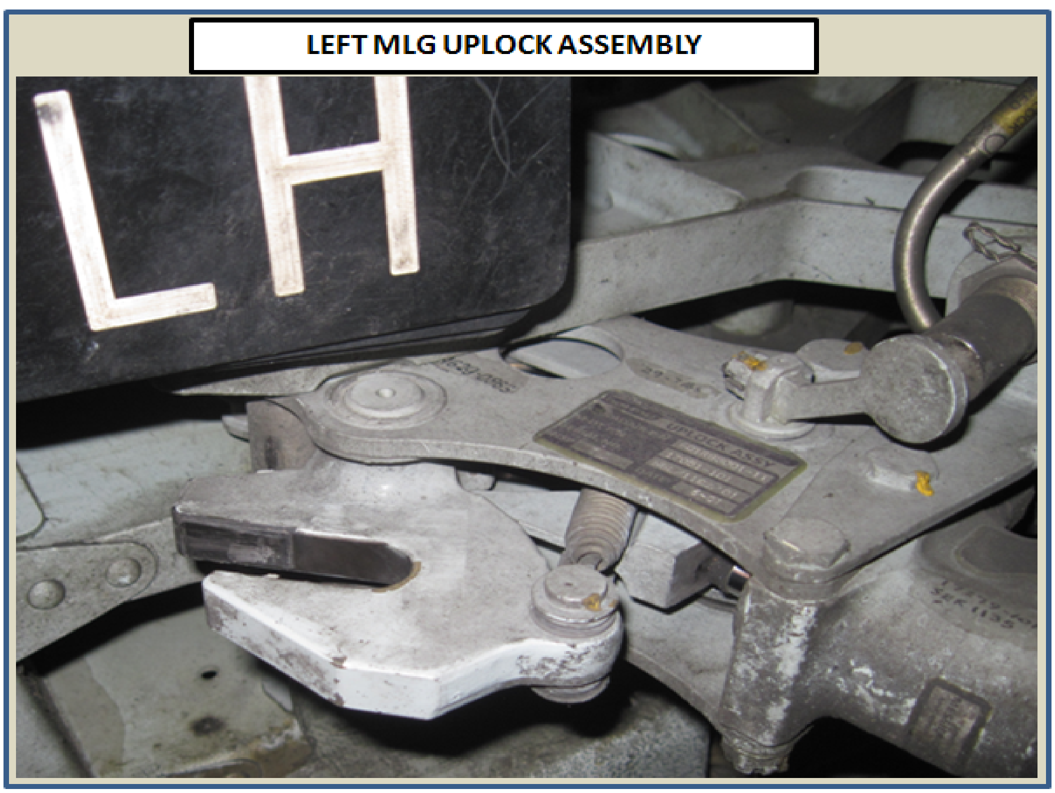


Figure 14 Left Main Landing Gear Uplock Assembly

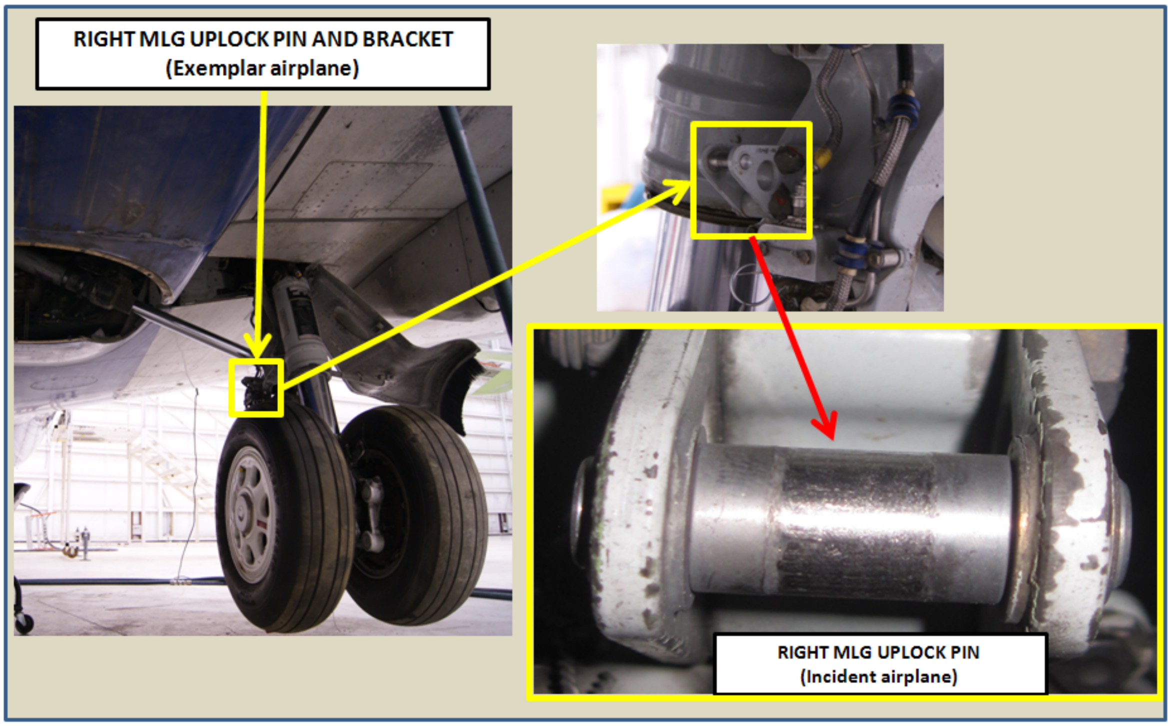


The right uplock assembly was manually closed and a measurement of the gap between the proximity sensor and its target was found to be 0.031 inches (requirement between 0.035 and 0.045 inch). The gap between the left uplock mechanism's proximity sensor and target was not measured.

Both the right and the left MLG uplock assemblies were removed from the airplane and shipped to Messier-Dowty for examination.

The right MLG uplock pin and assembly remained connected to the airplane at its respective attachment location. Inspection of the uplock pin revealed that it rotated smoothly and exhibited signs of wear, consistent with in-service usage. Refer to figure 15 for a photo of the pin assembly. The diameter of the pin was not measured during the on-scene activities. The left MLG uplock pin was not documented during the on-scene activities.

Figure 15 Location of the left MLG pin and bracket assembly



D.6.6.3 Examination/Disassembly of the MLG Uplock Assemblies:

On August 17, 2011, Messier-Dowty conducted an examination/disassembly of the left MLG uplock mechanism at their facility located in Ajax, Ontario, Canada. The examinations were conducted under the supervision of the Canadian Transportation Safety Board and witnessed by representatives from SkyWest Airlines, Messier-Dowty, and Bombardier.

D.6.6.3.1 Left Uplock Assembly:

Prior to conducting functional tests on the actuator, samples of hydraulic fluid were removed from the uplock actuator and provided to the Messier Dowty M&P laboratory for evaluation. According to the analysis, the submitted hydraulic sample appeared amber in color. A 2 ml. sample collected from the bottom of the container for SEM/EDX analysis was filtered using a 0.8 micron filter. The filter sample was prepared for SEM/EDX examination along with the black particulate collected from the surface of the filter using tape. Skydrol is typically violet in color. An analysis of the fluid sample revealed that it contained several particles. An analysis of the particles revealed the following:

1. Particle 1: A 20 micron by 50 micron particle.
2. Particle 2: A 50 micron particle containing Chromium, Iron, Nickel and Copper
3. Particle 3: A 50 micron particle containing Antimony
4. Particle 4: A 30 micron Teflon particle along with iron
5. Particle 5: A 50 micron by 100 micron particle.

Visual inspection found no abnormalities with the uplock assembly; normal wear patterns were observed on the latch with no discernable depth at pin contact locations.

The uplock assembly was installed on a hydraulic test stand and tested in accordance with the Acceptance Test Procedure 17051. All major functional checks passed their respective test requirement limits (Reference Table 5).

Table 5 Results of functional testing

ATP Paragraph	Requirement	Results
5.4.4 Seal Friction Test	Pressure to extend ≤ 50 PSIG	18 PSIG
	Pressure to retract ≤ 50 PSIG	25 PSIG
5.4.5 Alternate Release Force Test	Force must be ≤ 30 pounds	22 pounds
5.4.6 Unlocking Pressure Test	Unlocking Pressure No Load 150-250 PSIG	204 PSIG
	Unlocking Pressure Loaded 350-500 PSIG	346 PSIG
5.4.7 Locking Load Test	Locking Pressure must be ≤ 250 PSIG	183 PSIG

D.6.6.3.2 Right Uplock Assembly:

Prior to conducting functional tests on the actuator, samples of hydraulic fluid were removed from the uplock actuator and provided to the Messier Dowty M&P laboratory for evaluation. According to the analysis, the submitted hydraulic sample appeared amber in color. A 2 ml. sample collected from the bottom of the container for SEM/EDX analysis was filtered using a 0.8 micron filter. The filter sample was prepared for SEM/EDX examination along with the black particulate collected from the surface of the filter using tape. The observed yellow color for the submitted fluid suggests that the fluid is thermally stressed. Skydrol is typically violet in color. An analysis of the fluid sample revealed that it contained several particles. An analysis of the particles revealed the following:

1. Particle 1: A 75 micron particle consistent with garden variety rock.
2. Particle 2: A 40 micron particle consistent with garden variety rock.
3. Particle 3: A 60 micron particle consistent with garden variety rock.

4. Particle 4: A 30 micron particle containing Aluminum
5. Particle 5: A 20 micron particle consistent with garden variety rock.
6. Particle 6: A 10 micron by 20 micron particle containing Aluminum,

Visual inspection found no abnormalities with the uplock assembly; normal wear patterns were observed on the latch with no discernable depth at pin contact locations.

The uplock assembly was installed on a hydraulic test stand and tested in accordance with the Acceptance Test Procedure 17051. All major functional checks passed their respective test requirement limits.

Table 6 Results of functional testing

ATP Paragraph	Requirement	Results
5.4.4 Seal Friction Test	Pressure to extend ≤ 50 PSIG	18 PSIG
	Pressure to retract ≤ 50 PSIG	18 PSIG
5.4.5 Alternate Release Force Test	Force must be ≤ 30 pounds	25 pounds
5.4.6 Unlocking Pressure Test	Unlocking Pressure No Load 150-250 PSIG	189 PSIG
	Unlocking Pressure Loaded 350-500 PSIG	464 PSIG
5.4.7 Locking Load Test	Locking Pressure must be ≤ 250 PSIG	181 PSIG

D.6.7 Runaround and Bypass valve:

D.6.7.1 Description:

The runaround and bypass valve (R&BP), located downstream of the MLG selector valve, comprises two valve assemblies, a runaround valve and a bypass valve. During normal landing gear down selection[5], port VD (valve down) of the R&BP receives hydraulic pressure from the MLG selector valve. This fluid is ported through the valve and out the MLG actuator down (AD) port simultaneously to the extend side of both the left and right MLG sidestay actuators and the extend side of both the left and right MLG uplock mechanisms. During gear extension, the VU (Valve Up) port of the R&BP will be closed by a check valve preventing hydraulic pressure from being ported to return. Additionally, the runaround valve will be opened when the pressure differential between port (VD) and port (AU) is greater than 30 percent. This allows the return fluid from the retract side of both the left and right MLG sidestay actuators (AU) to be ported back to the MLG actuator down (AD) port of the R&BP.

When the landing gear manual release handle is pulled upward, a lever attached to the bypass valve assembly of the R&BP valve pulls the bypass valve outward opening the bypass valve and activating the bypass mode of the R&BP valve. In this configuration, all hydraulic fluid from ports VD, AU and AD is re-routed through the bypass valve port (R) to return. The bypass mode of the valve will be de-activated when the manual release

[5] During normal landing gear selection, the bypass valve of the R&BP will be closed (not activated).

handle is pushed down into its stowed position. According to the component maintenance manual[6], for the runaround and bypass valve P/N 750004000-003, a force of 40 pounds applied to the bypass valve lever should displace the valve approximately 0.2 inches to its activated position. When the R&BP is configured in bypass mode, it allows the MLG gear to free-fall regardless of the position of the MLG selector valve.

D.6.7.2 Runaround and Bypass Valve on Incident Airplane:

The runaround and bypass valve installed on the airplane at the time of the incident was identified as P/N 750004000-003, S/N 823A. This valve was manufactured by Kaiser Fluid Technologies on January 26, 2001. The valve has never been overhauled at Tactair Repair Station.

D.6.7.3 Examination/Disassembly of the Runaround and Bypass Valve:

On August 10, 2011, Tactair Fluid Controls conducted an examination/disassembly of the runaround and bypass valve at their facility located in Liverpool, New York. The examinations were conducted under the supervision of the Federal Aviation Administration and witnessed by representatives from SkyWest Airlines and Bombardier.

Prior to conducting functional testing on the R&BP, hydraulic pressure was applied to port VU and fluid was captured and retained from ports AU and AD for a patch test. The sample was visually observed to include some debris including a non-metallic strand. The runaround and bypass valve was subjected to acceptance test procedures ATP750004000 (Steps 5, 6, 7, 8, and 9). A summary of the results are as follows:

1. External leakage (ATP step 5.0): No external leakage was noted.

2. Internal leakage (ATP step 6.0):
   All leakage tests were found to be within limits.
   a) ATP Test 6.1: Leakage was observed to be about 7 drops per minute.
   b) ATP Test 6.2: Leakage was observed to be about 6 drops per minute.
   c) ATP Test 6.2: Leakage was observed to be about 48 CC's per minute.

3. Pressure drop test (ATP step 7.0):
   All pressure drop tests were found to be within limits.
   a) ATP Test 7.1: Pressure drop between ports VU to AU was 948 psi.
   b) ATP Test 7.2: Pressure drop between ports AD to VD was 54 psi.
   c) ATP Test 7.3: Pressure drop between ports AU to R was 20 psi.
   d) ATP Test 7.4: Pressure drop between ports AU to AD was 18 psi.

4. Operating force and bypass valve operation (ATP step 8.0)
   With a hydraulic pressure of 3,000 psi applied to the unit and a flow rate of 4.0 gallons per minute, the force to pull the handle of the bypass valve was measured and found to be between 36 and 39 pounds.

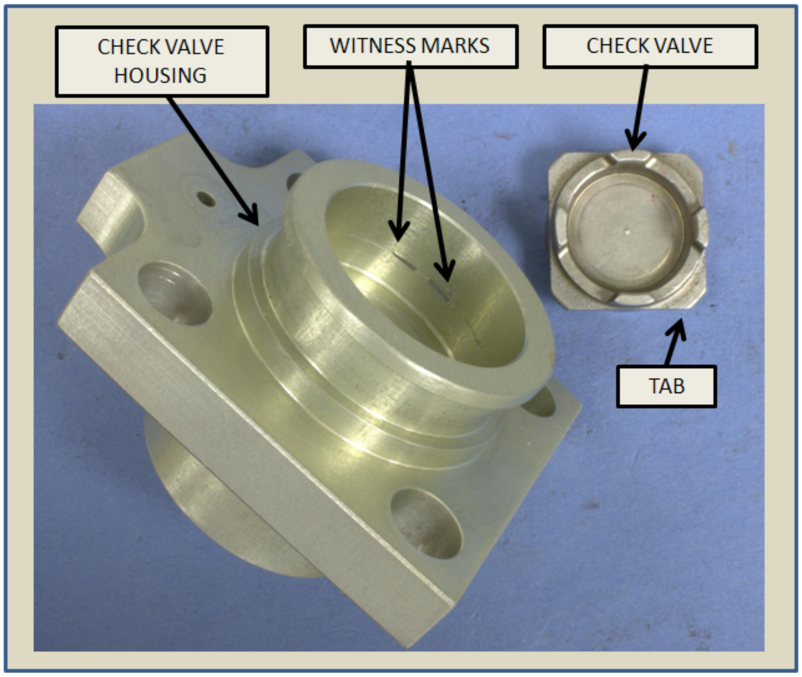
[6] Component Maintenance Manual (CMM) 32-30-03, dated July 1, 1992.

5. Runaround Valve Operation (ATP step 9.0)
   a) Runaround valve opened within the specified limits.

After testing, the R&BP valve was disassembled and examined. The following observations were noted.

a) Erosion was visually observed inside the valve body at the passages.
b) A piece of seal strand was present on the spool.
c) Witness marks were observed on the inside surface wall of the check valve housing (figure 16)[7]. The NTSB requested that Tactair ship the R&BP valve to the NTSB in Washington D.C.

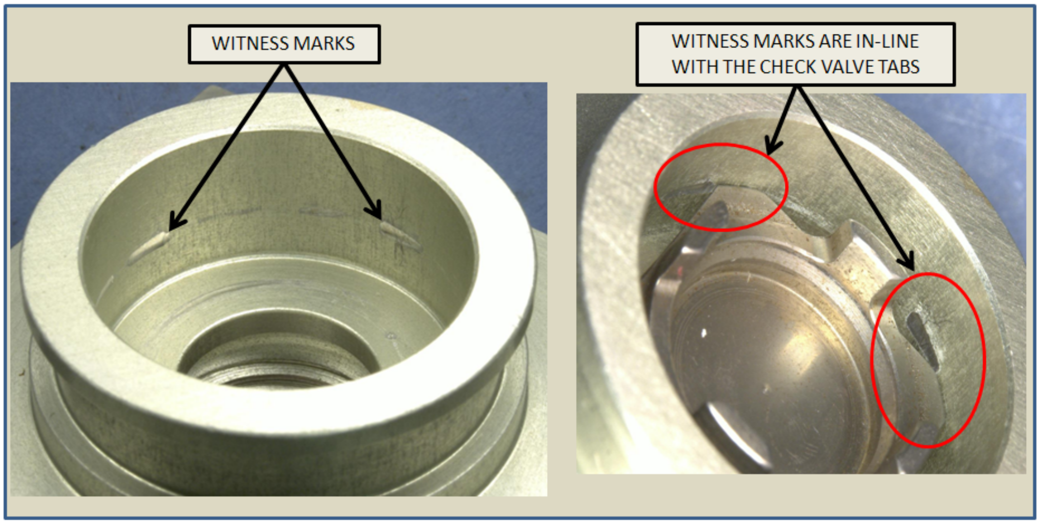
Figure 16 Check Valve and Housing Assembly



Upon receiving the R&BP valve, the NTSB examined the check valve and its respective housing under a microscope to evaluate the witness marks. Examination found that there were two sets of marks on the housing wall and they appeared to be slight indentations (removed material) having the approximate length and width as the tabs on the check valve (figure 17). The check valve was inserted into its housing which showed that the witness marks were in-line with the tab. The check valve was moved in and out and it was determined that the witness marks did not restrict the valve from moving.

[7] The photo of the check valve housing was taken at the NTSB laboratory in Washington D.C.

Figure 17 Witness Marks on Housing Wall



D.6.8 Priority Valve:

D.6.8.1 Description:

The landing gear system was equipped with a MLG priority valve that will close off and isolate hydraulic flow to the MLG system during periods of peak system flow demand from the flight control systems. If the pressure within System 3 falls below 2,200 PSI, the valve (poppet), which is spring-loaded, will move to it closed position preventing hydraulic flow to the MLG system. Once the pressure exceeds 2,200 ± 50 PSI, the poppet will re-open and allow hydraulic flow to the MLG system

On November 19, 2010, PneuDraulics conducted an examination/disassembly of the priority valve at their facility located in Rancho Cucamonga, California. The examinations were conducted under the supervision of the Federal Aviation Administration and witnessed by representatives from SkyWest Airlines.

D.6.8.2 Priority Valve on Incident Airplane:

The priority valve installed on the airplane at the time of the incident was identified as P/N 4619-3, S/N 2092B. According to PneuDraulics, this valve was first produced and shipped on March 31, 2009.

D.6.8.3 Inbound Preliminary Inspection:

Visual inspection of the unit revealed that both of its hydraulic ports were capped (figure 18). There were no anomalies other than insignificant tool marks on the wrench flat areas consistent with installation upon the aircraft. The safety wire was taut, normally oriented, and terminated with what appeared to be the original lead seal as installed during manufacture by PneuDraulics. The torque stripe was unbroken and appeared normal.

Figure 18 Priority Valve

D.6.8.4 Inbound Filter Patch:

A standard filter patch was taken for the purpose of evaluating and documenting the service environment in which the component had been installed. Various minor contaminates were found such as metallic particles, fibers, and elastomeric pieces.

D.6.8.5 Inbound Acceptance Test Procedure (ATP):

The priority valve was installed on a hydraulic test stand and tested in accordance with the original OEM Acceptance Test Procedure 4619-3, revision C. All major functional checks (cracking pressure, full flow pressure, constant pressure, reseat pressure, and reverse flow function test) passed their functional performance tests without failure (reference table 7).

Table 7 Results of Performance Testing

ATP Paragraph	Requirement	Results
3.4 Crack Pressure	2050-2300 PSIG	2095 PSIG
3.5 Full Flow	2300 PSIG Maximum	2237 PSIG
3.6 Pressure Characteristics	2650 PSIG Maximum	2635 PSIG at 5.0 GPM
3.7 Reseat Pressure	3.0 cc/minute	0.1 cc/minute
3.8 Reverse flow Function	100 PSID maximum at 5.0 GPM	46 PSID

Mike Hauf

Aircraft Systems Engineer