NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594
June 09, 2014

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

CEN13FA038

A. ACCIDENT:

Location:	Boyne City, MI
Date:	October 31, 2012
Time:	0930 local
Aircraft:	Piaggio P180, N401WS

B. SYSTEMS GROUP:

Chairman:	Adam Huray National Transportation Safety Board Washington, DC
Member:	Joshua Lindberg National Transportation Safety Board Denver, CO
Member:	Steven Betzer FAA Grand Rapids, MI
Member:	Carlo Cardu Piaggio Aero Industries S.p.A Genova, Italy
Member:	James Wise Flagship Private Air, LLC Belleville, MI
Member:	Simon Harris Messier-Bugatti-Dowty Gloucester, UK
Member:	Werner Dittrich Parker Mainz-Kastel, Germany

C. SUMMARY:

On October 31, 2012, about 0930 local time, a Piaggio P180 Avanti, N401WS, was damaged during a runway excursion while landing on runway 27 at Boyne City Municipal Airport in Boyne City, Michigan. The airplane was registered to Ann Arbor Aviation Partners LLC and operated by Flagship Private Air under the provisions of 14 Code of Federal Regulations Part 135 as a positioning flight. Instrument meteorological conditions prevailed for the flight and an instrument flight plan was filed. The certificated airline transport pilot and copilot were not injured. The flight originated from Willow Run Airport (KYIP) at 0820.

The pilot stated that after the airplane touched down, it made an uncommanded turn to the left and continued off of the runway. The airplane struck the airport perimeter fence and came to rest in the same location (See Figure 1).

Figure 1: Condition of Airplane After it Came to Rest

D. NOSE WHEEL STEERING SYSTEM DESCRIPTION:

The nose wheel steering system controls the airplane direction on the ground in response to rudder pedal movement. A control potentiometer operated by rudder pedal movement controls a hydraulic servo valve in a manifold assembly on the nose gear. The manifold assembly controls the movement of a hydraulic steering actuator and linkage. An electrical feed-back mechanism completes the closed loop control system.

The steering system has these main components:

– The steering manifold assembly
– The steering actuator
– The steering command potentiometer
– The flexible hoses
– The steering filter
– The steer master switches on the control wheel.

The steering manifold assembly includes the following components (See Figure 2):

– The select/bypass valve
– A servo valve
– Two restrictors
– Two relief valves
– Two non-return valves.

The select/bypass valve supplies hydraulic pressure to the servo valve. It also isolates the hydraulic supply and connects the actuator ports together to allow the nose wheel to castor when the steering is set to off. The servo valve controls the direction of fluid flow in proportion to the electrical control input signal from the rudder command potentiometer. The restrictors give shimmy damping when the steering is off. The relief valves protect the unit against pressure surges caused by external loads on the steering mechanism. The non-return valves prevent cavitation in the steering lines.

The steering master switches in the cockpit set the operational mode of the steering system. The two switches are on the LH horn of the Captain’s control wheel. There is a red steering OFF switch and a black two-position NOSE STEER switch. The NOSE STEER switch is used to engage the system in TAKE OFF or TAXI modes. When the steering OFF button is set to OFF, the solenoid of the select/bypass valve de-energizes and hydraulic pressure is removed from the servo valve. Electrical power is also removed from the servo valve at this time. When electrical power is removed from the servo valve there is no centering feature for the servo valve spool.

With the hydraulic system on and the steering control switch set to TAKE OFF or TAXI, the steering command potentiometer is set to the low gain or high gain mode respectively. The solenoid of the select/bypass valve energizes and hydraulic pressure is ported to the servo valve. The white STEER annunciator on the landing gear switch panel illuminates when TAKE OFF is selected and the yellow STEER annunciator illuminates when TAXI is selected. Electrical power is supplied to the servo valve and the nose wheel steering is commanded by the rudder command potentiometer.

When the airplane is in air the weight-on-wheels switch operates. The electrical power to the steering system is disconnected and the select/bypass valve de-energizes. The internal centering cam in the nose leg centers the gear.

Piaggio reported that the nose wheel steering can be used in TAXI mode during the taxi phase of flight without limitation. The steering can be used in TAKE OFF mode during take off up to 60 kts and then must be disengaged. The steering is not designed to be used on landing, and should only be activated in TAXI mode at the completion of the landing roll.

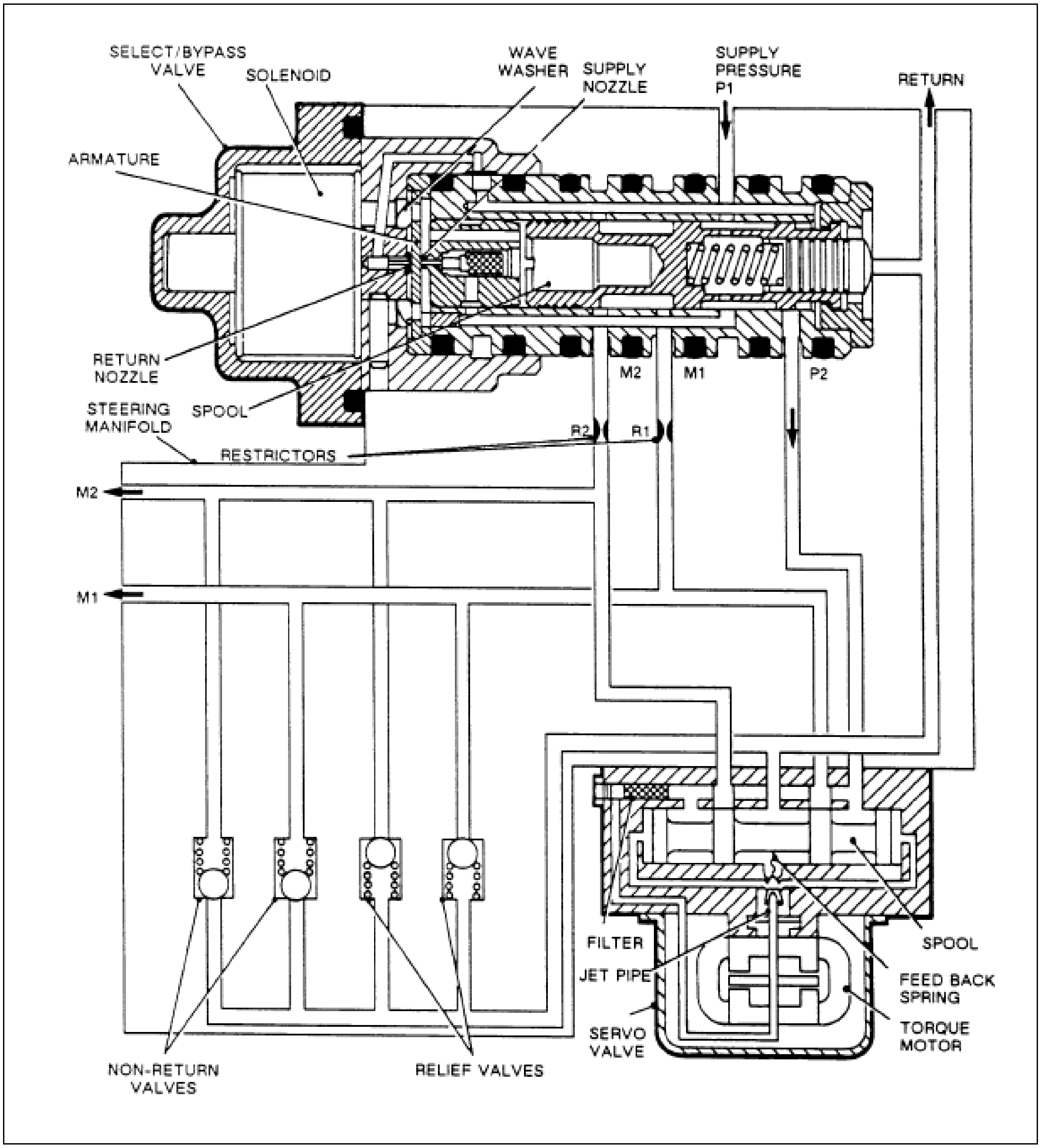

Figure 2: Schematic of the Steering Manifold Assembly

E. <u>DETAILS OF THE INVESTIGATION:</u>

The aircraft was moved into an unheated hanger located at Boyne City Municipal Airport prior to NTSB arrival on scene. The airplane was examined at this location on November 27-28, 2012. Recovery personnel stated they turned off the master battery before the aircraft was removed and that the electrical and hydraulic systems were not energized during the recovery process. They also stated that the steering pin was found engaged but was removed to facilitate aircraft recovery.

E.1 Aircraft Condition:

Figure 3: Condition of Airplane During On-Scene Testing

The front of the nose cone was dirty, fractured, and broken. The structure on the underside of the fuselage in the area around the nose taxi/landing light cavity was buckled and the light assembly was detached and damaged. The inboard aft corner of the left forward wing flap was bent and the leading edge outboard corner of the left forward wing was broken off. The left wing leading edge had a dent approximately 3 ft in length that was centered approximately 4 ft inboard of the outboard edge.

The crew reported that they may have hit birds during the descent. The nose landing gear assembly, engine intakes, and propellers were visually inspected for signs of a bird strike. The only identified evidence of a bird strike to these areas was a small feather that was stuck to the lower left corner of the aft nose landing gear door. The exposed wiring harnesses and components attached to the nose landing gear assembly were inspected and found to be secure.

E.2 Testing:

E.2.1 Initial Testing:

A ground power unit supplying 28 volts was connected to the aircraft. An air compressor supplying 30 psi air was connected to the hydraulic pump reservoir to prevent cavitation in the hydraulic system. The nose wheel steering (NWS) system and hydraulics were verified to be in the off position. With the nose wheel centered and on the ground the steering pin was removed. Hydraulics were then turned on (the NWS system remained electrically powered off) and at this time the NWS actuator began to extend. The actuator extended to a position of approximately 1.5 inch chrome extension.

The steering pin was then installed and the nose landing gear was placed on top of a grease skid plate. With hydraulics on and the NWS system electrically powered off, the actuator did not move. The steering pin was again removed and with hydraulics on and the NWS system electrically powered off the actuator extended at a rate of approximately 1 inch per minute.

E.2.2 Testing per Service Bulletin 80-0249:

Piaggio released Service Bulletin (SB) 80-0249 (Rev 1 dated 27/05/2009 with original issue dated 18/06/2008) after an incident involving uncommanded movement of the nose wheel. The reason for the SB states:

One case of poor sealing of the Steering Select / Bypass Valve (installed in the Steering Manifold) was observed, resulting in an uncommanded steering action. The aim of the procedure described in this Service Bulletin is to verify the leakage proofness of the Steering Manifold when the system is turned OFF and hydraulic power is available, by directly observing the behavior of the Steering Actuator.

This SB was current at the time of the incident and was required by AD 2009-21-08 Rev 1 with effective date of December 14, 2009. The SB requires completion a) at the next scheduled inspection, or within 6 months (whichever occurs first), b) at each “A” inspection as long as the SB is active, and c) whenever a new/overhauled manifold is installed. AD 2009-21-08 Rev 1 was completed and signed off by Flagship Private Air on 10/30/2012 for the accident aircraft. During investigative testing following the accident, N401WS was subjected to this SB in its entirety even though some observed failures would have concluded the test prior to completion.

The aircraft failed Section 2.A – Weight on Wheels, No Load on Steering Actuator. Step 15 and 23 of Section 2.A required that with the nose wheel steering pin disconnected, hydraulic pressure engaged, and electrical power to the nose wheel steering system disengaged, that no movement of the actuator should be observed for 1 minute. During Step 15, the actuator moved from centered to fully extended in 48 seconds. During step 23, the actuator moved from centered to fully extended in 22 seconds. The SB requires that if the steering actuator moves reaching the full stroke within 1 minute during at least one test, the manifold shall be replaced. Sections 2.B and 2.C of the SB were completed to the extent possible with no additional failures identified.

Following completion of the SB, the gear was centered and the steering pin was once again removed. Hydraulic pressure was applied with the NWS system electrically powered off and the actuator extended stopping after 47 seconds.

E.2.3 Aircraft Maintenance Manual: Steering – Operational Test:

Step 2 “Steering – Operational Test” of the “Steering – Adjustment/Test” section of the Piaggio P.180 Avanti Maintenance Manual (AMM) (Report 9066, Rev E3, Section 32-50-00 dated Oct 30/09) was performed. The aircraft passed the test in its entirety. The other steps of the “Steering – Adjustment/Test” section were not performed due to lack of available test equipment

E.2.4 Additional Testing:

With hydraulics on and the nose wheel steering system engaged to TAXI or TAKEOFF the nose wheel steering appeared to respond correctly to rudder pedal inputs. With the system set to TAXI, the deflection in both directions was considerably greater than when the system was set to TAKE OFF. An actual deflection measurement could not be taken as the proper tooling was not available.

An analog multimeter was attached to pins A and C on the NWS actuator connector. A tow bar was attached to the gear and the gear was rotated right of center. The resistance decreased smoothly with no drop outs. The gear was rotated left of center and the resistance increased smoothly with no drop outs. The multimeter was attached to pins B and C. The gear was rotated right of center and the resistance increased smoothly with no drop outs. The gear was rotated left of center and the resistance decreased smoothly with no drop outs. The multimeter was attached to pins D and F. The gear was rotated right of center and the resistance increased smoothly with no drop outs. The gear was rotated left of center and the resistance decreased smoothly with no drop outs. The multimeter was attached to pins F and E. The gear was rotated right of center and the resistance decreased smoothly with no drop outs. The gear was rotated left of center and the resistance increased smoothly with no drop outs.

E.3 Nose Landing Gear:

The left and right nose tires were both pressurized at 52 psi[1]. The Aircraft Maintenance Manual, Section 12-10-04, dated Oct 30/09, states that the nose landing gear tire pressure should be 64 +/- 2 psi. The nose assembly shock strut pressure was approximately 98 psi with weight off wheels. The placard on the aircraft states the pressure should be 120 +/- 10 psi. Both nose tires spun freely using hand force when the nose of the airplane was on jacks. There was no significant damage identified on either tire.

[1] The ambient air temperature was not recorded. For reference, Bellaire, MI is located approximately 20 miles southeast of Boyne City and recorded a high of 33 degrees Fahrenheit and a low of 25 degrees Fahrenheit during the dates of November 27 and 28, 2012.

E.4 Left Main Gear:

The left main gear tire pressure was 102 psi[1]. The Aircraft Maintenance Manual, Section 12-10-04, dated Oct 30/09, states that the main landing gear tire pressure should be 118 +/- 2 psi. The left main shock absorber pressure was approximately 500 psi with weight off wheels. The placard on the aircraft states the pressure should be 1075 +/- 20 psi. The tire was in good condition with no signs of rubber reversion or flat spotting. Both brake pins were of sufficient length. The brake caliper paint remained white and did not show external signs of overheating. With weight off wheels, the wheel could spin freely with a normal amount of pressure applied and a gritty sound was present. Dirt was observed around the wheel assembly.

E.5 Right Main Gear:

The right main gear tire pressure was 103 psi[1]. The Aircraft Maintenance Manual, Section 12-10-04, dated Oct 30/09, states that the main landing gear tire pressure should be 118 +/- 2 psi. The right main shock absorber pressure was approximately 500 psi with weight off wheels. The placard on the aircraft states the pressure should be 1075 +/- 20 psi. The tire was in good condition with no signs of rubber reversion or flat spotting. Both brake pins were of sufficient length. The brake caliper paint remained white and did not show external signs of overheating. With weight off wheels, the wheel could spin freely with a normal amount of pressure applied and a gritty sound was present. Dirt was observed around the wheel assembly.

E.6 Brake Test:

A brake test per the AMM could not be performed due to the presence of snow and ice on the airport runway and taxiways.

E.7 Engine Rigging:

The front cowlings were removed and the engines were visually inspected for proper rigging. The attaching hardware on both throttle control linkages for each engine was properly installed.

E.8 Rudder Test:

The rudder was visually examined during the testing of the NWS system. The rudder appeared to move correctly in response to rudder pedal inputs. The AMM test was not attempted due to the lack of available test equipment.

E.9 Circuit Breakers:

The circuit breakers in the aft cargo compartment and the cockpit were inspected. Only the “R LDG LT” circuit breaker was found open.

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[1] The ambient air temperature was not recorded. For reference, Bellaire, MI is located approximately 20 miles southeast of Boyne City and recorded a high of 33 degrees Fahrenheit and a low of 25 degrees Fahrenheit during the dates of November 27 and 28, 2012.

E.10 Maintenance Records:

The incident flight was reported by Flagship Private Air to be the third flight following the aircraft's completion of a D-Check (including an overhaul of the nose gear, both main gears, and both engines). AD 2009-21-08 Rev 1 was last completed and signed off by Flagship Private Air on 10/30/2012.

F. COMPONENT EXAMINATIONS:

F.1 Nose Landing Gear Assembly:

The nose landing gear and attached nose wheel steering components were removed from the aircraft. The group met at Messier-Bugatti-Dowty (MBD) in Gloucester, UK on April 16-19, 2013 for the examination of these components. MBD is the original equipment manufacturer for the landing gear but did not perform the most recent overhaul on the assembly.

The nose landing gear assembly label information was as follows:

MFG: Messier-Dowty (Safran)
Type (Part) Number: 201033002
S/N: M/DAG42/01
Mod: 011999 Issue 09

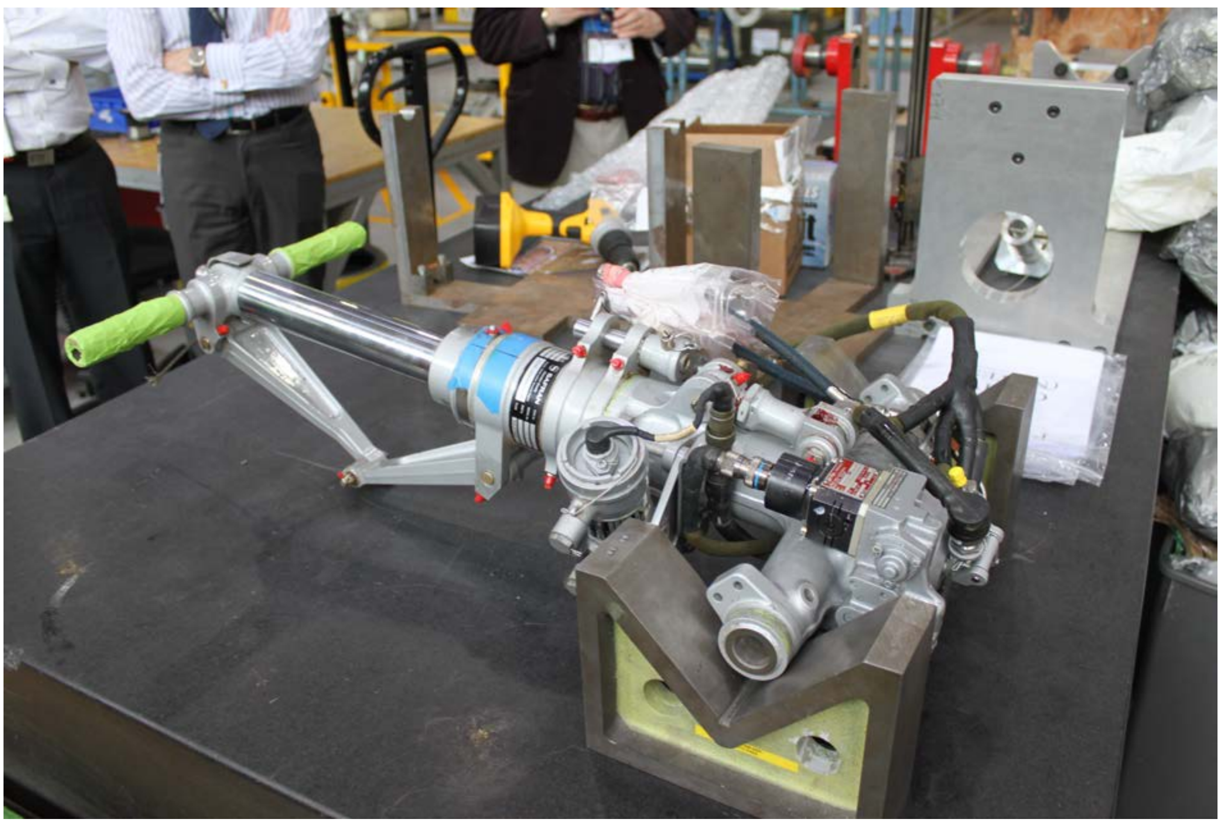

Figure 4: Nose Landing Gear Assembly During Testing at MBD

The landing gear was removed from the shipping container. The nose wheel steering manifold assembly and steering actuator remained installed on the gear assembly. Some scratches in the paint were identified and the linkage torsion spring was installed backwards when referenced to the illustrated parts list in CMM 32-20-58, Rev 11, Figure 2, Item 240. All hydraulic and electric connections were secure.

Residual fluid from the manifold assembly was collected by tilting the landing gear and cycling the actuator by hand. A small amount of fluid from the nose wheel steering filter housing was also retained from the on-scene investigation and shipped to MBD with the landing gear assembly. Both samples were mixed into one container and the resultant sample was analyzed by MBD. See MBD Materials & Processes Report 13/4026 which can be found in the public docket for this accident.

The metal hydraulic tubing was removed and the landing gear was attached to a test bench to perform Piaggio Service Bulletin 80-0249, Rev 1, Part A. When the assembly was first installed the hydraulic power was activated and the electrical power was off, the actuator slowly extended. After cycling the unit multiple times to clear air out of the hydraulic lines, the electrical power was engaged and the nose wheel centered as expected. Electrical power was turned off and the actuator extended. Electrical power was then turned on and the nose wheel centered correctly. Electrical power was again turned off and the actuator retracted. This test sequence was run two times with identical results. The actuation rate varied each time, ranging from a slow creep to an easily noticeable speed. These results failed the requirements of SB 80-0249.

The gear was then subjected to the steering sections of the Testing and Fault Isolation chapter of CMM 32-20-58, Rev 11, dated Nov 16, 2012. Revision 11 added additional testing to step 3.K (Free Castor Test) and was not available when the subject landing gear was last overhauled. The testing was started at step 3.E (Zero Steering Angle Indication and Datum Check) and completed at step 3.K.10 (Free Castor Test). The strut pressure remained in the as shipped condition (the lock down ring was loose) for the entire test and the strut pressurization charging and testing sections were not performed.

During Step 3.E.5 it was found that in order to obtain the feedback potentiometer centered position (4.91/4.93 Volts reading on the potentiometer test set), the axle had to be rotated 3.9 degrees to the left of the axle center position as identified by extending the strut to engage the cam. There was approximately 1 degree of play in this position that appeared to be originating from where the steering actuator rod end was connected to the nose wheel steering linkage. Following all testing the axle had to be rotated 2.5 degrees to the left of the center position as identified by extending the strut to engage the cam in order to obtain the feedback potentiometer centered position.

Step 3.I.4 (Steering Angle Check – High Gain) verifies that the actual steered angle is correct for nine different commanded angles when the steering mode is set to high gain. All actual steered angles were within test tolerances for their inputted angles except for the actual steered angle when 0 degrees was commanded. The test required the steered angle to be 0 +/- 0.5 degrees; the actual value was -1 degree.

Step 3.I.5 (Steering Angle Check – Low Gain) verifies that the actual steered angle is correct for nine different commanded angles when the steering mode is set to low gain. All actual steered angles were within test tolerances for their inputted angles except for the actual steered angle when 0 and +5 degrees were inputted. The test required the steered angle to be 0 +/-0.5 degrees when a 0 degree command was inputted. The test required the steered angle to be 0.3 +/-0.75 degrees when a +5 degree command was inputted. The actual steered angles were 0.9 degrees and 1.25 degrees respectively.

The unit failed step 3.J.4. This step required that the weight-on-wheels lamp and the steering-on lamp on the test bench went off when the sliding tube sub-assembly was between 0.080 and 0.100 inch of the fully extended position. During testing the lights went off when the sliding tube sub-assembly was 0.940 inch from the fully extended position.

The unit failed step 3.K.8. This step required that there was no change in the steered angle when 1000 psi hydraulic pressure was supplied to the assembly, the steered input command was 34 degrees, and the solenoid valve was powered off. The unit under test steered to a hard-over position. It was noted that this test was added to the manual at Revision 11 and was not available when the subject unit was last overhauled.

MBD original equipment build records show that the nose landing gear was assembled on December 13, 2001. MBD Maintenance Repair and Overhaul UK had no records of repair for this unit.

F.2 Steering Actuator:

The steering actuator label information was as follows:

TYPE (Part) Number: 114068003
S/N: SM-M-DG-0045
MOD: P180-32-24

The steering actuator was removed from the landing gear assembly and foreign object debris that resembled a gray paint chip was observed resting on top of the orifice in the S1 port. The unit was placed in a test jig per CMM 32-50-51, Rev 5 (page 702, Section 2.C titled Calculation of Shim Thickness). This test is used to ensure the linear feedback potentiometer is properly positioned to provide the correct reading when the piston is centered. While the actuator was in the test rig with the piston centered, the LVDT output was 5.4 Volts (4.91/4.93 Volts required).

F.3 Manifold Assembly:

The manifold assembly label information was as follows:

MFG: Dowty-Rotol Ltd
P/N: 114180003
S/N: DH-0002
MOD: None identified
Inspection Sticker Label: (Date: 0192, Issue: 1, INSP: DAH9)

Figure 5: Steering Manifold Assembly with Servo Valve Attached

The manifold assembly was removed from the landing gear assembly. To the extent possible, the manifold assembly was tested per portions of the Testing and Fault Isolation Chapter of CMM 32-50-50, Rev 6. It was noted that Rev 8 was the current revision available at the time of testing but that Rev 6 was the current version available at the time the subject landing gear assembly was last overhauled. The test procedure had to be performed in reverse order as the procedure was designed to be accomplished during manifold build. The first phase of testing was Step 3.G-3.H. The servo valve was then removed from the manifold and steps 3.D-3.F were performed. The solenoid valve was then removed from the manifold and steps 3.A(1) – 3.A(9) were performed. The remaining steps in section 3.A were not performed as failures were identified in steps 3.A(6) and 3.A(9).

The unit failed the following steps:

3.G(8)(c) – This step required that the supply pressure must equal the pressure at port M2 when the maximum negative current is supplied to the servo valve. During this step the supply pressure was 200 psi and the pressure at M2 was 180 psi.

3.H(7) - This step required that the supply pressure must equal the pressure at port M2 when a current of -4mA is supplied to the servo valve. During this step the supply pressure was 1000 psi and the pressure at M2 was approximately 950 psi.

3.F(6) – This step required that with the select/bypass valve de-energized, port M2 blocked, and pressure supplied to port M1 to maintain a pressure drop of 1000psi to return, that the flow rate at return must not be less than 0.19 in^3/sec. The observed flow rate at return measured 0.06 in^3/sec.

3.F(10) - This step required that with the select/bypass valve de-energized, the return port blocked, and pressure supplied to port M1 to maintain a pressure drop of 1000psi to port M2, that the flow rate between port M1 and port M2 be between 1.40 in^3/sec and 2.03 in^3/sec. The observed flow rate at port M2 measured 0.057 in^3/sec.

3.A(6) – This step was performed with the select/bypass valve assembled in a test block and 2000 psi supplied to P1. The test required that the voltage to the coil assembly be slowly increased from zero until the pressure at P2 equaled the pressure at P1. Per the test instructions, this voltage should be between 10 and 12 VDC. The actual voltage required to equalize the pressures was not recorded as the pressure at P2 measured approximately 540 psi with 0 VDC applied to the coil. With 0 VDC applied to the coil there should not have been pressure at P2.

3.A(9) – This step was performed with the select/bypass valve assembled in a test block and 4500 psi supplied to P1. The pressure at P2 was required to rise when 28 VDC was applied to the coil assembly and the pressure at P2 was required to fall when the voltage was removed from the coil assembly. During the test pressure remained at P2 when the voltage was removed from the coil assembly.

The following additional observations were noted during testing and disassembly of the manifold assembly:

- During test setup it was noted that the flexible hydraulic line connections were torqued to the extent that the lines were not free to rotate about the M1 and M2 connections. Per CMM 32-50-50, Rev 6, Page 706, Step K(4), these flexible hose assemblies connections should be able to rotate after they are installed.
- When the manifold was first connected to the test bench with 200 psi hydraulic power engaged and all electrical power disengaged, the pressure at M1 was observed to increase to 150psi.
- While the manifold was connected to the test bench with electrical power engaged to the servo valve and disengaged to the select/bypass valve, the observed pressure at the output ports M1 or M2 was equal to the pressure at the input port depending on the position of

the servo valve spool. When electrical power to the servo valve was disengaged, the fluid would port in the direction of the last spool movement.

- While the manifold was connected to the test bench with power engaged to the select/bypass valve, 0.00mA applied to the servo valve resulted in a hydraulic pressure of approximately 150 psi at port M1.
- The solenoid coil resistance was 298.7 Ohms (within specification)
- The electrical wires connected to the select/bypass valve coil were chaffed in the direction opposite of wire removal when pulled through the manifold body. One area of exposed wire was observed. A 2 inch insulation sleeve that is not called out in the CMM or component drawings surrounded the wires on the end connected to the electrical connector.
- The select/bypass valve coil gap (dimension Z, CMM 32-50-50, Rev 6, page 704) was 0.0002 inch and was within limits. The requirement is 0.00 inch to 0.0002 inch.
- Two parallel and uniform gouges were found on the outside diameter of the spool stop (P/N 101459603) near the end opposite the nozzle. The ring (P/N 100668608) was scored in multiple places along the inner diameter edge on the face that is adjacent to the armature. In addition, the armature (P/N 100668609) exhibited a nozzle imprint in its center and multiple scratches on the side facing the return. The side of the armature facing the sleeve and spool exhibited a nozzle imprint in the center, a half nozzle imprint on the edge of one of the smaller center holes and a gouge connecting two of the larger holes on the outer circumference. Although these components are not specifically called out for special inspection in CMM 32-50-50, Rev 6, these surfaces should be free of visual defects.
- When the select/bypass valve armature was placed inside of the ring, the gap from the top of the ring edge to the armature surface measured 0.0023 inch. This is outside of the required limit of 0.0032 inch to 0.0035 inch per CMM 32-50-50, Rev 6, page 702, step 2.B.2.
- The lap tip of the return nozzle projection in the select/bypass valve measured 0.0003 inch. This is outside of the required limit of 0.0004 inch to 0.0006 inch per CMM 32-50-50, Rev 6, step 2.C.3 on page 702.
- The spring for the select/bypass valve spool felt normal using hand force and was intact when removed.
- The select/bypass valve was configured with one 0.002 inch thick shim installed next to the wave washer. Testing was performed using the manifold test block P/N 460006832 (not the actual manifold body) and using various shims and a new wave washer to determine if altering the shim thickness would result in a properly functioning unit. Using a new wave washer resulted in a spool that could not retract when electrical power was supplied to the coil. Using the original wave washer, the original shim of 0.002 inch thickness, and an additional 0.003 inch of shims (total of 0.005 inch of shimming) the spool repeatedly functioned correctly when power was engaged and removed up to a pressure of 2500psi.

MBD original equipment build records show that the steering manifold body was assembled on February 17, 1992. The acceptance inspection was completed and passed with no discrepancies. The select/bypass valve was assembled on October 15, 1991. The acceptance inspection was completed and passed with no discrepancies. MBD Maintenance Repair and Overhaul UK had no records of repair for the manifold assembly or select/bypass valve.

F.4 Servo Valve Assembly:

MFG: Parker (Abex)
P/N: 47002
S/N: AH-0026
MOD: 410-02056

The servo valve was removed following steps 3.G-3.H of the manifold testing performed at MBD. The servo valve ports were capped using a blanking plate and the servo valve was hand carried to Parker (the component manufacturer) in Mainz-Kastel, Germany. The examination of the servo valve took place on April 22-23, 2013.

The servo valve assembly was externally inspected and appeared to be in good physical condition. The safety wire was intact and the electrical pins were straight and free of corrosion. The unit was then subjected to testing based on Technical Specification ES-02056, Rev E. Rev C was in effect during initial build. Rev D changed the torque motor stroke requirement. Rev E changed the hydraulic pressure requirements for some tests to align them more closely with operational requirements. The Technical Specification was performed in appropriate order to minimize disassembly and steps 120 through 150 and steps 230 through 240 were performed. The following observations were noted during testing:

- Step 120 was performed at 3000 psi per Rev C as this revision was current at the time of initial build. The unit met all requirements per this step.
- The unit failed Step 130 (Unloaded Flow). The observed flow rate was 16.56 liters/minute when the required flow rate was 17.0 to 20.8 liters/minute. Additional testing revealed that with the manifold restrictor plate (P/N 114108201) installed the max flow rate of 0.7 liters/min was reached at 0.8 mA. MBD confirmed that the flow rate with the restrictor plate installed was acceptable for proper manifold assembly operation.
- The unit failed Step 130 (Overlap). The Technical Specification required that any overlap would be overcome with 0.20 mA maximum applied to the torque motor. The unit under test required 0.22 mA.
- Step 140 Supply Proof Test and Return Proof Test were not performed to preserve the unit for the remaining testing. The Null Shift Temperature Change Test was not performed as it was not a required acceptance test parameter. The unit met the other requirements of this step.
- The unit failed Step 230 (Torque Motor Final Calibration Test - Stroke Requirement). The actual stroke was measured to be 0.0212 inches and the required stroke was 0.0225 inches +/- 5%. This requirement was changed from 0.0207 inches +/- 5% to 0.0225 inches +/- 5% at Rev D; therefore, this unit would have met the original build requirements per Rev C.

- The tools were not available to calculate actual linearity per Step 230; however, Parker confirmed the graph appeared to be typical.

During additional testing, the servo valve was commanded to various positions and electrical power was turned off. The servo valve would center with a bias dependent on the last position the spool was in while the servo valve was electrically powered. Drift was not observed when electrical power was removed and hydraulic power was supplied. Parker stated that there is no requirement for the spool to be centered when electrical power is not supplied to the servo valve.

Parker performed a historical search for initial build and repair records for S/N AH-0026 for their Mainz-Kastel facility. The unit was initially built in March 1990. No records of repair were found. No indications of repair since manufacturer were identified.

Adam Huray
Mechanical Engineer