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

Systems Group Chairman's Factual Report of Investigation

February 24, 2016

A. INCIDENT DCA12IA113

Location:	El Paso, Texas
Date:	July 27, 2012
Time:	1414 mountain daylight time (MDT)
Aircraft:	Southwest Airlines flight 1871, a Boeing 737-3H4, registration N379SW

B. GROUP

Chairman:	Tom Jacky National Transportation Safety Board Washington, D.C.
Member:	Simon Lie Boeing Company Seattle, Washington
Member:	Dennis Post Southwest Airlines, Co. Dallas, Texas
Member:	David Keenan Federal Aviation Administration Washington, D.C.

C. SUMMARY

On July 27, 2012, about 1400 mountain daylight time, Southwest Airlines flight 1871, a Boeing 737-3H4, registration N379SW, experienced a structural failure of the nose gear actuator retract beam when the landing gear was selected down during approach to El Paso International Airport (ELP), El Paso, Texas. There were no injuries to the 71 passengers and 5 crewmembers on board and the airplane sustained substantial damage. The flight was operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 on a regularly scheduled passenger flight from Las Vegas McCarran International Airport (LAS), Las Vegas, Nevada to ELP. Visual meteorological conditions prevailed at the time.

The group met at the Boeing Equipment Quality Analysis (EQA) Laboratory in Seattle, Washington from November 14 – 15, 2012 to examine the following components removed from the incident airplane:

1. Nose Landing Gear Actuator Retract Flexible Hydraulic Hose

   Boeing Part Number: BACH8A04EE-0263S

   Data Plate on Hose:

Manufacturer:	AEROQUIP-ACM
Specification:	AS1339 00624
Manufacturer Part Number:	AS154A04EE-0263S
Boeing Part Number:	BACH8A04EE-0263S
Date Code:	A 1 92 PT

2. Nose Landing Gear Hydraulic Transfer Cylinder

   Part Number: 69-14106-7
   Serial Number: 3118

3. Nose Landing Gear Retract Actuator

   Part Number: 65-44610-4
   Serial Number: ES770

4. Nose Landing Gear Modular Package

   Part Number: 65-44691-6
   Serial Number: 2749

The examination test plan for each component was agreed to by the group and was conducted in accordance with the pertinent Component Maintenance Manual (CMM), with exceptions as noted.

A Door Crank (Part Number 65C27360-5, ASSY 8/20/92) was noted in the shipping box. However, the component was not examined as part of the investigation.

The group also met at the Southwest Airlines (SWA) Maintenance Facility in Dallas, Texas, on January 3-4, 2013 to document the position, on a similar airplane, of the flexible hydraulic hose attachment to the nose gear actuator and to witness the extension and retraction of the nose landing gear. A Southwest 737-3Q8 airplane, registration N317WN, was used for the demonstration.

At the conclusion of each activity, the pertinent documents, photographs and video recordings were provided to each party.

D. DETAILS OF INVESTIGATION

According to Boeing and Southwest Airlines, the airplane, Boeing effectivity code PS765, was delivered to Southwest Airlines in February, 1994. At the time of the incident, the airplane had accumulated 59,933 hours and 49,776 cycles.

1.0 Description of Nose Landing Gear System

The nose landing gear is part of the airplane's landing gear system. The nose gear is located below the aft bulkhead of the flight deck and supports the forward end of the fuselage. The nose gear is equipped with two tire and wheel assemblies, one on each side of the gear leg. The nose gear provides the airplane's directional control on the ground by use of flightcrew pedals and/or captain's tiller.

The nose landing gear structure components include a drag brace, shock strut, and torsion links. The nose gear is hydraulically actuated to retract forward and up into the nose landing gear wheel well. The clamshell nose gear doors close to fair with the fuselage contour when the nose gear is retracted and remain open when the nose gear is extended.

The shock strut consists of inner and outer cylinders. The upper part of the outer cylinder is "Y" shaped with arms extended to the sidewalls of the wheel well, providing lateral stability. Trunnion pins connect the gear to airplane structure. The nose gear rotates about the trunnion pins during extension and retraction. See Figure 1.

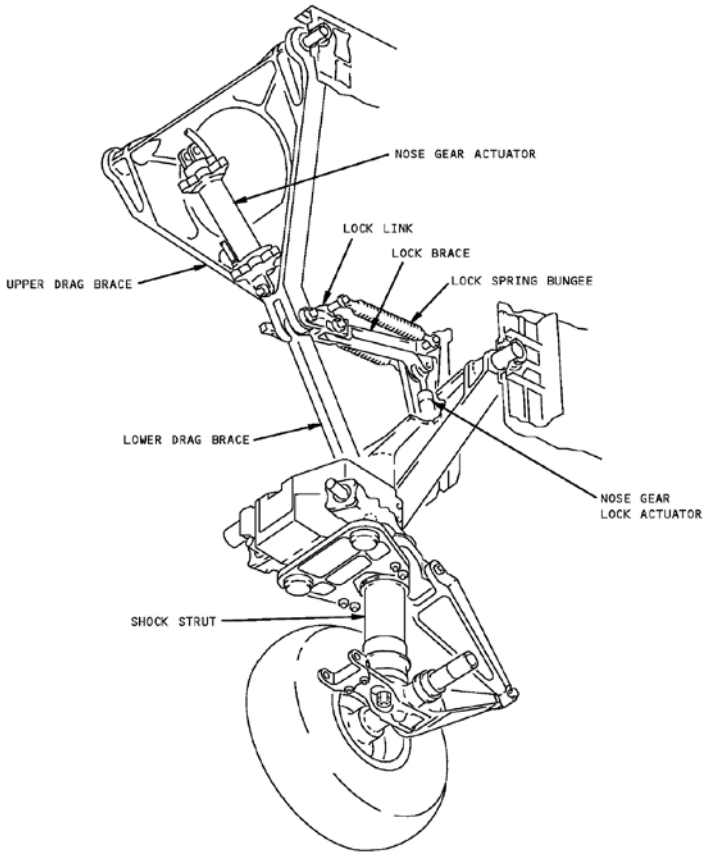

Figure 1 - 737 Nose Landing Gear Structure

Extension and retraction of the nose gear (and main gear) is by hydraulic power (and a manual extension system for lowering the gear when hydraulic power is not available). The landing gear is controlled by a single control lever mounted on the pilots' center panel. Motion of the landing gear is transferred by cables to a selector valve that directs hydraulic pressure for gear actuation. When the control lever is moved to the UP position, the nose gear is hydraulically actuated to retract forward into the fuselage. A lock strut assembly locks the nose gear in the up and down positions. The nose landing gear hydraulic actuator extends while retracting the nose gear and retracts while extending the nose gear to the down/extended position. See Figure 2.

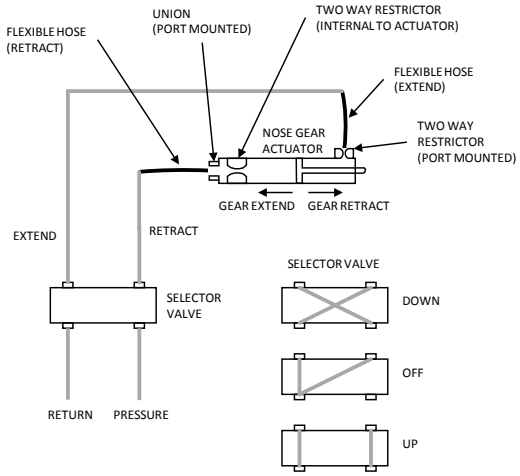

Figure 2 - Nose Gear Hydraulic Schematic

The nose landing gear actuator is designed to extend and retract the nose gear in a controlled manner. During gear extension the actuator works to prevent the gear from "free falling" into place and causing damage to the gear; the actuator also controls the retraction into the wheel well. To facilitate the controlled movement, the actuator is fitted with an internal snubbing valve. The snubbing valve is engaged when the actuator is in use, but is closed when the gear is either extended or retracted. The snubbing valve acts as a hydraulic buffer to slow the gear near the ends of travel, retract and extend. In addition, the gear down/extend actuator port is fitted with a two-way restrictor, while the gear up/retract portion of the actuator has an internal restrictor. See Attachment 1.

Two flexible hydraulic lines connect the nose landing gear actuator ports into the airplane's hydraulic systems, in the nose landing gear wheel well (structure). The flexible hoses are used to accommodate the movement of the nose actuator and gear during the retract/extend sequences; a hardened hydraulic tube is inappropriate for this application. Each hose runs along the top of the wheel well, along the lower T-chord and web of the NLG Retract Actuator (Cylinder) Beam Assembly (See Figure 3).

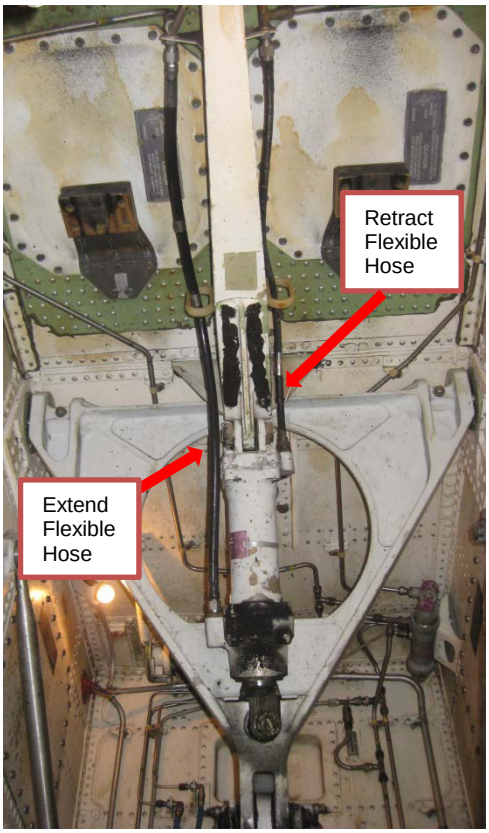

Figure 3 - Flexible Hydraulic Hose Locations (Nose Landing Gear Extended)

Each line is "threaded" through a guide to allow movement along the longitudinal axis of the airplane while restricting the lateral movement of the hose. The hose installation and guide is intended to prevent the hose from coming into contact with the nose gear wheels. See Figure 4.

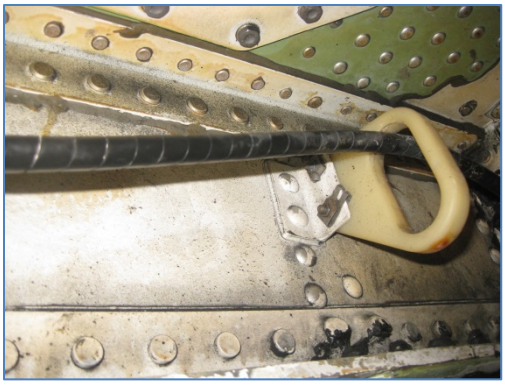

Figure 4 - Flexible Hydraulic Hose Threaded Through Guide

The flexible hydraulic lines are constructed with Teflon inner tubing, wrapped in corrosion resistant steel (CRES) braid. An outer layer of black plastic spiral wrap covers the length of the hose.

2.0 Examination of the Removed Nose Landing Gear Components

An initial examination of the airplane was conducted by the NTSB Structures Group Chairman. During this on-scene phase of the investigation, the operator removed four nose landing gear system components for further examination.

Prior to removal, the location of a damaged flexible hydraulic hose and a fracture of the Nose Gear Retract Actuator Support Beam Assembly[1] were documented. See Figure 5.

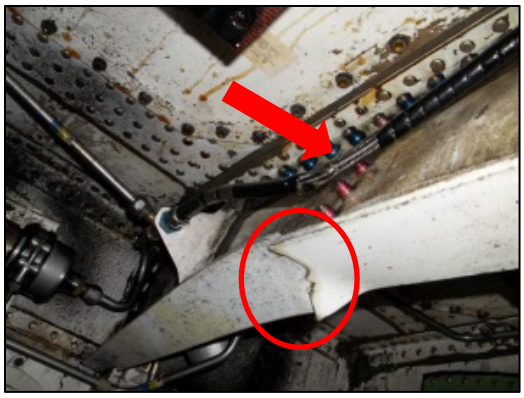

Figure 5 - The flexible hydraulic hose prior to removal. The fracture of the Nose Gear Retract Actuator Support Beam is circled; the abrasion on the flexible hydraulic hose is noted by the arrow.

The damaged flexible hydraulic hose was identified as the Retract Hose. Figure 6 shows the hose after removal from the airplane:

Figure 6 - The Retract Flexible Hose after removal from the airplane.

The group met at the Boeing facility in Seattle, Washington, on November 14-15, 2012 to examine the components removed from the airplane.

The details of the examinations are as follows:

[1] For more information regarding the Nose Gear Retract Actuator Support Beam Assembly, see the Structures Group Chairman's Factual Report.

2.1.0 Examination of Flexible Hydraulic Hose BACH8A04EE0263S

The shipping box containing the hydraulic hose was removed from a secure locker and the unit removed from the plastic packaging. The Southwest Airlines (SWA) quarantine seals on the packaging were intact.

A visual examination of the hose was conducted with the following findings:

- A rupture of the hose was identified 8.5 inches from the "A" end (the end with the data plate tag) of the hose. Approximately 3.18 inches of black outer plastic spiral wrap was missing in the area of the rupture. In this area, the ends of the wrap showed abrasions mostly aligned with the axis of the hose; however an arc shape was evident. See Figure 7.

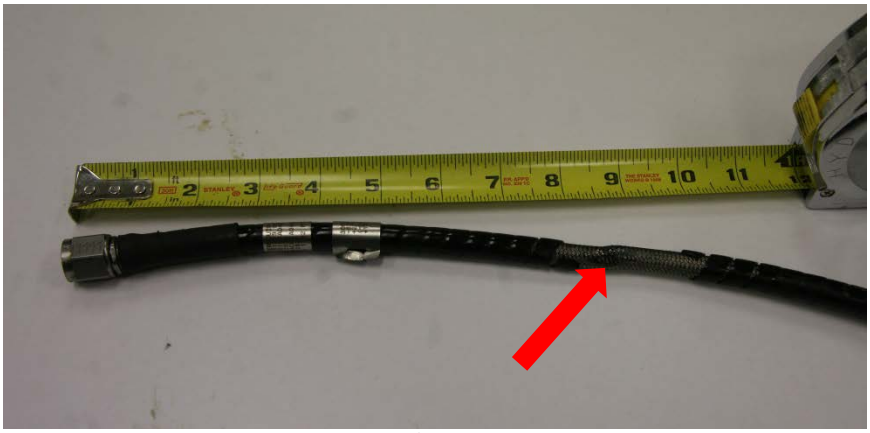

Figure 7 - Location of Hose Damage

- Abrasion marks were also evident on the corrosion resistant steel (CRES) braid, also aligned with the axis of the hose. Individual CRES strands were broken with the free ends abraded down to "chisel points" in numerous locations. The free ends of a number of broken CRES strands were bent over remaining intact strands and were pointing in the forward direction. The Teflon inner liner was ruptured in the area of the damaged CRES braid. Black debris was evident in and around the damaged CRES braid strands, but was not evident in other areas of the hose. Comparison with on-scene photos showed that the abraded area was the outboard side, facing away from the actuator beam. The damaged area was examined under the microscope and photographs were taken. See Figure 8.

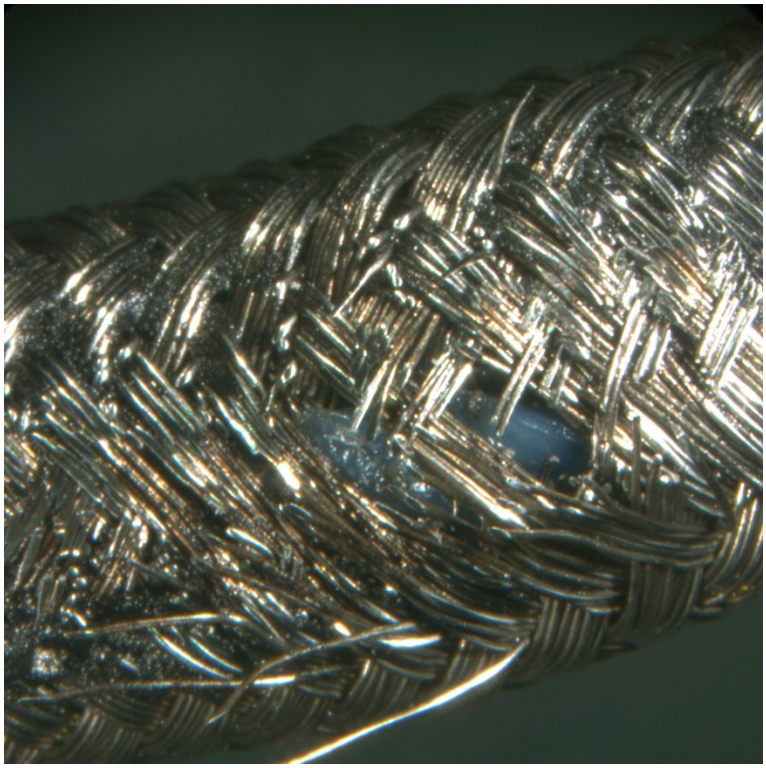

Figure 8 - Area of Abrasion

- The sleeve retainer was slid away from the “B” end of the hose about 3.2 inches.
- The hose A & B end fittings were noted as tight with nothing remarkable noted. Both fittings rotated freely.
- The exposed swage on B end looks good. When the sleeve retainer was slid away from the A end nothing remarkable was noted.
- The hose length was measured as 26 1/3” (as defined by specification gage points). The specific length is 26 3/8” +/- 0.25”.

Boeing EQA personnel and Boeing Research & Technology (BR&T) personnel collected samples of the black debris noted within the CRES braid (See Figure 9). The samples were provided to BR&T for identification. In addition, a piece of the spiral wrap was removed from the hose and provided to BR&T for comparison. See section 2.5.0 for results of the BR&T examination.

Figure 9 - Area of abrasion, magnified, showing black material located in the CRES braid.

Southwest Airlines provided tire part numbers to help with the BR&T analysis. The tire part numbers provided were: Goodyear 275K22-1 (made in USA) and 275K22-T1 (made in Thailand).

Following the examination, the hose was repackaged for shipment back to SWA.

2.2.0 Examination of Nose Landing Gear Hydraulic Transfer Cylinder

The shipping box containing the transfer cylinder was removed from a secure locker and the unit removed from the packaging. Southwest Airlines (SWA) quarantine seals on the packaging were intact.

The transfer cylinder was visually examined, with no visible damage or defects noted, except that a tab on the identification tag was broken. The lock wire was intact and the end caps were tightly installed on the cylinder ports. See Figure 10.

Figure 10 - Nose Landing Gear Transfer Cylinder, As Received

The cylinder was installed on the EQA Laboratory Hydraulic Test Bench #1 and the Leakage and Operational tests were conducted. The tests were conducted per CMM 32-40-01 1.C. (4) and 1.C. (6)

The results of the transfer cylinder testing were as follows:

- **Test Per Paragraph C.(4)**

Test performed with 3,000 PSI applied to one end for one minute; measured 21 cc leakage out opposite end. Performed same test with pressure applied to the opposite end. Leakage measured 14 cc. Max allowable is 40 cc.

- **Test Per Paragraph C.(6)**

The cylinder was held on the bench deck and a non-metallic rod was inserted into one end of the cylinder. No load piston movement measured 1.4 inches. The total piston stroke play was measured as 3.75 inches, which was within test tolerance (in middle of acceptable range).

The transfer cylinder passed the CMM Leakage and Operational Tests with no faults found. The group decided that disassembly of the cylinder was unnecessary. The unit was repackaged for shipment back to Southwest Airlines.

2.3.0 Examination of Nose Landing Gear Retract Actuator

The shipping box containing the nose landing gear retract actuator was removed from a secure locker and the unit removed from the plastic packaging. The Southwest Airlines quarantine seals on the packaging were intact. See Figure 11.

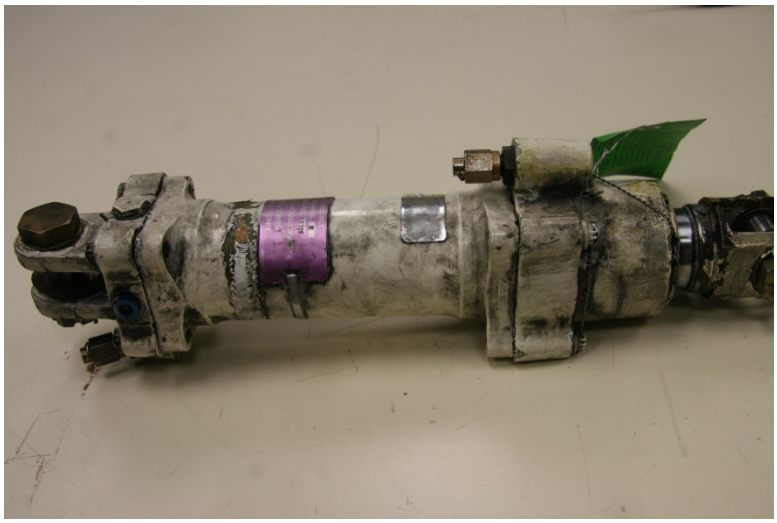

Figure 11 - Nose Gear Retract Actuator, as Received at Boeing EQA Laboratory

2.3.1 Visual Examination

A visual examination of the actuator was conducted. The shipping caps were tightly installed on the actuator ports.

As received, the distance between the attachment bearings measured 17 5/16" inches, center to center.

The green tag was removed prior to taking retract actuator to the x-ray room.

To determine whether the actuator was disturbed during shipping, an x-ray scanning of the retract actuator was conducted. The digital radiography inspection revealed no anomalies. Photographs of the images were recorded and provided to the parties.

2.3.2 Functional Test of the Retract Actuator

The actuator was installed in the EQA Laboratory Hydraulic Test Bench #1 and a functional test of the actuator was conducted. The functional test was conducted in accordance with the Component Maintenance Manual (CMM) Section 32-30-41, revision 21. See Figure 12.

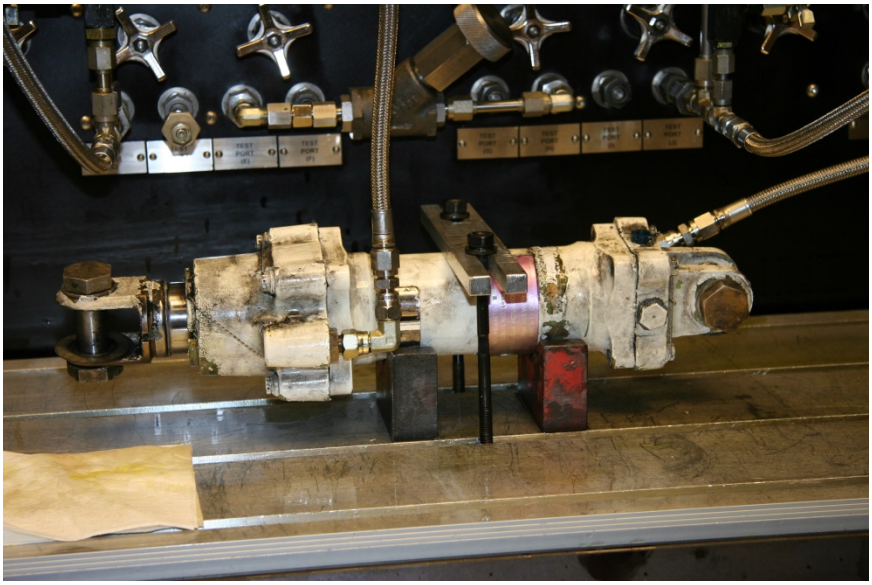

Figure 12 - Nose Landing Gear Retract Actuator, Installed on Test Bench

The air was bled from the actuator by cycling it fully in the extend and retract direction five times at 500 PSI. The actuator appeared to operate normally.

Per CMM section D4, the actuator was operated for five complete extend and retract cycles at 3,000 PSI. The actuator snubbing was apparent at both ends of stroke. No external leakage was noted during the testing.

Additional testing beyond the scope of the CMM was conducted on the actuator. While in the horizontal position, the actuator was extended as if in the gear retract position, and then hydraulic pressure was removed. The gear extend hose fitting was removed, which would be similar to opening the cylinder retract port to atmosphere, in an attempt to simulate a ruptured hydraulic hose. Leakage started as a drip and progressed to a steady stream.

2.3.3 Actuator Disassembly

The retract actuator was disassembled in accordance with CMM 32-30-41, Paragraph 1, Procedure C.

The safety wire securing the four bolts on each end of the actuator was intact and correctly installed. It was then removed.

Bolt Removal Torque

The eight bolts were removed. The torque value required to loosen each bolt was recorded in Table 1. The actuator was marked with a black felt marker adjacent to the bolts to identify where they were removed from. All eight bolts were in good condition; some showed a little wear. See Table 1.

Table 1: Bolt removal torque (inch pounds)

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Head end	190	150	130	<50
Rod end	135	loose	90	200

The two plugs in the head were removed.

Incorrect Position of Restrictor and Union

During the actuator disassembly, the actuator's restrictor fitting and union were each noted by the group in the incorrect position. The restrictor and union positions were noted as swapped from their correct position.

The restrictor fitting 66-22711-1 (0.070 inch orifice) was removed from the head end.

The union MS21902-6 (0.30 inch ID) was removed from the rod end cap.

According to Boeing Engineering Drawing 66-22711, the restrictor is the same as the union except for the internal orifice diameter, grooves cut in the corner of the hex flats, and a vibro-engraved part number (See Attachment 1). The engineering drawing, CMM, and Illustrated Parts Catalog (IPC) all require that the restrictor be installed in the rod end cap and the union in the head end (e.g. opposite of condition found on the actuator).

The remainder of the actuator was disassembled in accordance with the CMM procedure. All internal components appeared to be installed correctly and appeared to be in serviceable condition. The snubbing valve assembly appeared clean and normal, with no defects noted.

The unit was repackaged for shipment back to Southwest Airlines.

2.4.0 Examination of Hydraulic Modular Package Assembly

The hydraulic modular package was removed from a secure locker and removed from the packaging. The Southwest Airlines quarantine seals on the packaging were intact.

The package was visually examined, with no visible damage or defects noted. The plugs were tightly installed on the ports. See Figure 13.

Figure 13 - Nose Landing Gear Modular Package, as Received

Two subassembly relief valves were documented as follows:

Part Number: BAC10-60599-1
Serial Number 1: 19139M
Serial Number 2: 19181M

A functional test per CMM 32-09-11 1.D (Section D) was performed on the hydraulic modular package. The hydraulic modular package was installed on the EQA Laboratory Hydraulic Test Bench #1 for the test. The results of the test were noted in Table 102, shown below.

Table 102: 65-4491-4, -6 Functional Test Sequence and Results

Test	Plugged port	Pressurized port	Applied PSI	Flow measurement		
				Flow from (Form) Port	Rate of Flow	Results
1	None	4	3000	5	0.41-0.49	0.44
2	Slowly apply pressure to port 4 until the flow from port 5 is 0.94 GPM. Pressure differential between ports 4 and 5 must be 3500-3960 PSI					3642
3	None	5	3000	4	0.41-0.49	0.45
4	2	3	3000	1	0.15-0.190	0.16
5	Slowly apply pressure to port 3 until the flow from port 1 is 0.66 GPM. Pressure differential between ports 3 and 1 must be 3500-3960 PSI					3642
6	2	1	3000	3	0.15-0.190	0.16
7	3	1	400	2	2.30-2.90	2.37
8	3	1	3000	2	2.30-2.90	2.34
9	3	2	400	1	2.30-2.90	2.60
10	3	2	3000	1	2.30-2.90	2.54

The hydraulic modular package assembly passed all 10 elements of the functional test, with no faults found. Based on this finding, the group determined that a disassembly of the unit was not necessary.

The unit was repackaged for shipment back to SWA.

2.5.0 Boeing EQA Report AS11733

At the request of the group, Boeing developed EQA Report AS11733 and submitted to the group on December 14, 2012. The report subject was "Examination of Nose Landing Gear Components Removed From Southwest Airlines 737-300 Airplane PS765".

The report provided the following information:

- As indicated in Section 2.1 of this report, the collected samples of the black debris noted within the CRES braid of the Hydraulic Hose BACH8A04EE0263S was examined by BR&T. The examination concluded that the black material was consistent with material from a nose gear tire sidewall (an exemplar Goodyear 275K22-1/276K22T1 nose gear tire).
- The rupture in the flexible hydraulic hose was coincident with section of missing spiral wrap and abrasion marks on the corrosion resistant steel (CRES) wire braids.

The report was included in Attachment 2.

3.0 Nose Gear Swing Demonstration

Prior to the demonstration, a test plan, titled "Nose Landing Gear Demonstration Plan", was drafted by the NTSB and agreed to by the group members. The test plan is included in Attachment 3.

For the demonstration, Southwest Airlines provided a Boeing 737-3Q8, airplane registration N317WN, (Boeing effectivity code PP353, serial number 24068).

Prior to the group's arrival, the airplane was parked inside the Southwest Maintenance hangar. In preparation for the demonstration, the airplane's nose was jacked off the hangar floor so the nose gear could be actuated and the wheels free to spin when the nose landing gear was extended. The airplane's two nose landing gear doors were also removed for access.

The group examined the flexible hydraulic NLG retract hose, the nose gear retract actuator, and the connections. The group made the following observations:

- The restrictor was located per drawing in the actuator retract port (NLG extend direction).
- The union was located per drawing in the actuator extend port (NLG retract direction).
- NLG retract hose black spiral wrap showed no sign of abrasion.
- NLG extend hose black continuous sheath showed no sign of abrasion.

3.1 Measurement of the NLG Actuator Flexible Hose Before/After Gear Extension

The flexible hydraulic retract hose's movement and position before, during, and after the extension/retraction of the nose landing gear was assessed. The nose landing gear was extended and retracted three times. Two measurements were taken between the NLG actuator beam web and the shortest distance to each hose, in both the extend position and the retract position using a tape measure.

In addition, the motion of the flexible hydraulic retract hose motion was observed and video recorded.

The following measurements and observation were made:

- The closest proximity of the NLG retract hose to the NLG tire surface was measured to be 0.5";
- The NLG retract hose could be manually moved into contact with the retracted tire; significant hand force was needed to achieve contact;
- The hose clearance varies about ±0.35" during NLG cycling;

- The hose motion appears to be generally in a vertical plane. The NLG retract actuator motion during gear retraction appears to slightly shorten the hose run, so the extra length of the hose tends to move in a vertical plane (along the NLG actuator support beam);
- The flexible hydraulic retract hose "jumps" or pulses once when the gear handle is selected “OFF”, but hose appears to come back to approximately the same position after the jump;

See Figure 14.

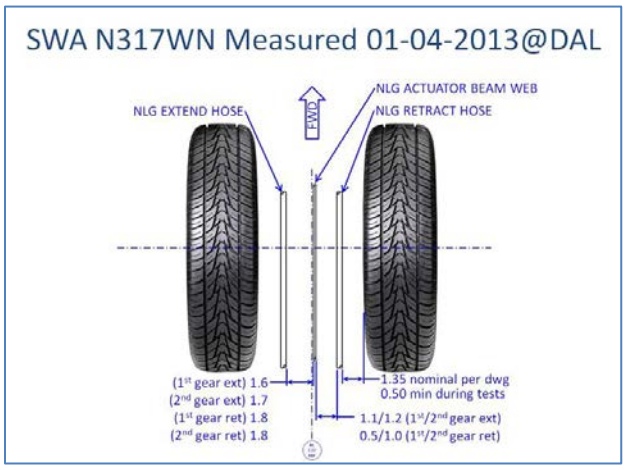

Figure 14 - Measured Clearance from Tires to Flexible Hoses

3.2 Removal and Installation of the Flexible Hydraulic Hose

While the nose landing gear was extended, Southwest maintenance personnel depressurized the hydraulic system and loosened and/or removed the end of the flexible hydraulic retract hose which was connected to the NLG retract actuator.

The flexible hydraulic hose is installed on condition as per the 737-300/400/500 AMM 20-10-52-404-001 Standard Practices – Flexible Hose Installation.

After one end was loosened, the flexible hydraulic retract hose was twisted and then retightened to secure the hose with a twist outward towards the NLG tire. Approximately 1.5 revolutions of the hose were required to move the hose a sufficient distance to contact the tire.

In addition, a brand new flexible hydraulic retract hose was provided by Southwest for observation. As received, the new hose had a gentle arc or set to it.

The consensus of the group was that the direction of motion or the static position of the hose appears to be related to two factors:

a) A twist of the hose during installation can cause horizontal motion as well as vertical motion of the hose during gear extension and/or retraction. See Figure 15.

b) While it seems natural to install the hose with the as-new curve in the vertical plane, it is possible to install it per the Aircraft Maintenance Manual Chapter 20 with the hose bowed in a horizontal plane, away from the NLG actuator beam web and towards the area where the NLG wheels are positioned after gear retraction. The hose tends to accommodate the excess length on gear retraction by accentuating the original as-new curve, whether it was installed horizontally or vertically.

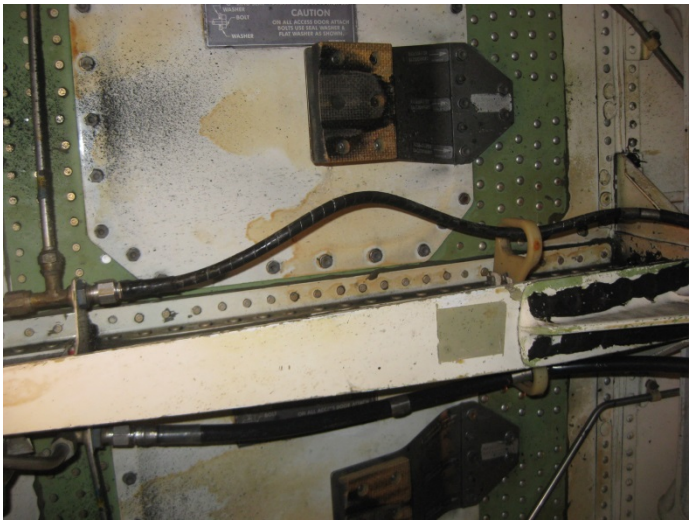

Figure 15 - Intentionally Twisted Flexible Hose

3.3 Examination of Hydraulic Hose and Nose Landing Gear Retract Actuator in Other, Similar Airplanes in the Southwest Maintenance Hangar

A second Southwest 737-3H4, registration N360SW (Boeing effectively code PP157, serial number 26571) was also parked in the maintenance hangar during the demonstration. An inspection of the flexible hydraulic retract hose installed on N360SW did not reveal any visible physical damage.

Inspection of the nose landing gear retract actuator revealed that that the actuator appeared to have two restrictors installed, as both fittings had corner notches identifying the fittings as restrictors. A union should have been installed in the actuator extend port.

4.0 Actions Taken Following the Accident, as a Result of Group Examinations

The following actions were taken following the accident and the group examinations:

4.1 Boeing Changes to Airplane Maintenance Manual (CMM)

As a result of the finding of the union and restrictor swapped on the nose landing gear retract actuator, Boeing issued a change of the component maintenance manual 32-31-40, including insertion of the following text:

> WHEN YOU INSTALL UNION (1) AND RESTRICTOR (3) IN THE ACTUATOR HYDRAULIC PORTS, BE SURE TO INSTALL THE UNION (WITH A LARGE BORE) IN THE EXTEND PORT, AND INSTALL THE RESTRICTOR (WITH A SMALL BORE OR A SCREENED BORE) IN THE RETRACT PORT, AS SHOWN IN FIG. 701 AND IPL FIG (URE). 2. BECAUSE THE EXTEND PORT AND RETRACT PORT HAVE THE SAME THREAD SIZE, IF THE UNION AND THE RESTRICTOR ARE INSTALLED IN THE WRONG PORTS, THE ACTUATOR WILL NOT OPERATE CORRECTLY.

4.2 Southwest Fleet Campaign to Inspect Union and Restrictor Positions

As a result of the examination of the nose landing gear actuator and the union and restrictor positions (and the swapped positions), on February 1, 2013, Southwest Airlines issued an internal fleet campaign (Special Item 12001-32) to examine the 737-300/400/500 series airplanes in the fleet.

The fleet campaign required Southwest Airlines maintenance personnel to examine each airplane during other maintenance procedures. The inspection also required that the retract actuator hose be inspected for any damage resulting from contact with the NLG tire.

Southwest Airlines reported that, per the special item fleet campaign, the airline's 149 737-300 and 23 737-500 airplanes were inspected. Of the 172 total airplanes examined, four aircraft were noted with findings. The findings were as follows[2]:

- Two airplanes (737-300) with two unions installed (one union instead of restrictor);
- One airplane (737-300) with two restrictors installed (one restrictor instead of union);
- One airplane (737-500) with two restrictors installed (one restrictor instead of union) and flexible hose damage;

4.3 Other Changes, Including Component Maintenance Manual

[2] Included in Southwest Airlines' findings was N360SW, the 737-3H4 noted two restrictors installed during the nose landing gear demonstration in January, 2013. For more information, please see section 3.3 of this report.

In addition to the CMM changes, Boeing made a change to the AIPC (Airplane Illustrated Parts Manual) to provide additional guidance on the difference between the union and restrictor, as well as the correct location for each of the components.

Tom Jacky
Aerospace Engineer

Attachment 1 – Diagram of Nose Gear Actuator, Union, and Restrictor Locations

Attachment 2 - Boeing EQA Report AS11733, "Examination of Nose Landing Gear Components Removed from Southwest Airlines 737-300 Airplane PS765"

Attachment 3 – Nose Landing Gear Demonstration Plan