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

December 15, 2020

Systems and Structures Group Chairman's Factual Report

DCA20MA002

A. ACCIDENT

Operator: PenAir
Aircraft: Saab 2000
Location: Dutch Harbor, AK
Date: October 17, 2019
Time: 1740 ADT

B. SYSTEMS AND STRUCTURES GROUP

Member — Steven Magladry
National Transportation Safety Board (NTSB)
Washington, DC

Member — Daniel Downs
PenAir
Anchorage, AK

Member — Gideon Singer
Swedish Accident Investigation Authority (SHK)
Stockholm, Sweden

Member — Jan Andersson
SAAB
Linkoping, Sweden

Member — Jan Pettersson
SAAB
Linkoping, Sweden

Member Ulf Andersson
SAAB
Linkoping, Sweden

Member Jeremy Sturdy
Crane Aerospace
Burbank, CA

C. SUMMARY

On October 17, 2019, about 1740 Alaska daylight time, PenAir flight 3296,[1] a Saab 2000, N686PA, overran the runway while landing at the Thomas Madsen Airport (DUT), Unalaska, Alaska. The airplane was making its second landing approach when it touched down on runway 13 and overran the runway passing through the airport perimeter fence, crossing a road, and then pitching down over shoreline rocks. The airplane came to rest with the main landing gear wheels at the top of the rocks and the nose wheel in the water. Of the 39 passengers and 3 flight crew on board, 1 passenger was fatally injured, 4 passengers sustained injuries, and 37 passengers and flight crew were uninjured. Visual meteorological conditions prevailed. The airplane was substantially damaged. The airplane was operating as a regularly scheduled passenger flight in accordance with the provisions of 14 *Code of Federal Regulations* Part *121* from Ted Stevens International Airport (ANC), Anchorage, Alaska to DUT.

The NTSB Group Chairman arrived on-scene on 10/19, the PenAir representative arrived on 10/21 and the Swedish Accredited Representative and the Saab team arrived 10/22. The on-scene documentation occurred between 10/19 and 10/24. On November 19, 2019 Collins downloaded the airplane fault data from the Maintenance Diagnostics Computer. On December 9-10, 2020 the anti-skid components were examined at Crane Aerospace. On January 16, 2020 the left outboard tire was examined at Michelin. On February 12-13, 2020 the power brake valve was examined at Tactair. On June 20, 2020 a team recovered additional wheel speed transducer wire harnesses and removed the left inboard wheel. On July 1, 2020 the wheel speed transducer wire harnesses were examined. The following summarizes those activities.

[1] The airplane was owned and operated by Peninsula Aviation Services Incorporated d.b.a. PenAir.

D. DETAILS OF THE INVESTIGATION

Contents

1.0 General Information and Airplane Recovery

This report will provide an overview of the airplane recovery, details of the relevant airplane systems, with the focus on the wheel brake system, and an overview of the condition of the structures.

Before the Systems and Structures Group Chairman arrived on-scene, the nose of the airplane was secured by straps around the fuselage and connected to a small crane to secure it from further movement into the water. The airplane was documented by photos before being lifted by a crane onto a barge. The barge was moved a short distance to the recovery company's location and moored for two nights while a trailer was modified to hold the airplane. The airplane was then placed on the trailer and transported to a revetment on airport property, Figures 1-7.

Figure 1 Final position of airplane, secured by crane.

Figure 2 Airplane rigged for recovery

Figure 3 Airplane being lifted by crane onto barge

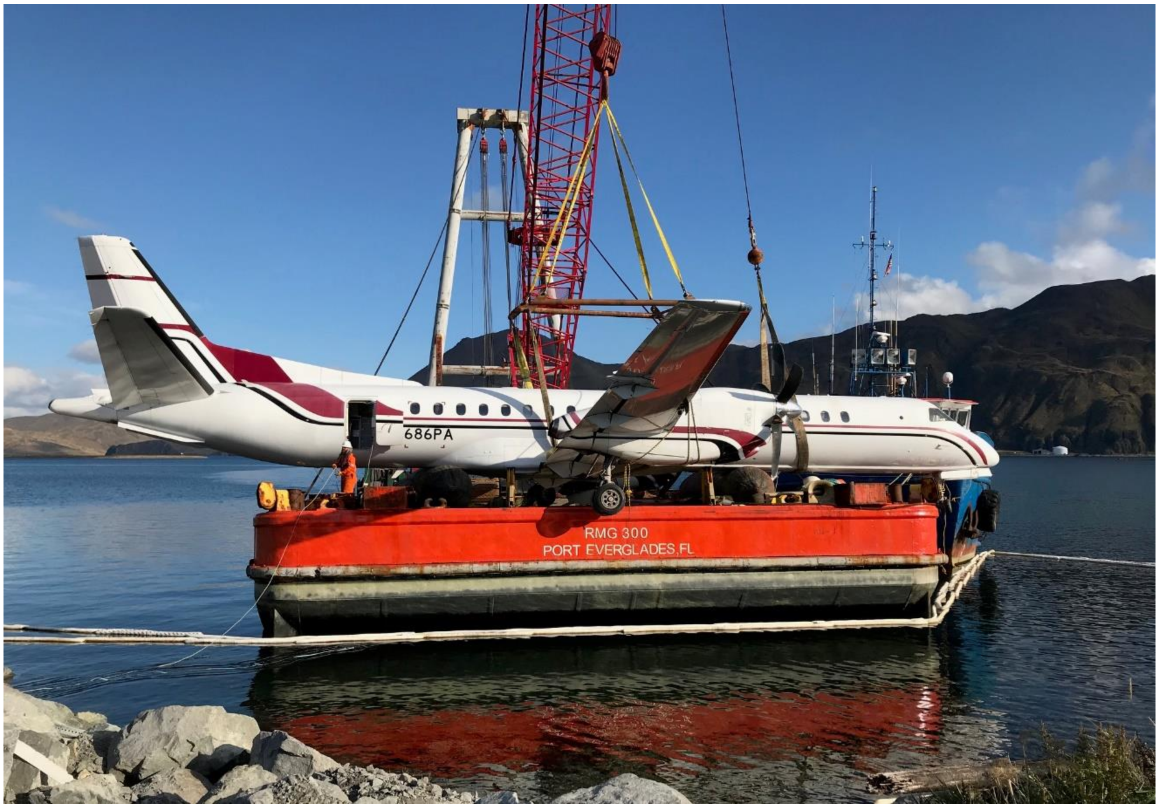


Figure 4 Airplane secured on barge


Figure 5 Airplane moved from barge to trailer

Figure 6 Airplane transported to airport property

Figure 7 Airplane placed in revetment on airport property

2.0 Brake System, Wheels, and Tires - System Description

The airplane has two main landing gear, each with two wheels, Figure 8. For convenience, the wheel assemblies will be identified by numbers 1 through 4 from left to right facing airplane forward. The brake system primary components are the brake pedals, the power brake valve, the anti-skid system, and the brake units which transmit the braking force to the wheels and tires, Figures 9-10. The captain's and first officer's brake pedals operate independent of each other. If for some reason both captain and first officer depress the left (or right) pedal, whichever pedal is depressed further will control the brake pressure for that side. A control cable from each pedal transmits the inputs of the pedal to the power brake valve (PBV). The PBV converts the motion into hydraulic pressure and provides proportional force feedback to the pilots. The hydraulic pressure goes to the anti-skid control valves, and the control valves determine how much pressure is sent to each brake. The PBV is split in two parts, one for the outboard brakes powered by the No. 1 hydraulic system, and one for the inboard brakes powered by the No. 2 hydraulic system.

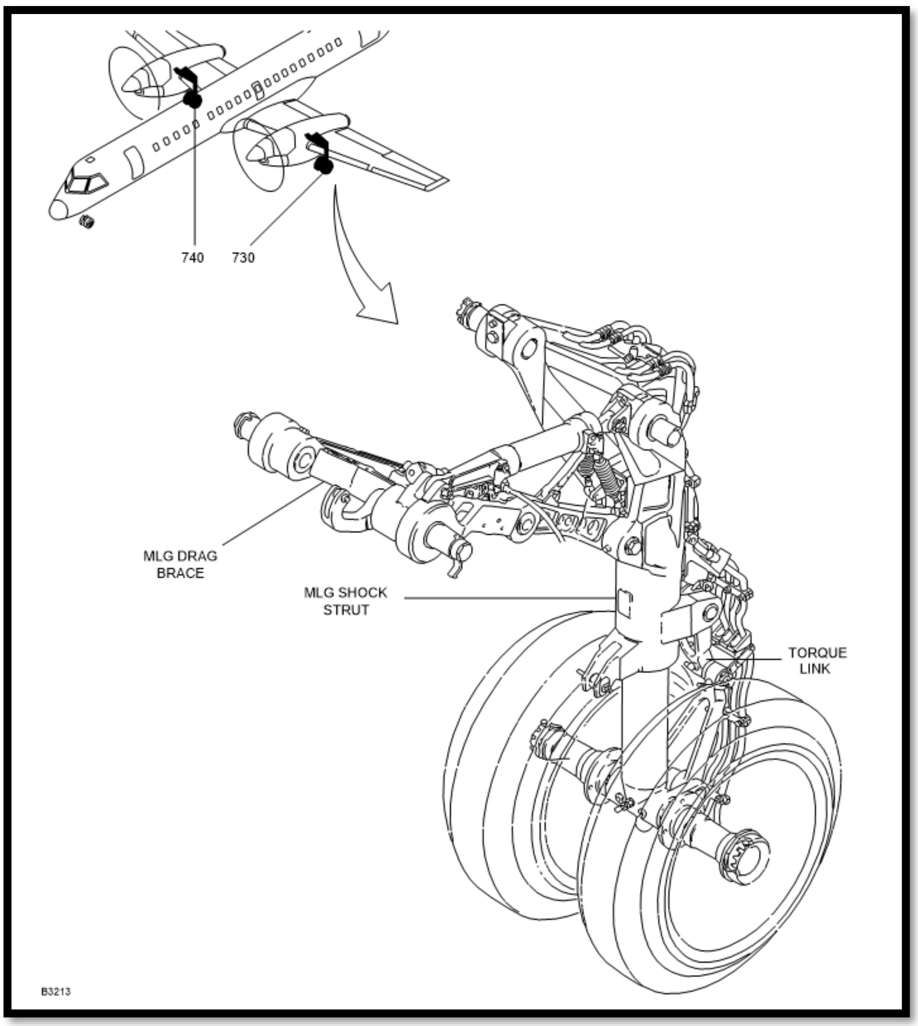
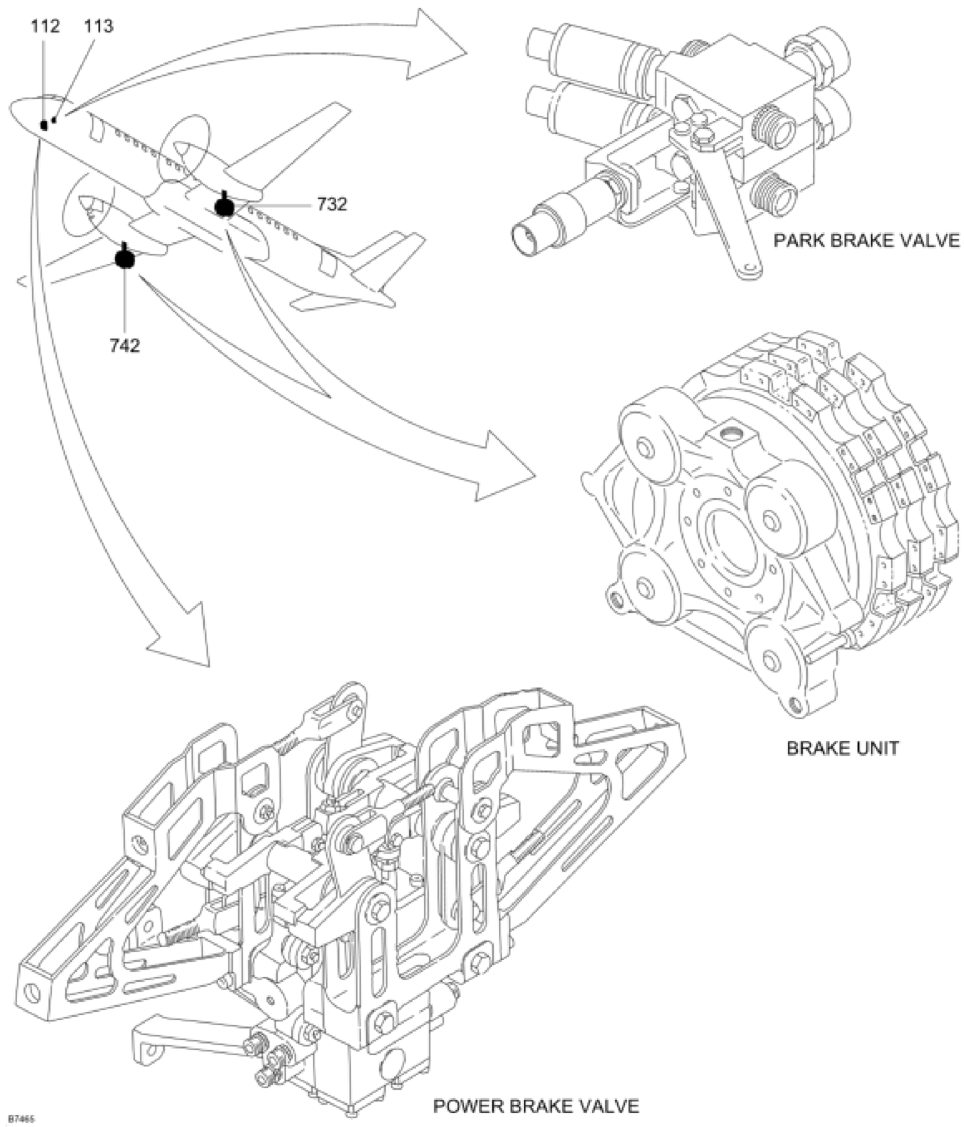


Figure 8 Landing Gear

SAAB 2000 **Operator:** Not Allocated, **MSN:** 017, **ACR:** N686PA

Aircraft Maintenance Manual



FOR A/C ALL
Fig. 1 Brakes - C/L
TASK 32-42-00-990-801-1

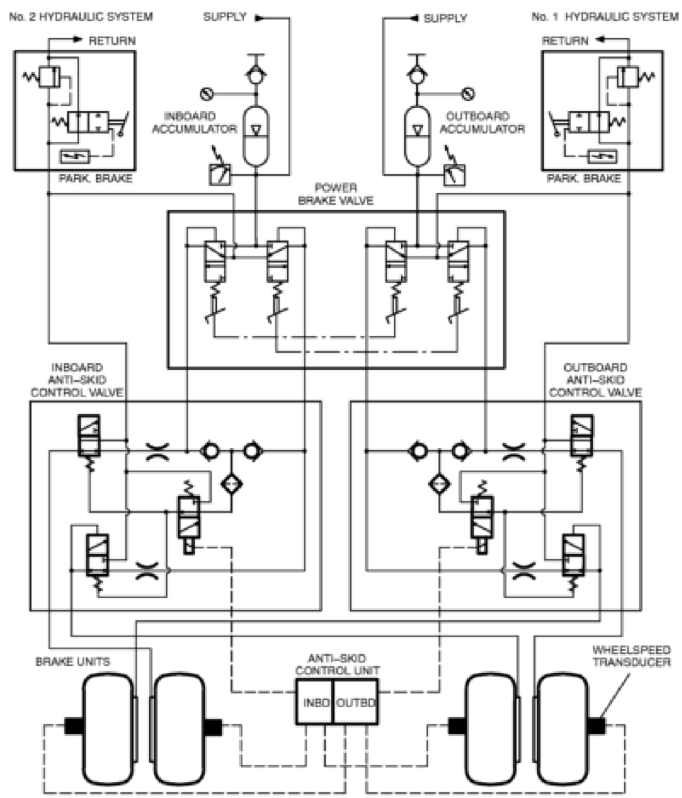
3. System Description

Not Export Controlled **AMM 32-42-00-00** **Apr 01/08**

Figure 9 Brake system components

SAAB 2000 **Operator:** Not Allocated, **MSN:** 017, **ACR:** N686PA

Aircraft Maintenance Manual



FOR A/C ALL

Not Export Controlled **AMM 32-42-00-00** **Apr 01/08**

Figure 10 Brake system schematic

3.0 Brake System, Wheels, and Tires - Accident Airplane Component Information

3.1 Power Brake Valve

The Power Brake Valve was mounted on a bulkhead in the nose wheel well, Figure 11. While still installed, each of the brake pedals were moved separately and the inputs to the mechanism were observed. It was confirmed that motion of each pedal moved the separate inputs to the mechanism. The hydraulics were disconnected and capped, the four input rods were difficult to access to disconnect so they were cut close to the sidewall. The component was removed and retained by NTSB. It was a TACTAIR Fluid Controls Inc, P/N HP1408300-1, S/N 1115, MFG 8-94.

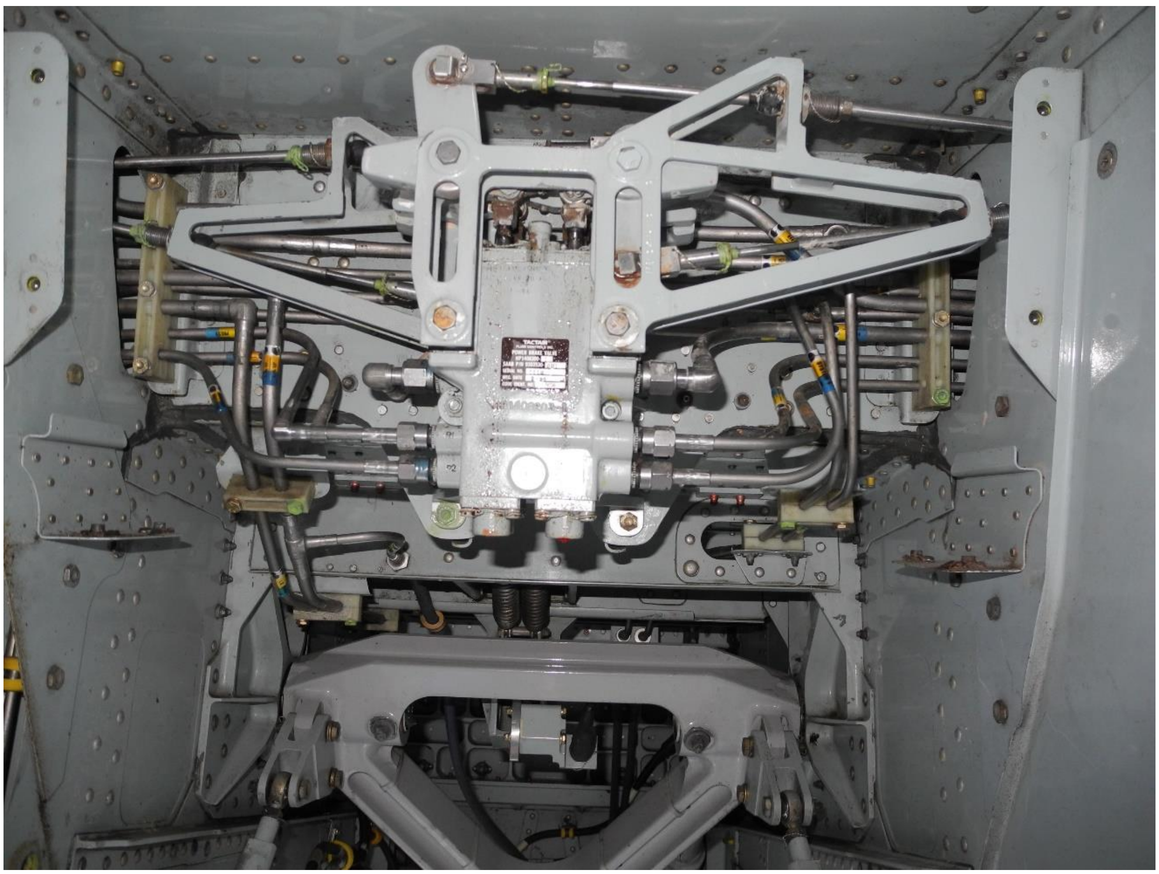


Figure 11 Power Brake Valve

Between February 12-13, 2020 representatives from the team, including NTSB, PenAir, SHK, and Saab convened at the Tactair facility in Liverpool, NY to examine the PBV. Tactair advised that the unit had no repair history, and it not been returned for servicing during its life. The unit was tested according to the production Acceptance Test Procedure 1408300, Rev D. All tests passed except there were slight exceedances in three of the four brake pressure versus plunger test near full displacement (approximately 0.025 inches from full travel). On each, the exceedance occurred during the return from full travel or decreasing pressure. There was also substantial corrosion of the clevis pins which attached the captains input cables to the mechanism. Neither of these conditions were considered to be significant in the operation of the PBV.

3.2 Tires

The #1 tire was found to be deflated and had an area approximately 11 inches in length which was ground flat all the way through the tire, Figures 12-13. There was a hole in the sidewall of the tire near the flat spot, and an oval shaped worn area approximately 180 degrees from the ground flat area, Figure 14. The runway was inspected and there was a long skid mark on the left side of the runway past the touchdown area.

Figure 12 Left main gear tires


Figure 13 Hole in left outboard tire

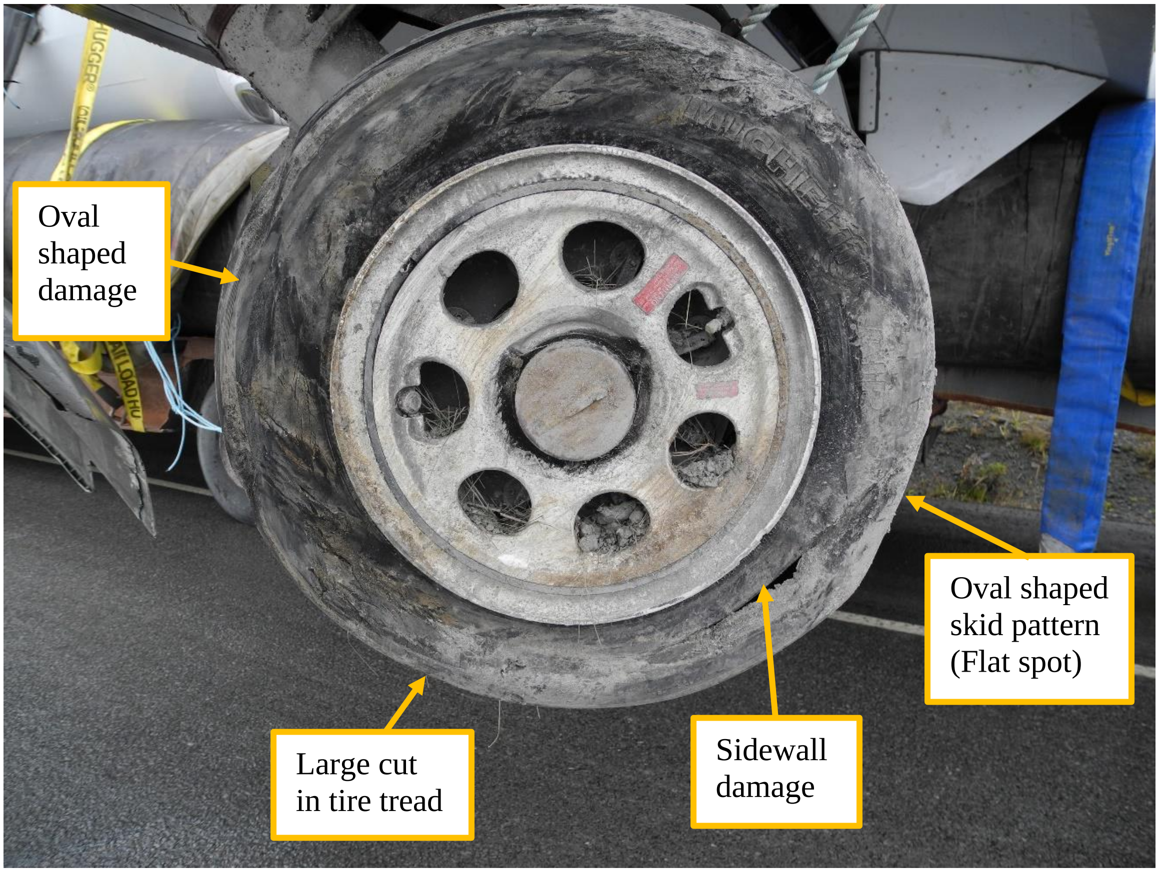


Figure 14 Damage to left outboard tire

During the interviews of the flight crew it was revealed that the #1 tire had a flat spot prior to departure of the accident flight, Figure 15. It did not appear that the wear exposed any of the reinforcing plies.


Figure 15 Flat spot on #1 tire prior to accident flight

Tires 2-4 were intact and pressurized. The pressure in the tires was checked at the accident site, prior to lifting the airplane onto the barge. The #2 tire was at 135 psi. The #3 and #4 tires, Figure 16, were at the maximum reading of the available gauge, which was 160 psi. A placard on the landing gear door indicated that the allowable pressures were between 165-173 psi. The tires were later cleaned with water and rags to remove the bulk of the dirt to reveal the condition of the tread. These tires had numerous abrasions and cuts in the tires but did not have any flat spots, and all had significant tread remaining.

Figure 16 Right main gear tires

The tires were Michelin Air 32/8.8/14/210, P/N 27-711-0, a bias tire. The wheels were SAAB part numbers 9303527-001, and the serial numbers were as follows:

#1 JAN95-0192
#2 FEB93-0210
#3 JAN00-0046
#4 NOV06-0507

An initial sweep of the runway by airport personnel found some rubber fragments, and a subsequent sweep by the team identified some more of the same and a small screw. In total there were seven rubber pieces and one screw. The location of the initially recovered fragments is not known. At least one of the rubber fragments recovered by the team was known to have been in the area near the end of a dark skid mark on the runway. The runway was documented in the Aircraft Performance Crash Site Factual Report in the docket.

The team removed the left outboard wheel and tire and shipped it via Ravn flight to Anchorage. On October 25th the tire was separated from the wheel at the PenAir tire shop. The NTSB shipped the tire to NTSB Headquarters in Washington, DC. The tire was transported by the NTSB to the Michelin Charlotte testing facility, and on January 16, 2020 the tire was examined by Michelin and the NTSB.

Michelin experts concluded the following:

- The oval shaped skid pattern (flat spot) was the initial skid that resulted in the complete pressure loss of this tire. The tapered and oval shape of the plies indicated the tire was inflated while skidding. As the tire skidding action wore into the plies, the reduction in plies (casing strength) was unable to maintain pressure, Figure 17.

- After complete pressure loss, the skid pattern showed the tire skid footprint increased to include the sidewall damage in that area of the tire. This was the result of the tire collapsing and skidding on both of the sidewalls, Figure 17.

- At some point later the tire / wheel assembly rotated and then skidded again as indicated by the oval skid pattern, Figure 18. This skid also shows skidding on both sidewalls indicating the tire was deflated.

- The large cut / damage on the tread that extended through the casing and inner-liner appeared to have occurred after the pressure loss, Figure 19. If this was the initial cause of the pressure loss, there would be no tapered and oval shaped skid pattern at the flat spot. Also, if this was the initial pressure loss, there most likely would be a bias, or X-type rupture of the casing – pressurized blow-out. The debris found in this cut / damage appears to be gravel, pieces of rock, concrete, etc.

- The small amount of fragments appear to be from the area of the initial skid, Figure 20. The small screw was not part of the tire.

- With regard to the flat spot prior to dispatch, if there were no reinforcing plies visible the tire was serviceable in that condition.

MICHELIN
A better way forward

Tire Analysis Report

Date: 23 January 2020
Page 9 of 19
RGA No: **020-001**

RGA 020-001 Photo E

STD AV 107 FOR 03	Edition date : 15 Feb. 2014	Classification :D3	Conservation : WA + 12

Figure 17 Flat spot and sidewall damage

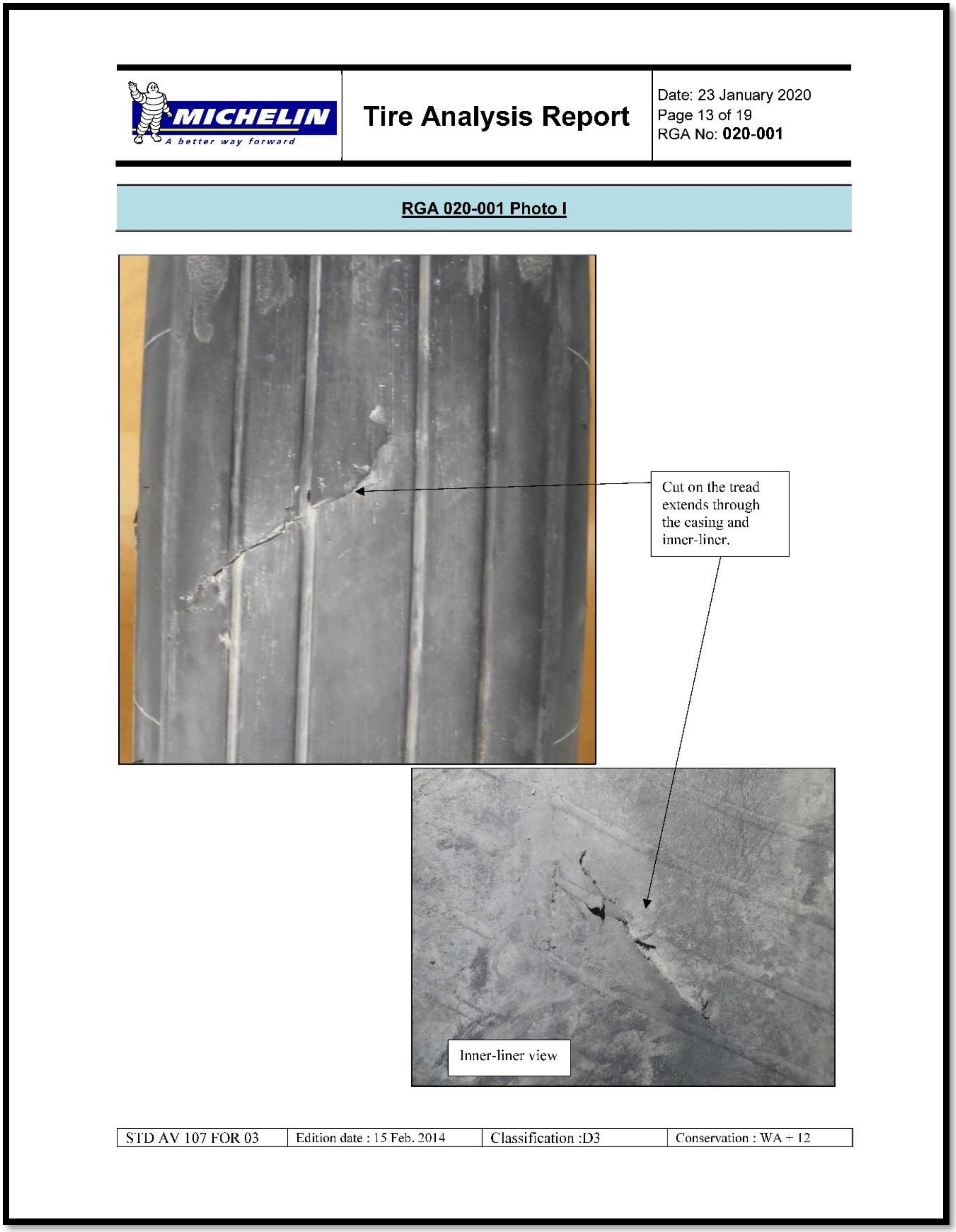
MICHELIN A better way forward	**Tire Analysis Report**	Date: 23 January 2020 Page 11 of 19 RGA No: **020-001**

RGA 020-001 Photo G

Skid pattern extends into the sidewall area.

STD AV 107 FOR 03	Edition date : 15 Feb. 2014	Classification :D3	Conservation : WA + 12

Figure 18 Oval skid pattern into sidewall



MICHELIN A better way forward	**Tire Analysis Report**	Date: 23 January 2020 Page 13 of 19 RGA No: **020-001**

RGA 020-001 Photo I

Cut on the tread extends through the casing and inner-liner.

Inner-liner view

STD AV 107 FOR 03	Edition date : 15 Feb. 2014	Classification :D3	Conservation : WA + 12

Figure 19 Large cut through tire

MICHELIN A better way forward	Tire Analysis Report	Date: 23 January 2020 Page 18 of 19 RGA No: **020-001**

RGA 020-001 Photo N

STD AV 107 FOR 03	Edition date : 15 Feb. 2014	Classification :D3	Conservation : WA + 12

Figure 20 Tire fragments and screw

Maintenance records indicated PenAir last checked tire pressures on October 13, 2019, see Maintenance Factual Report for maintenance program details. The maintenance program required tire pressure checks during the Line Check 2 (LC2) at intervals of 50 flight hours or 7 days. This interval is the same as that recommended by the Saab maintenance planning document. Michelin tire care documentation recommended checking tire pressures daily, as did FAA advisory circular 20-97B, Aircraft Tire Maintenance and Operational Practices. The tire servicing procedure in the PenAir maintenance manual indicate the various steps required if tires are found to be operated at less than normal operating pressure, Figure 21. These ranges match the values found in the Michelin care and service manual for a cold tire operational pressure of 165 PSI.

COLD MAIN WHEEL TIRE PRESSURE		RECOMMENDED ACTION
UNLOADED	LOADED	
167 psi and above (11.51 bars)	173 psi and above (11.95 bars)	Record overinflated reading in aircraft log book along with the ambient temperature. Adjust to right tire pressure (Table 304).
159 - 167 psi (10.96 - 11.51 bars)	165 - 173 psi (11.38 - 11.95 bars)	None - normal cold tire operation.
151 - 159 psi (10.41 - 10.96 bars)	157 - 165 psi (10.81 - 11.38 bars)	Inflate to the correct tire pressure (Table 304).
143 - 151 psi (9.87 - 10.41 bars)	148 - 157 psi (10.20 - 10.81 bars)	Inspect tire/wheel assembly for cause of pressure loss. Reinflate and record in aircraft log book.
127 - 143 psi (8.77 - 9.87 bars)	132 - 148 psi (9.10 - 10.20 bars)	Remove the tire from the aircraft (see note).
127 psi or below (8.77 bars)	132 psi or below (9.10 bars)	Remove the two tires from the same landing gear (see note).
Blown fusible plug	Blown fusible plug	Discard the tire. If the fusible plug was blown during service (rolling) discard the other tire from the same landing gear.

Figure 21 Table from tire servicing procedure in maintenance manual

The #2 wheel was removed from the accident airplane during a return visit to the accident airplane in June 2020. The wheel was shipped to Michelin for examination. The tire was removed from the wheel, cleaned, and inspected. The bead showed no abnormal conditions. There was wrinkling of the inner liner in the shoulder area, but only on the serial number side, which was the inboard side of the tire as installed on the airplane. Michelin advised that wrinkling can occur when a tire is operated at low pressure or overloaded, however if it is due to low pressure the wrinkling would be expected on both sides.

PenAir reviewed maintenance records and found the following tire replacements:

Tire changes from 7/1/2019 through 10/16/2019:

7/31/2019: #1 MLG tire has crack in grooves with fabric exposed. Total Aircraft Time (TAT) 12,176.5

8/15/2019: #2 MLG tire worn to limits. TAT 12,289.3

8/28/2019: #4 MLG tire worn to limits. TAT 12,311.4

8/30/2019: #3 MLG tire worn to limits. TAT 12,325.7

9/02/2019: #1 MLG tire has bald spot with threads cut. TAT 12,343.6

9/15/2019: #2 MLG tire pressure found to be
90 PSI, which necessitated replacement of the #1 MLG tire as well. TAT 12,440.8

3.3 Brakes

The airplane had carbon brakes and the brake wear pins were observed. An accurate measure of wear could not be made without applying hydraulic pressure, but an approximate condition could be determined in the unpressurized state. The #1 and #4 brakes had about an inch or more of pin above the measuring plate, which indicated most of their service life remained, the #2 brake had about ½ inch showing and the #3 brakes had about 1/8 inch showing. All were in serviceable ranges. After removal of the #1 wheel the brake was visually inspected. Other than the ingested dirt and debris, the brake did not appear to have any damage.

4.0 Anti-skid System - Description and Operation

The anti-skid system controls the hydraulic pressure applied to the brakes. It receives the four brake pressure commands from the power brake valve (left outboard, left inboard, right outboard, right inboard) and reduces them if an excessive skid is sensed. The system manages the anti-skid function in pairs or channels. The outboard (OUTBD) wheel on the left landing gear and outboard wheel on the right landing gear are one pair and the inboard (INBD) wheels on each gear are the other pair.

The antiskid system consists primarily of the anti-skid control unit, anti-skid control valves, and wheel speed transducers, Figures 22 - 23. The anti-skid control unit contains two identical anti-skid channels. The OUTBD channel controls the outboard brakes and the INBD channel controls the inboard brakes. The INBD and the OUTBD anti-skid channels get signals from their related wheel speed transducers. These signals give a frequency which is proportional to the speed of the wheel. The signals go to the anti-skid control unit. In the two control circuits, the signals (from each wheel speed transducer) go to their related squarer and frequency/DC converter. The squarer and the frequency/DC converter change each wheel speed frequency to a DC voltage. The velocity average circuit calculates these DC voltages and gives the average voltage for each pair of wheel speeds. This average voltage goes to the velocity processor which compares the average voltage with a simulated aircraft velocity. When the difference of these two velocities exceeds certain thresholds, the control unit commands the appropriate antiskid control valve to reduce brake pressure to the pair of wheels.

In addition to this antiskid control, the antiskid control unit has a locked wheel protection function. This function compares the wheel speed of one of the wheels in the pair to the other. When one is 40% or less than the other, the unit commands the antiskid control valve to reduce brake pressure to both wheels to the minimum value, also called a full valve dump.

The antiskid control unit has a touchdown protection function. With the squat switch in the “Air” position a full valve dump is commanded. When the squat switch changes to the “Ground” position brake pressure is allowed if wheel spin reaches a threshold or after an approximate three second delay.

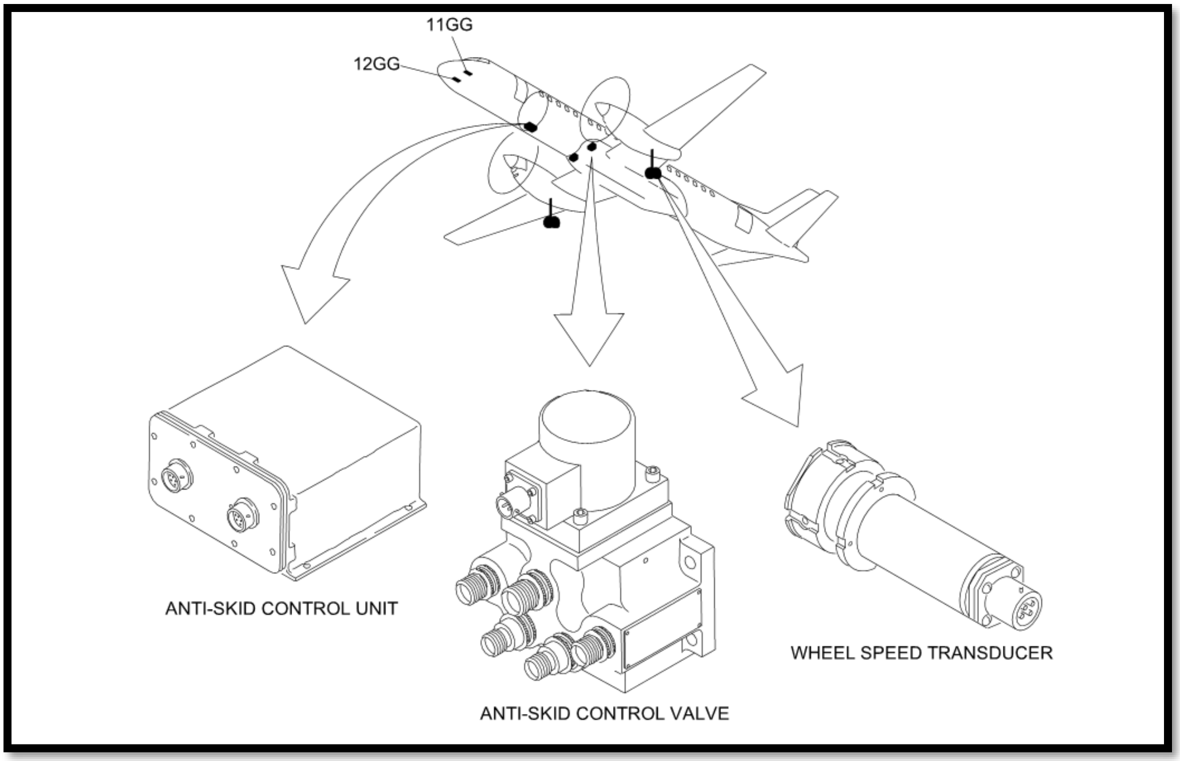


Figure 22 Anti-skid system component locations.

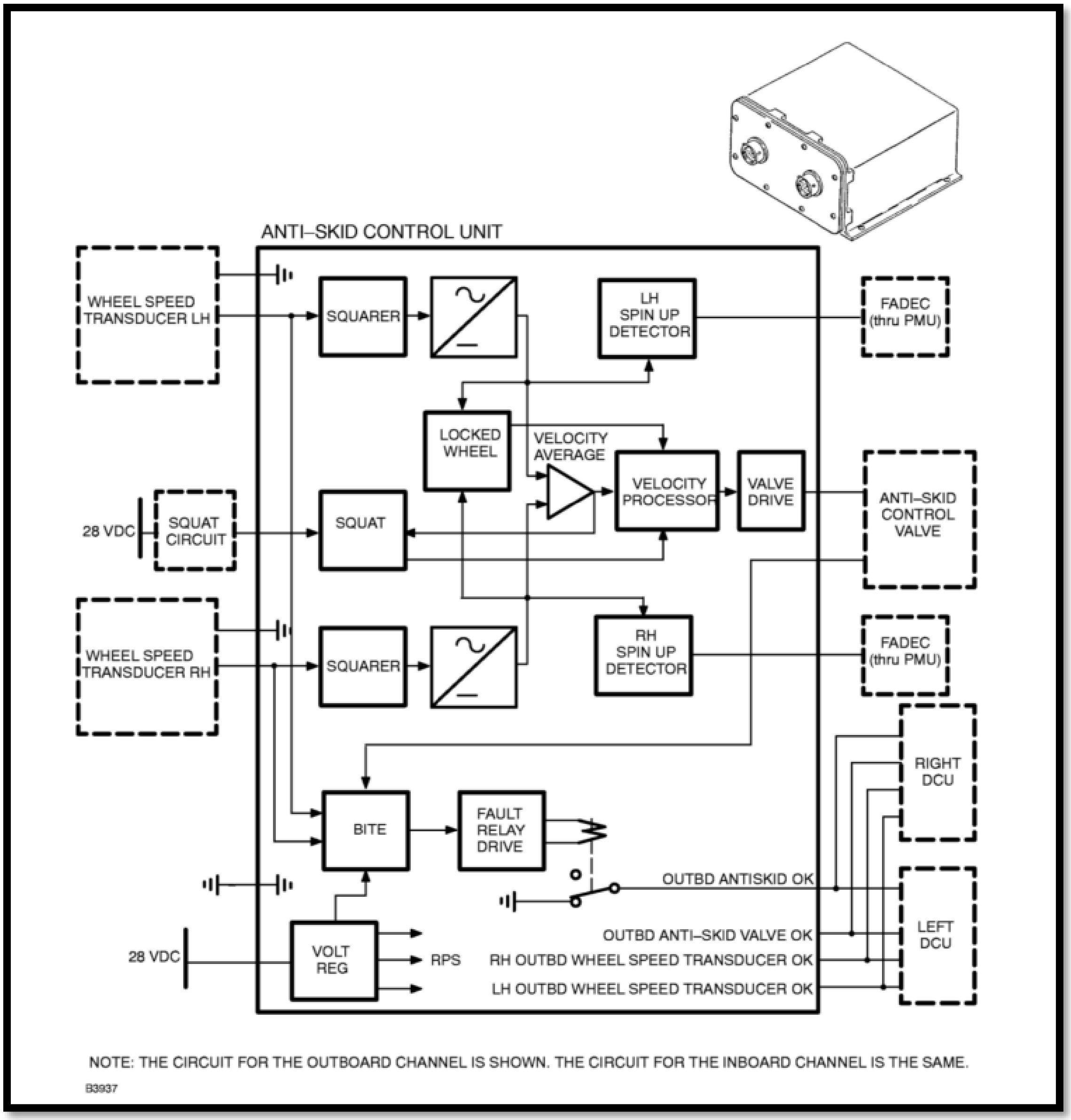


Figure 23 Anti-skid system schematic

All these functions send signals to a summing amplifier, which is the cumulative command voltage. This voltage is converted to a valve driver current which is sent to the anti-skid control valve. The range of valve driver current is 0 to 45 milliamps (ma). The higher the current the greater the reduction in commanded brake pressure.

The anti-skid control valve primary components are an electro-hydraulic servovalve and two slide and sleeve assemblies. The operation of the valve is essentially the operation of the servovalve and the slide and sleeve assembly, acting as the first and second stage control, respectively, over brake pressure. The first stage of the valve, the servovalve, incorporates a torque motor with an armature that extends between two nozzles, one nozzle connected to pilot's metered pressure (P1 or P2) and the other connected to return pressure. The position of the armature between the two nozzles is determined by the amount of current applied to the servovalve. With no current applied, the armature is positioned against the return nozzle, and as current increases the armature moves toward the pressure nozzle. The second stage of the valve consists of a slide that moves back and forth inside of a sleeve. The position of the slide within the sleeve is determined by control pressure from the servovalve. Check valves installed in the valve body enable pressure from P1 or P2, whichever is greater, to be applied to the servovalve. With no current applied, the armature is held against the return nozzle and pilot's metered pressure from P1 or P2 pushes the slide to one end of the sleeve. This operation routes pilot's metered pressure directly to the brakes (P1 to B1 or P2 to B2). As a braked wheel exceeds the skid level, the anti-skid system increases electrical current to the servovalve, causing the armature to move toward the pressure nozzle, decreasing pressure against the slide. This enables brake pressure feedback to push the slide in the opposite direction, routing B1 and B2 pressure away from the brakes and out the return port.

The antiskid control unit has the following continuous monitors of system components:

- Valve Dump Detector – monitors for valve driver current greater than 40ma for greater than 1.5 seconds. This will detect a longer than expected full release of brake pressure to a wheel pair.
- Valve Monitor – monitors for control valve driver voltage of less than 0.25V or greater than 11V. This will detect a short or open connection between control unit and the control valve.
- Transducer Monitor – monitors the output of the wheel speed transducers for less than 1.4V or greater than 8V. This will detect a short or open between the control unit and wheel speed transducer.

If faults occur, the signal is sent to the right and left data concentrator units (DCU). The DCU contains logic which determines if the fault will be displayed to the flight crew on the EICAS display and/or if the fault will be recorded on the Maintenance Diagnostics Computer (MDC). The following table shows all possible fault messages for the anti-skid system. Each of the messages recorded on the MDC should also be accompanied by a maintenance source message. The messages on the Primary EICAS are Amber Caution messages and are accompanied by a master caution. The message on the Secondary EICAS is a white status message.

Fault message	**EICAS/MDC**
INBD A-SKID FAULT	Primary EICAS
OUTBD A-SKID FAULT	Primary EICAS
A-SKID OFF	Secondary EICAS
INBD A-SKID	MDC (maintenance source)
OUTBD A-SKID	MDC (maintenance source)
32#ANTI SKID CTL	MDC (maintenance message)
32#ANTI SKID VLV	MDC (maintenance message)
32#R WHEEL SPD XDCR	MDC (maintenance message)
32#L WHEEL SPD XDCR	MDC (maintenance message)

The following Boolean logic sets the faults:

INBD A-SKID FAULT = [(.NOT.INBD ANTISKID OK **OR**
.NOT.INBD ANTISKID VLV OK **OR** (.NOT.L INBD WHEEL SPD XDUC OK **AND**
.NOT.R INBD WHEEL SPD XDUC OK)) **AND**
(.NOT.WEIGHT ON WHEEL **OR** (WEIGHT ON WHEEL **AND** ENG ON ENABLE))] **AND**
0.5 Sec Delay;

OUTBD A-SKID FAULT = [(.NOT.OUTBD ANTISKID OK **OR**
.NOT.OUTBD ANTISKID VLV OK **OR** (.NOT.L OUTBD WHEEL SPD XDUC OK **AND**
.NOT.R OUTBD WHEEL SPD XDUC OK)) **AND**
(.NOT.WEIGHT ON WHEEL **OR** (WEIGHT ON WHEEL **AND** ENG ON ENABLE))] **AND**
0.5 Sec Delay;

32#ANTI SKID CTL = [(.NOT.INBD ANTISKID OK **OR**
.NOT.OUTBD ANTISKID OK) **AND** (INBD A-SKID FAULT **OR**
OUTBD A-SKID FAULT)];

32#ANTI SKID VLV = [(.NOT.INBD ANTISKID VLV OK **OR**
.NOT.OUTBD ANTISKID VLV OK) **AND** (INBD A-SKID FAULT **OR**
OUTBD A-SKID FAULT)];

32#L WHEEL SPD XDCR = [(.NOT.L INBD WHEEL SPD XDUC OK **OR**
.NOT.L OUTBD WHEEL SPD XDUC OK) **AND**
(INBD A-SKID FAULT **OR** OUTBD A-SKID FAULT **OR**
((R INBD WHEEL SPD XDUC OK **OR** R OUTBD WHEEL SPD XDUC OK) **AND**
(.NOT.WEIGHT ON WHEEL **OR** (WEIGHT ON WHEEL **AND**
ENG ON ENABLE))))];

32#R WHEEL SPD XDCR = [(.NOT.R INBD WHEEL SPD XDUC OK **OR**
.NOT.R OUTBD WHEEL SPD XDUC OK) **AND**
(INBD A-SKID FAULT **OR** OUTBD A-SKID FAULT **OR**
((L INBD WHEEL SPD XDUC OK **OR** L OUTBD WHEEL SPD XDUC OK) **AND**
(.NOT.WEIGHT ON WHEEL **OR** (WEIGHT ON WHEEL **AND**
ENG ON ENABLE))))];

INBD A-SKID = [[(.NOT.INBD ANTISKID OK **OR**
.NOT.INBD ANTISKID VLV OK) **AND** INBD A-SKID FAULT] **OR**
[(.NOT.L INBD WHEEL SPD XDUC OK **OR**
.NOT.R INBD WHEEL SPD XDUC OK) **AND** (INBD A-SKID FAULT **OR**
(((L INBD WHEEL SPD XDUC OK **OR** R INBD WHEEL SPD XDUC OK) **AND**
(.NOT.WEIGHT ON WHEEL **OR** (WEIGHT ON WHEEL **AND** ENG ON ENABLE))) **AND**
0.5 Sec Delay))]] **AND** 1.0 Sec Delay;

OUTBD A-SKID = [[(.NOT.OUTBD ANTISKID OK **OR**
.NOT.OUTBD ANTISKID VLV OK) **AND** OUTBD A-SKID FAULT] **OR**
[(.NOT.L OUTBD WHEEL SPD XDUC OK **OR**
.NOT.R OUTBD WHEEL SPD XDUC OK) **AND**
(OUTBD A-SKID FAULT **OR** (((L OUTBD WHEEL SPD XDUC OK **OR**
R OUTBD WHEEL SPD XDUC OK) **AND** (.NOT.WEIGHT ON WHEEL **OR**
(WEIGHT ON WHEEL **AND** ENG ON ENABLE))) **AND**
0.5 Sec Delay))]] **AND** 1.0 Sec Delay;

This table shows which anti-skid control unit monitors set the DCU logic states:

Logic state	Antiskid unit monitor
INBD ANTI SKID OK	INBD VALVE DUMP DETECTOR
OUTBD ANTI SKID OK	OUTBD VALVE DUMP DETECTOR
INBD ANTI SKID VLV OK	INBD VALVE MONITOR
OUTBD ANTI SKID VLV OK	OUTBD VALVE MONITOR
L INBD WHEEL SPD XDUC OK	L INBD TRANSDUCER MONITOR
R INBD WHEEL SPD XDUC OK	R INBD TRANSDUCER MONITOR
L OUTBD WHEEL SPD XDUC OK	L OUTBD TRANSDUCER MONITOR
R OUTBD WHEEL SPD XDUC OK	R OUTBD TRANSDUCER MONITOR

4.1 Wheel Speed Transducer Wiring - Description

Figure 24 shows the routing of the wheel speed transducer wire harnesses (items 10 and 20), according to the manufacturers component maintenance manual. The left and right main landing gear use the same part number harnesses. At the top of the landing gear, the connectors attach to bulkhead fittings at the aft end of the wheel well, Figure 25. In Saab drawings the left (right) gear upper electrical connector on the bulkhead is identified as 5GA-J4 (6GA-J4) and the lower electrical connector is 5GA-J5 (6GA-J5). The mating connectors at the end of each wire harness are identified as 5/6GA-P4 and 5/6GA-P5, Figure 26. The P4 (J4) and P5 (J5) connectors are keyed differently, they have different part numbers, so only P4 can be connected to J4 and only P5 can be connected to J5.

The bottom ends of both harnesses are inserted through a single hole in the base of the strut, Figure 27, and are routed to the appropriate axle opening; Figure 24 illustration does not show the harnesses in the axles as they would actually be routed. The connectors at the bottom of the wire harnesses, which attach to the wheel speed transducers in the axles, are the same part number. There is no distinguishing feature at the bottom end of the harnesses to determine which should be routed to which wheel.

The manufacturer for the landing gear is APPH Ltd (Heroux Devtek), located in the UK. According to the Heroux Devtek Component Maintenance Manual 32-10-13, the Saab Illustrated Parts Catalog 32-11-15-01A, and the Heroux Devtek wire harness drawings, the following information was gathered:

Wheel speed transducer wire harness (item 10) is part number AIR 134484 and is routed to the right wheel; for the left gear this is the inboard wheel, for the right gear it is the outboard wheel. The harness has a label near the upper connector indicating 5/6 GA-P4. The upper electrical connector part number is MS 27467T9B35P.

Wheel speed transducer wire harness (item 20) is part number AIR 134485 and is routed to the left wheel; for the left gear this is the outboard wheel, for the right gear it is the inboard wheel. The harness has a label near the upper connector indicating 5/6 GA-P5. The upper electrical connector part number is MS 27467T9B35PA.

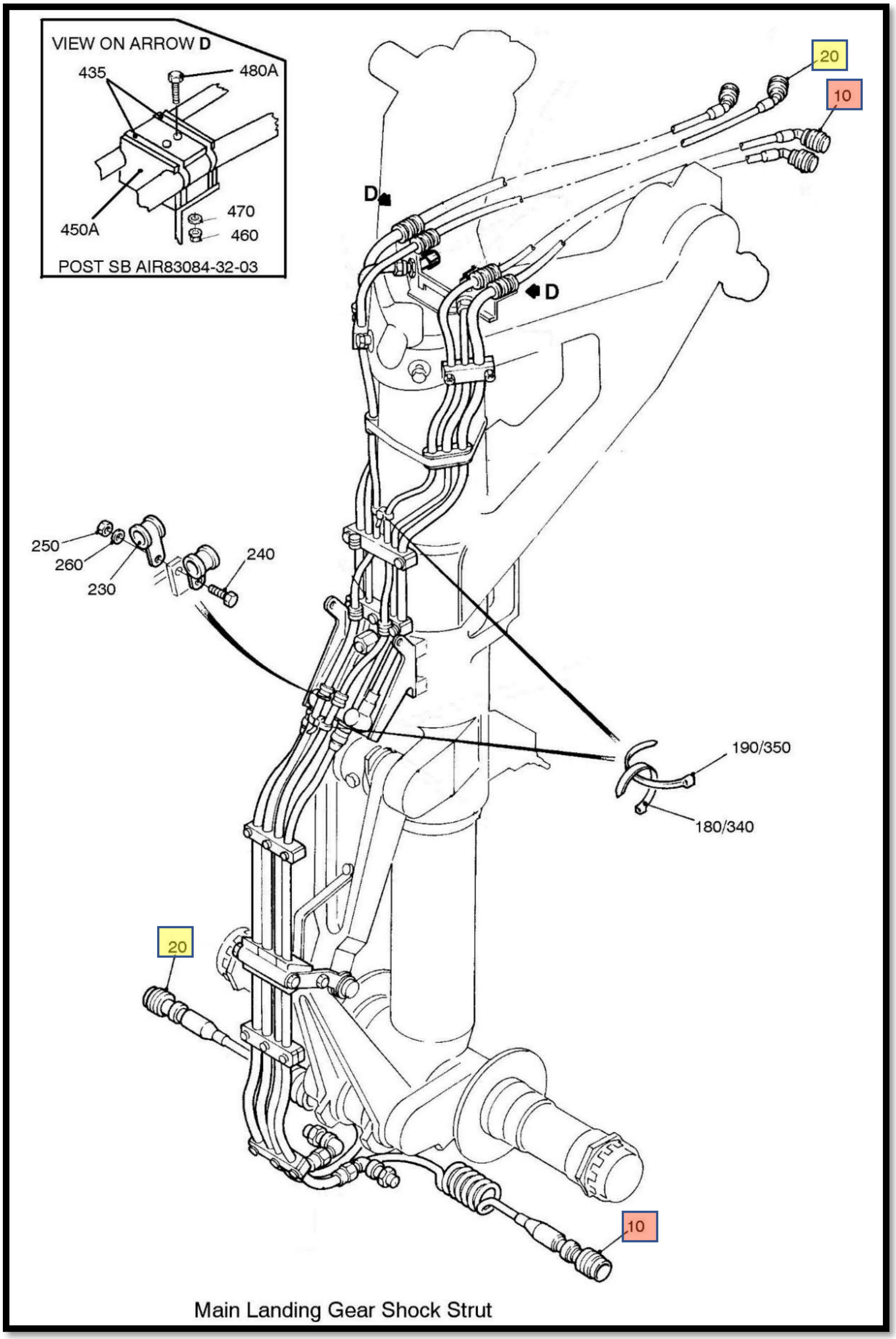


Figure 24 Wheel speed transducer wire harness routing

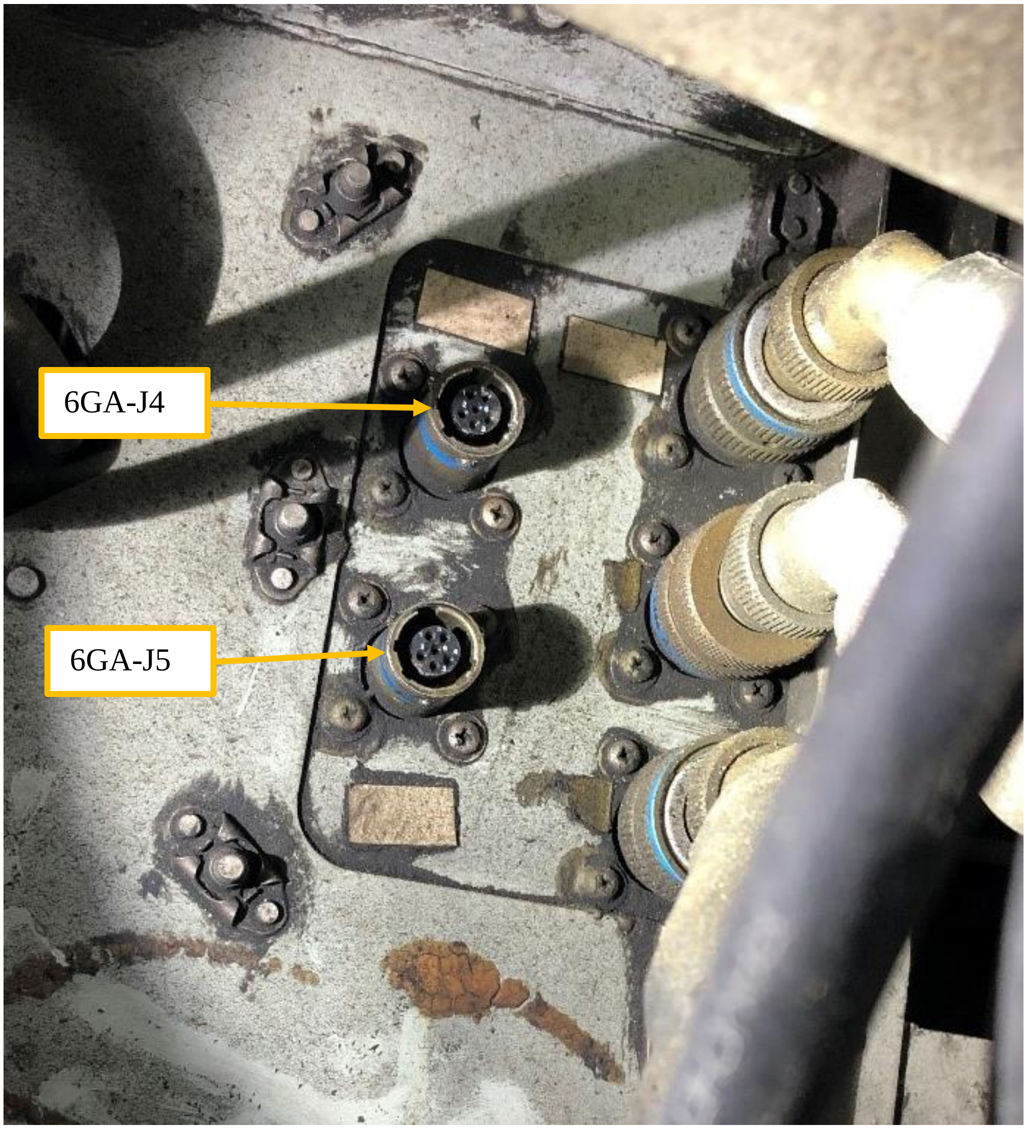


Figure 25 Accident airplane right main gear wheel well, wheel speed transducer bulkhead fittings

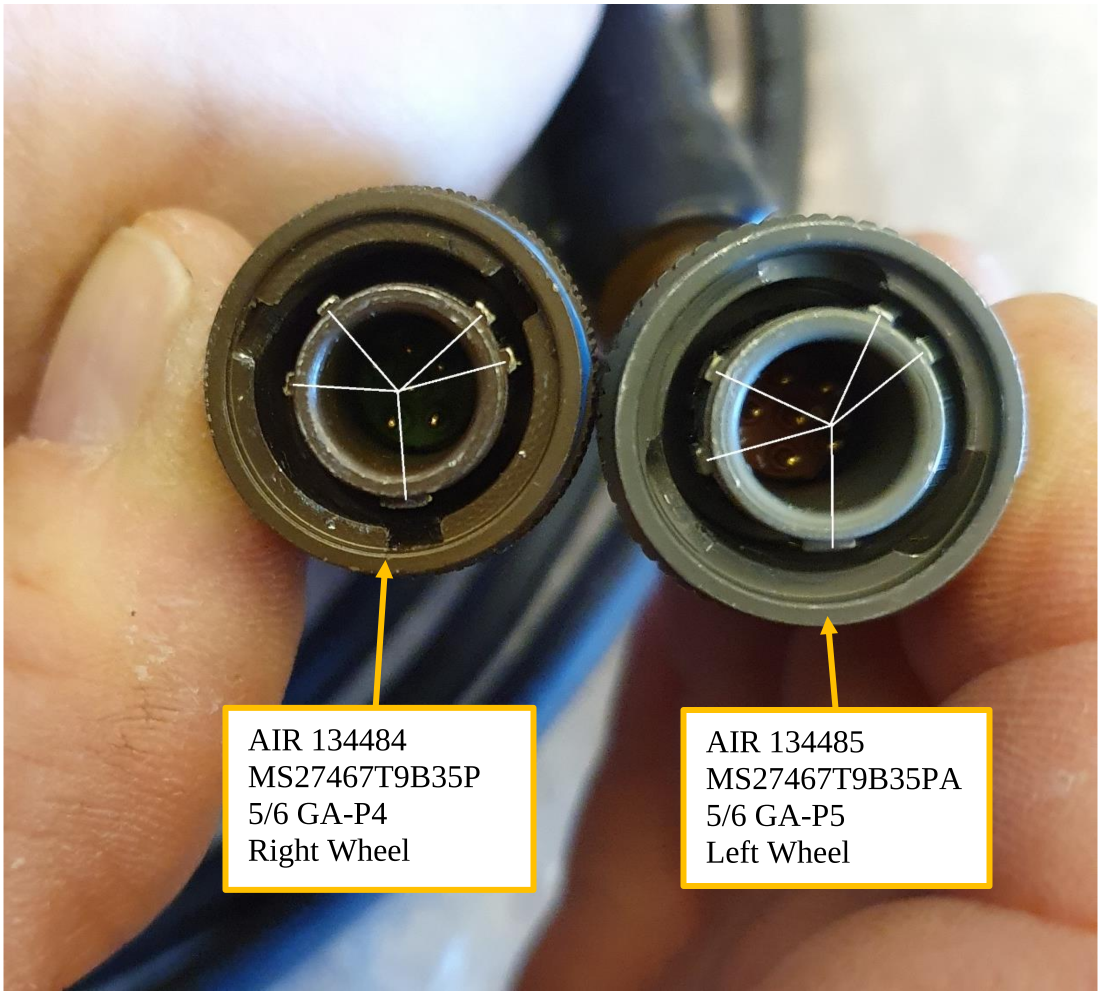


Figure 26 Exemplar wheel speed transducer wire harness upper connectors

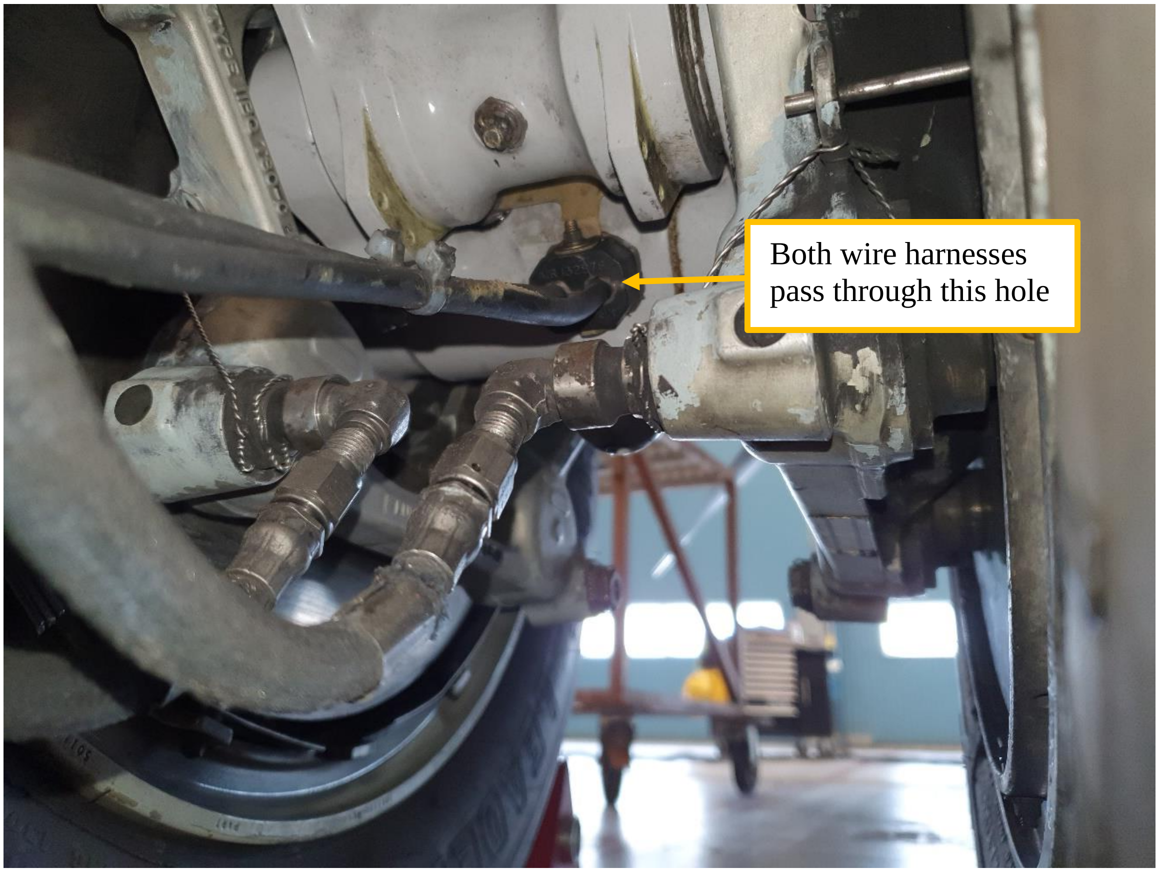


Figure 27 Exemplar airplane wheel speed transducer wire harness routing at base of strut

5.0 Anti-Skid System - Accident Airplane Component Information

5.1 Wheel speed transducers and wiring

The hubcaps were removed to expose the wheel speed transducers, Figure 28. It was observed, by the feel of a light force required to remove the caps, that each of the sensors were still attached to the clip in the cap. All clips were in excellent condition.

The components were disconnected from the axle, the electrical connectors were left in place and the wiring was cut in the area of the coiled portion, Figure 29. The wheel speed transducers were Crane Hydro-Aire P/N 140-159, and the serial numbers were as follows:

#1 312
#2 214
#3 225
#4 213

The wheel speed transducers were retained for examination.


Figure 28 #1 wheel hubcap with transducer clip

Figure 29 #1 wheel speed transducer removed from axle

The impact damage to the left main gear fractured both wheel speed transducer wire harnesses and the bulkhead fittings in the wheel well. During the initial on-scene work, the #1 wheel speed transducer wire harness was removed. It was intact to the top of the strut but fractured with no connector at the top end. The #2 harness was also removed, but only the lower portion to the first fracture, which was near the midpoint of the strut. Because of the damage, it was difficult to access the bulkhead fittings, so they were not removed and not all the wire harness portions were recovered. It was not possible initially to determine which wire harness was connected to which bulkhead fitting in the wheel well. To determine if the wiring was correct, the #1 wire harness was cut open to reveal the wire numbers. However, it was found that the landing gear manufacturer did not place wire numbers on the wires. The team then contacted the manufacturer, Heroux Devtek to better understand the construction of the wire harnesses.

On June 20, 2020 the NTSB and a representative from PenAir returned to Dutch Harbor to document and removed the right gear wheel speed transducer wire harnesses and recover the remaining pieces from the left gear. These parts were shipped to the NTSB group chairman. On July 1, a video conference examination of all the recovered wheel speed transducer wire harnesses was performed by the group chairman and team members from Saab and the Swedish Accredited Representative. The details of the examination are provided in Appendix A. The examination showed that the left gear wheel speed transducer harnesses were constructed differently. The #1 wheel harness was made with one filler wire (a non-conducting wire with a fiberglass center used to fill space in the conduit and increase the strength), and the right wheel harness was found to have two filler wires. This enabled the team to match up the #1 harness segment removed initially with a short wire segment recovered by the second team visit. This short segment had a label indicating that it was a 5/6 GA-P4 harness. The short segment was also able to be matched with the recovered MS 27467T9B35P connector, which could only have been attached to the 5GA-J4 bulkhead fitting. According to the installation instructions detailed above, this harness should have been routed to the #2 wheel, not the #1 wheel. This showed the left gear wheel speed transducer wire harnesses were incorrectly installed. The examination showed that the right gear wire harnesses were installed correctly.

Photos of the left main gear wheel speed transducer wiring, Figures 30 – 35 showed the harness was routed according to the manufacturer’s instructions from the axles to the top of the strut (the harness from the left wheel was routed on the left side of the strut). The routing from the top of the strut to the bulkhead fittings was not known because of the damage.

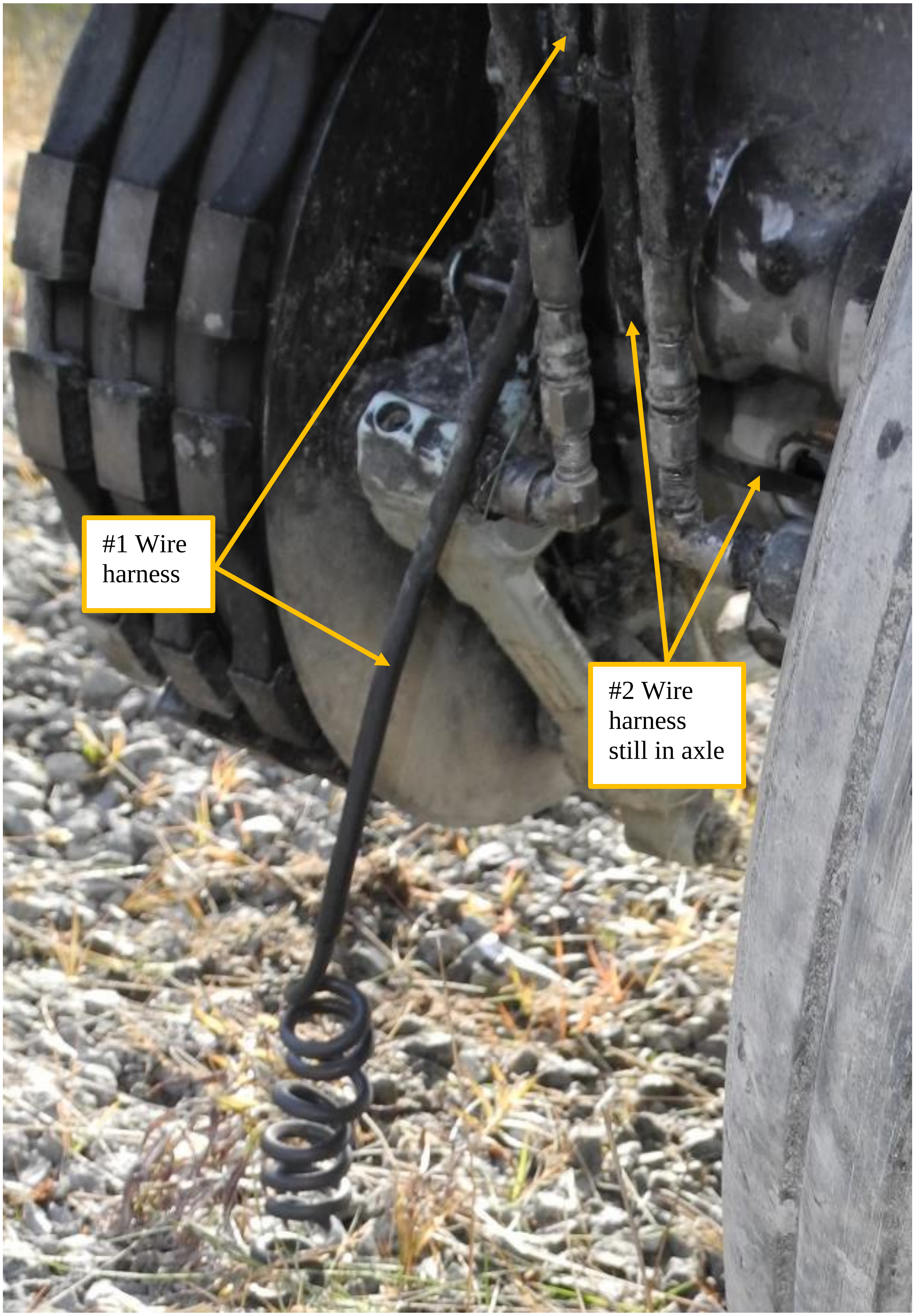


Figure 30 Left gear wheel speed transducer harness routing

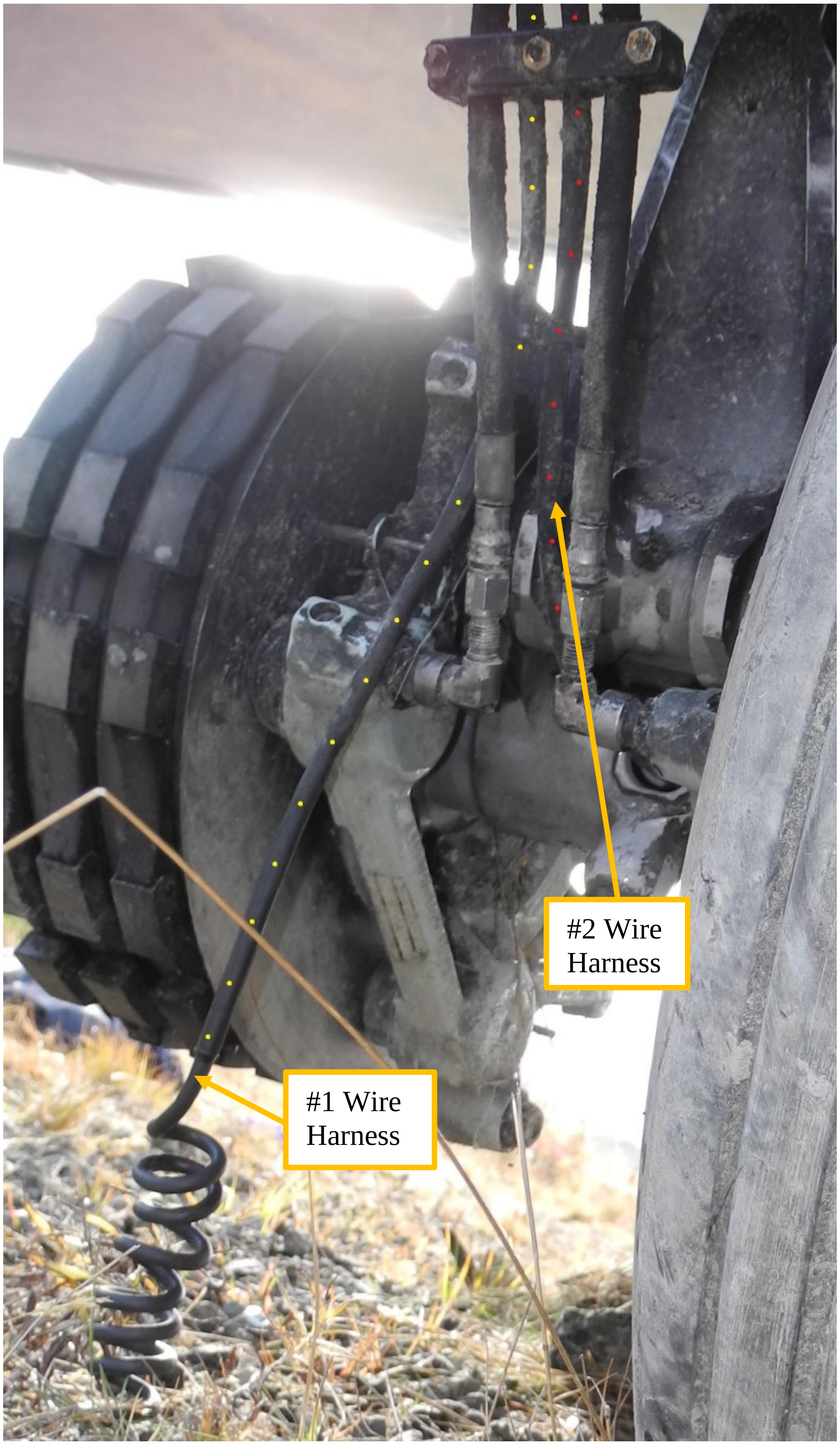


Figure 31 Left gear wheel speed transducer routing

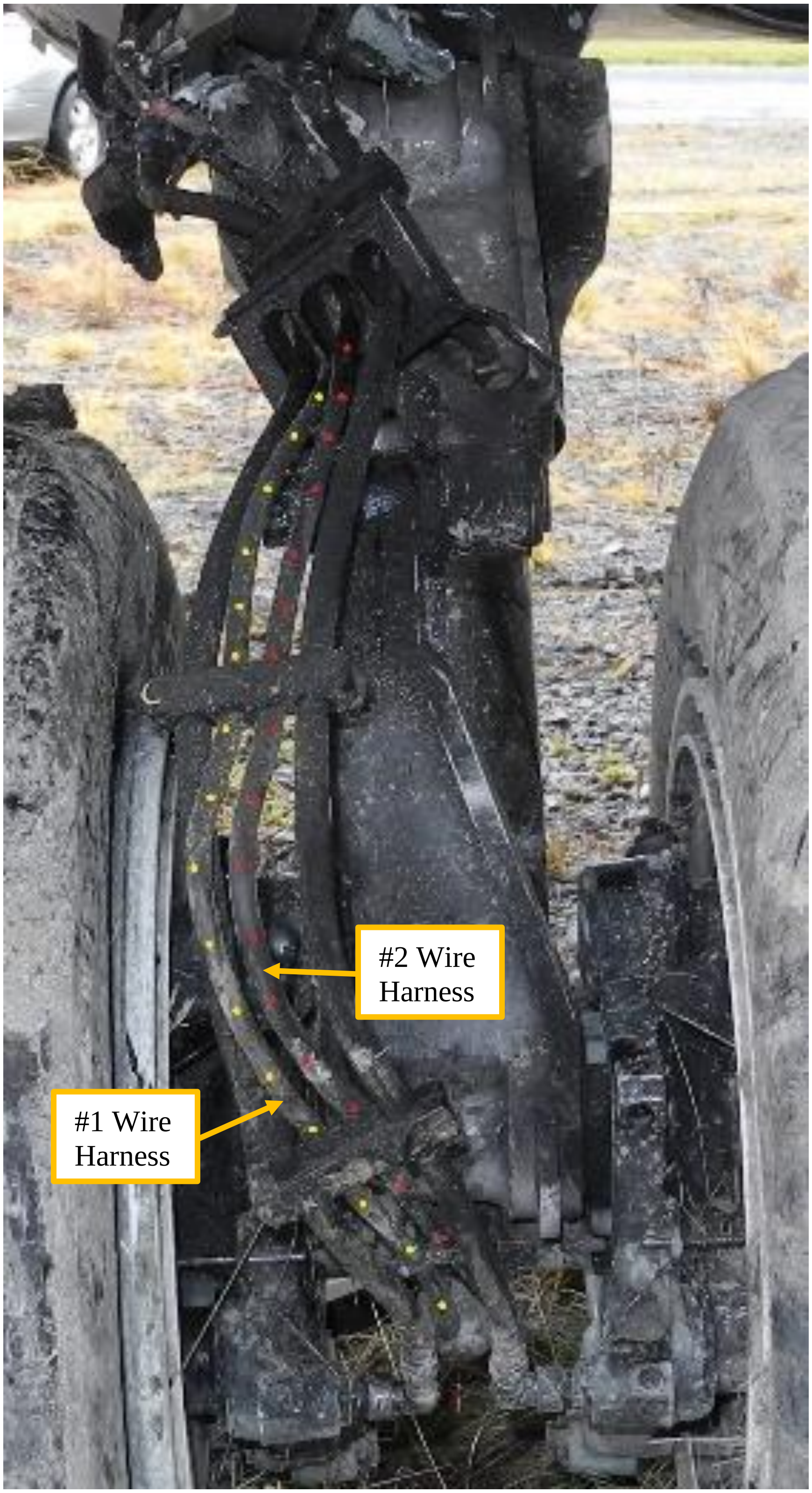


Figure 32 Left gear wheel speed transducer routing

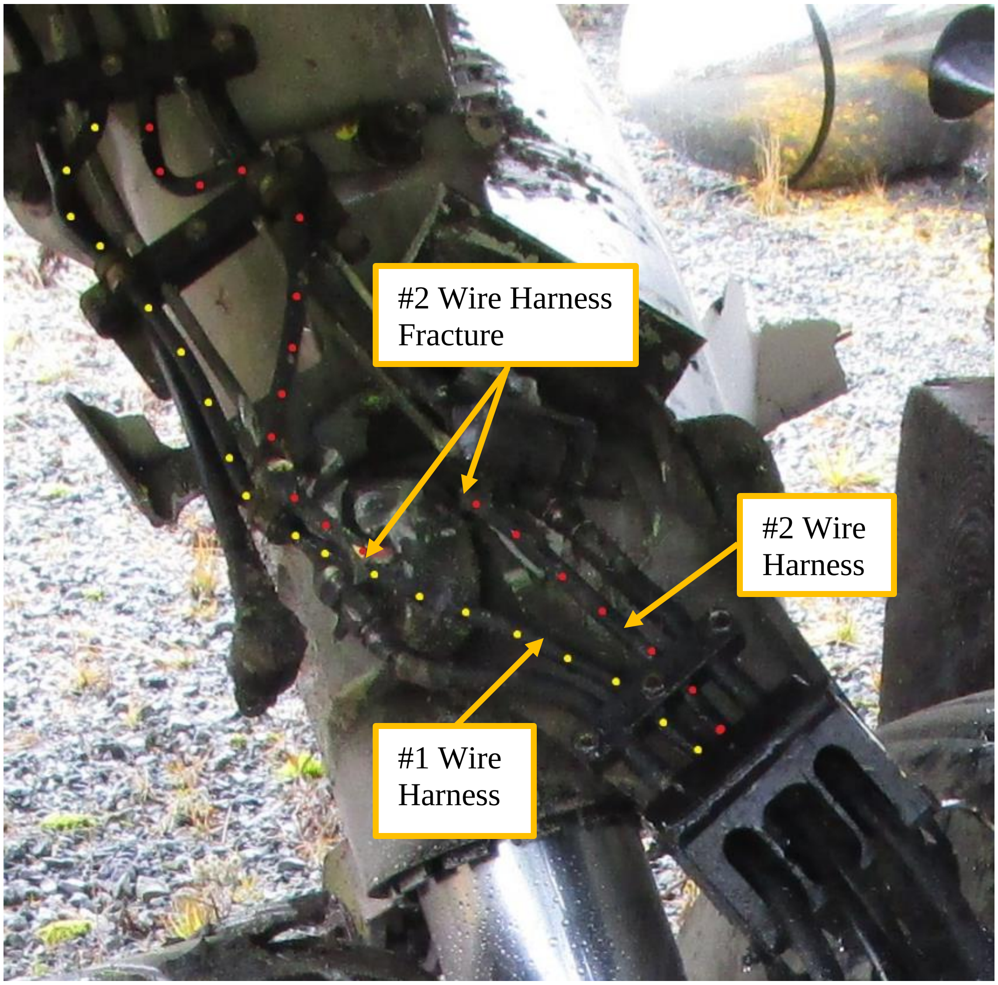


Figure 33 Left gear wheel speed transducer routing

Figure 34 Left gear wheel speed transducer routing

Figure 35 Left wheel well wheel speed transducer bulkhead fittings

The left and right main gear were part number AIR83084/10, Serial Numbers OZ9460045, and OZ9460046 respectively. The manufacturer for the landing gear, APPH Limited ("Heroux Devtek UK"), was contacted about overhaul information for the left and right main gear. They advised that they completed overhaul on both gear in January 2017.

According to the manufacturer, they have begun a full investigation, which will include the following actions.

1. Quality Alert to be raised – reminding all operators to ensure legibility of Harness Labels during Survey.
2. Quality Alert to be raised - Ensuring all operators and certifying staff (across all Heroux Devtek sites) are aware of the potential to fit the Saab 2000 harnesses incorrectly or to any harnesses fit on twin axle main landing gear.
3. The Quality Control Inspection check - sheet will be updated to include a photograph and sign off step for the harnesses to validate correct fitment.
4. An operator duplicate inspection is to be added to the works order (Job card) to ensure the Harnesses are correctly fitted during build.
5. There was no stock on site to check for correct routing.
6. APPH Limited Engineering team will review possible improvements to both the installation instructions and the harness identification where required for clarity as well as additional safeguard on Product Acceptance Test.
7. APPH Limited will reach out to Saab for possible improvement to the Product and/or to aircraft integration and documentation.

5.2 Anti-skid Control Unit

The anti-skid control unit was installed under the floor panels in the forward cabin. The carpet and panels were removed. The control unit was in good condition with no observable damage to the area Figure 36. The electrical connectors were left in place and the wiring was cut to remove the component. The component data plate showed it was a Crane Hydro-Aire P/N 42-897-1, S/N 150, MFG 02-94. The unit was retained for examination.

Figure 36 Antiskid control unit (left side of image)

5.3 Anti-skid Control Valves

The access panel was opened for the antiskid control valves. The components were observed to be in good condition with no damage to the area, Figures 37 - 38.

The hydraulic lines were disconnected and capped, except the hydraulic return tubes were cut, and crimped because no caps were available. The electrical connector was left in place and the wiring was cut. The component data plates showed the parts were as follows:

Outboard control valve (item 5GG), Crane Hydro-Aire P/N 81982/39-779, S/N 143, MFG 02-93
Inboard control valve (item 6GG), Crane Hydro-Aire P/N 81982/39-779, S/N 206, MFG 05-95

The components were removed and retained for examination.

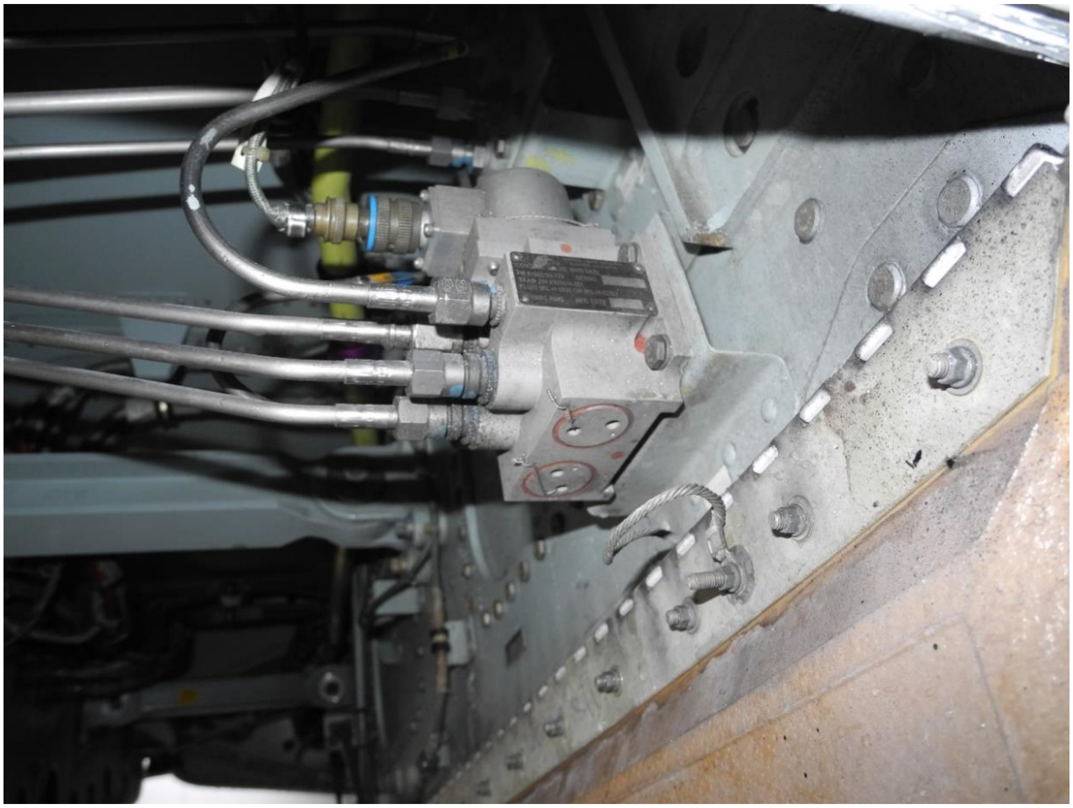


Figure 37 Outboard anti-skid control valve

Figure 38 Inboard antiskid valve

The NTSB shipped the removed components to Washington, DC via UPS in a single cardboard box. When the shipment was received, it was found to be water damaged and missing the outboard anti-skid control valve. The NTSB contacted UPS, but they were unable to locate the missing part. The remaining components were hand carried by the NTSB to the Crane facility in Burbank, CA. On December 9-10, the NTSB, Saab, and Crane representatives examined the anti-skid components. The following summarizes those activities.

5.4 Anti-skid Component Repair History

Crane reviewed the repair history of all the components, including the serial number of the lost control valve (Outboard control valve (item 5GG), Crane Hydro-Aire P/N 81982/39-779, S/N 143, MFG 02-93). The following were the only parts returned for repair. Crane provided a copy of the repair documentation as an attachment.

Inboard control valve PN 39-779, SN 206, returned May 2015
#1 wheel speed transducer PN 140-159, SN 312, returned July 2009

5.5 Antiskid Control Unit Examination

The airplane electrical connectors were removed. It was observed that one of the pins of connector J2 was broken part way down, only a stub remained. The broken pin was determined to be pin J2-14. Saab wire diagrams indicated that the pin is connected to the left outboard wheel speed transducer excitation signal. The pin was examined under a microscope and was observed to be bent at the fracture location.

The unit was tested according to test procedure TP42-897-1, Rev B DTD 8/20/93. The results were recorded on data sheets by the technician.

The component passed all tests except steps 6.1.3 – 6.1.12. These tests were for the Locked Wheel Crossover tests for the outboard wheel pair. This function releases the brake pressure to both outboard wheels if one of the two wheel speeds drops to less than 40% of the other wheel.

The unit was opened, visually inspected and photographed. There were no anomalies noted. The wheel speed/bite circuit card PN 42-897141, SN 097 was removed. It was visually examined, no anomalies. A red mark was placed on the chassis to indicate the original location of the SN 097 card. The wheel speed/bite circuit card PN 42-897141, SN 098 was removed and visually inspected, no anomalies. The position of the two cards were swapped, the cover was re-installed, and section 6.0 of the functional test was performed again. All section 6.0 tests passed. The unit was powered down, opened and the two cards were swapped back to the original positions and section 6.0 of the functional test was performed. All section 6.0 tests passed.

The testing showed the broken pin stub was making good contact with test connector under all tests. Additional continuity tests were performed in the NTSB lab using the actual airplane electrical connector. These tests showed the stub was making solid contact through the connector. To cause loss of the continuity the connector had to be unlatched and rotated an additional few degrees (total motion, approximately 45 degrees from latched position). This caused the connector to move approximately 0.03 inches away from the fixed connector.

The recovered airplane wiring to the anti-skid control unit electrical connectors was inspected (actual wire numbers compared to that indicated on the wire diagrams) and were determined to be correct.

5.6 Inboard Control Valve Examination

The unit was tested according to test procedure TP39-779, Rev B. The results were recorded on a data sheet by the technician. The test bench was using Mil-H-83282 hydraulic fluid, which is an acceptable equivalent to 5606.

The order of performance was as follows:

1. Performed resistance checks per section 2.5
2. Connected the valve pressure ports to the test bench supply and took 3 fluid samples; from the return port, from B1, and B2.
3. Performed the Functional Test
4. Performed other electrical tests 2.1 – 2.4

All tests passed except for 6.3.2 internal leakage with 5mA command. The result was 170 cc/min, and the allowable for a new or overhauled part was 40 cc/min.

The fluid samples were filtered through patches and examined under microscope by a Crane technician. The particle count data was found to be acceptable.

The recovered airplane wiring to the inboard anti-skid control valve electrical connectors was inspected (actual wire numbers compared to that indicated on the wire diagrams) and were determined to be correct.

5.7 Wheel Speed Transducer Examinations

The wheel speed transducers were tested according to test procedure TP140-159. The test results were recorded on data sheets by the technician. All wheel speed transducers passed all tests.

5.8 Wheel Speed Transducer – Crossed Wiring Scenario

The manufacturer of the anti-skid system, Crane, was asked about the system response to a scenario of crossed left main gear wheel speed sensor wiring and the left outboard tire entering a skid condition. According to Crane the following would be expected:

1. As long as the left outboard tire is in a deep skid, the inboard circuit would sense the skid and quickly reduce brake pressure to the inboard wheels to near zero.
2. The right outboard wheel would still have skid protection, except it would be compared to the left inboard wheel.
3. Some skid protection for the left outboard could occur if the right outboard tire started to skid. The outboard circuit would sense the skid and reduce brake pressure to the outboard wheels.

The crossed wire scenario is indicated by the red lines in Figure 39. The effect of the crossed wiring is further examined in the four scenarios below.

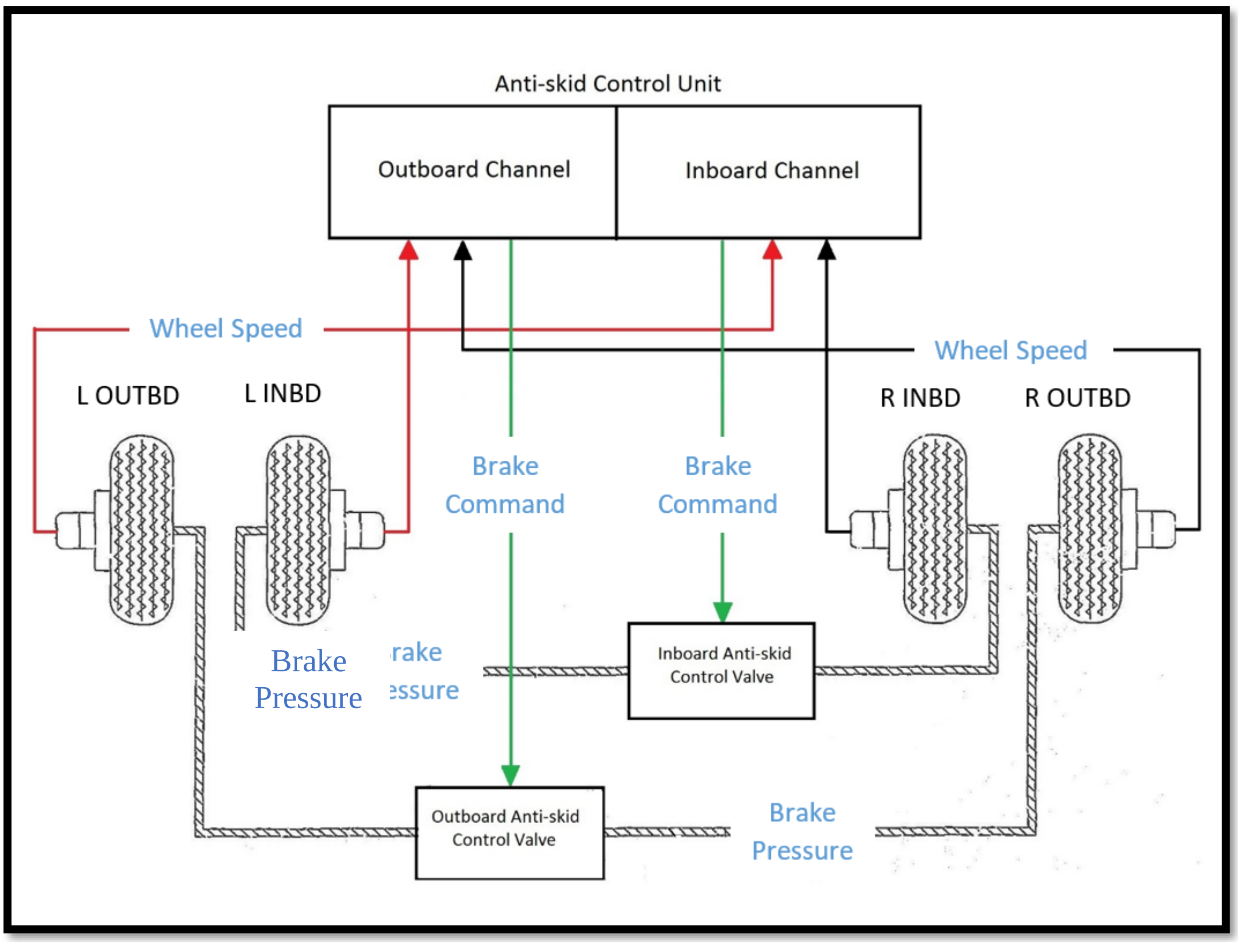


Figure 39 Anti-skid wheel speed transducers cross wired

Scenario 1: Left outboard wheel skid
-Inboard anti-skid channel uses speeds from L OUTBD and R INBD wheels
-Brake command to inboard anti-skid valve results in brake release on inboard wheels (L INBD, R INBD)
-Outcome:
-L OUTBD brake pressure not released
-L INBD brake pressure released
-R INBD brake pressure released

Scenario 2: Left inboard wheel skid
-Outboard anti-skid channel uses speeds from L INBD and R OUTBD wheels
- Brake command to outboard anti-skid valve results in brake release on outboard wheels (L OUTBD, R OUTBD)
-Outcome:
-L INBD brake pressure not released
-L OUTBD brake pressure released
-R OUTBD brake pressure released

Scenario 3: Right inboard wheel skid
-Inboard anti-skid channel uses speeds from L OUTBD and R INBD wheels
-Brake command to inboard anti-skid valve results in brake release on inboard wheels (L INBD, R INBD)
-Outcome:
-R INBD Brake pressure released
-L INBD Brake pressure released

Scenario 4: Right outboard wheel skid
-Outboard anti-skid channel uses speeds from L INBD and R OUTBD wheels
- Brake command to outboard anti-skid valve results in brake release on outboard wheels (L OUTBD, R OUTBD)
-Outcome:
-L OUTBD brake pressure released
-R OUTBD brake pressure released

6.0 Maintenance Diagnostics Computer (MDC) Information

The MDC circuit card was removed from the accident airplane (MDC-4000), part number 622-9818-122, serial number 469. The MDC was shipped to Collins Aerospace in Cedar Rapids, IA. On November 19, 2019, Collins performed a download of the MDC fault data and provided it to the NTSB. The entire download is provided in Appendix B. All the messages with the time stamp of 1:40 occurred around the time of the accident landing. According to Saab the messages are recorded in chronological order. The message 52#AFT S-DOOR would occur when one of the aft doors was opened. The only messages that occurred before an aft door was opened were the following four anti-skid system faults. The messages with the 32# in front are the fault, and the subsequent message indicates which anti-skid channel generated the message or the source (INBD or OUTBD.

32#ANTI SKID CTL	(Maintenance Message)
INBD A-SKID	(Source)
32#ANTI SKID CTL	(Maintenance Message)
INBD A-SKID	(Source)
32#L WHEEL SPD XDCR	(Maintenance Message)
OUTBD A-SKID	(Source)
INBD A-SKID	(Source)

7.0 Flight Deck

Initial on-scene condition of the flight deck prior to lifting the airplane to the barge was documented by photos and videos. Details of the flight deck condition are in the Operations and Human Performance Factual.

8.0 Structures and Flight Controls

8.1 Left Wing

The wing was intact and had only minor impact marks on the leading edge, Figure 40. There was no damage to the wing tip. During recovery the tip impacted a telephone pole which caused scrapes and damage to the static wick. The aileron and aileron trim surfaces were intact, Figure 41. The flaps were intact and partially extended to a similar position as the right flap, Figure 42. There was an impact mark on the bottom inboard portion of the flap, Figure 43, which extended through to the top.

Figure 40 Left wing leading edge

Figure 41 Aileron and tab

Figure 42 Inboard portion of flap and wing.

Figure 43 Damage to bottom inboard portion of flap

8.2 Right Wing

The wing was intact and had no apparent damage, Figures 44-45. During recovery the wing tip scraped a hillside which caused damage. The aileron and aileron trim surfaces were intact. The flaps were intact and partially extended to a similar position as the left flap. The right gear doors had impact damage and could not be opened by pulling the release mechanism, Figure 46.

Figure 44 Outboard portion of right wing.

Figure 45 Top of right wing


Figure 46 Right main gear door damage

8.3 Aileron Controls

The ailerons can only be actuated mechanically by cables. When the captain's control wheel was moved, the left aileron moved in the correct direction, but the right did not move. When the first officer's control wheel was moved, the right aileron moved, but not the left. The aileron disconnect mechanism appeared to be in the connected position, but when motion of the input occurred it would disconnect. The disconnect mechanism was unable to connect the two inputs as it normally would.

8.4 Flaps

The flaps have an auto retract function. The logic to arm and activate the function are as follows:

Armed = At least one gear down and flaps set to 20° or 35°.
Activate = Wheel spin-up active signals from the INBD and OUTBD wheel pairs.

The signal goes active when one of the two wheels in a pair spin-up above 25knots. This signal comes from the anti-skid unit wheel spin-up detector circuit card.

When activated the flaps will retract at twice normal rate (approximately 4-5 degrees per second) to the flaps 15 position. The function is intended to enhance braking performance. The flaps are actuated by the #2 hydraulic system.

8.5 Empennage

The vertical and horizontal stabilizers were intact and undamaged, Figures 47-48. The elevators and rudder were intact and undamaged. There are no separate trim surfaces on the elevators or rudder, trim moves the entire surface.

8.6 Elevator and Rudder Controls

The elevator and rudder surfaces are fly-by-wire, actuated by electrical signals to hydraulic actuators, so they could not be checked for operation. Pitch trim is accomplished by switches to the Power Elevator Control Units (PECUs). Rudder trim is controlled by a yaw trim switch to an electric yaw trim actuator.

Figure 47 Left side empennage


Figure 48 Right side empennage

8.7 Fuselage

There was a hole and impact damage on the left forward side around the 5th window on the left side. A propeller blade was loosely stuck in the surrounding structure external to the fuselage and another propeller blade was inside the fuselage vertically positioned between the floor and the overhead bin between seats 4D and 4F. There was damage to the seats and overhead bin in this area.

The fuselage has scrape marks and dirt on the lower portion of the fuselage near the tail where it appears there was a previous repair, Figure 49. Just forward and on the left of this area was a scratch along a similar line, Figure 50.

On the right side forward of the wing there was an impact mark which started shallow on the top and got deeper toward the bottom on a trajectory in line with the propeller blades, Figure 51. There were also three punctures and numerous small dents in the skin in this area.

Figure 49 Scrapes on lower aft fuselage

Figure 50 Scrape aft lower left fuselage

Figure 51 impact, punctures and dents, right side forward of wing.

9.0 Main Landing Gear

The right main gear was intact, down, locked and supporting the airplane, Figure 52. The lock pin was inserted to secure the gear for storage.

Figure 52 Right main gear

The left main was collapsed and pushed aft and inboard, Figure 53. The gear doors were damaged, and the left could not be opened. There were broken and bent linkages, Figures 54-57.

Figure 53 Left main gear

Figure 54 Left main gear

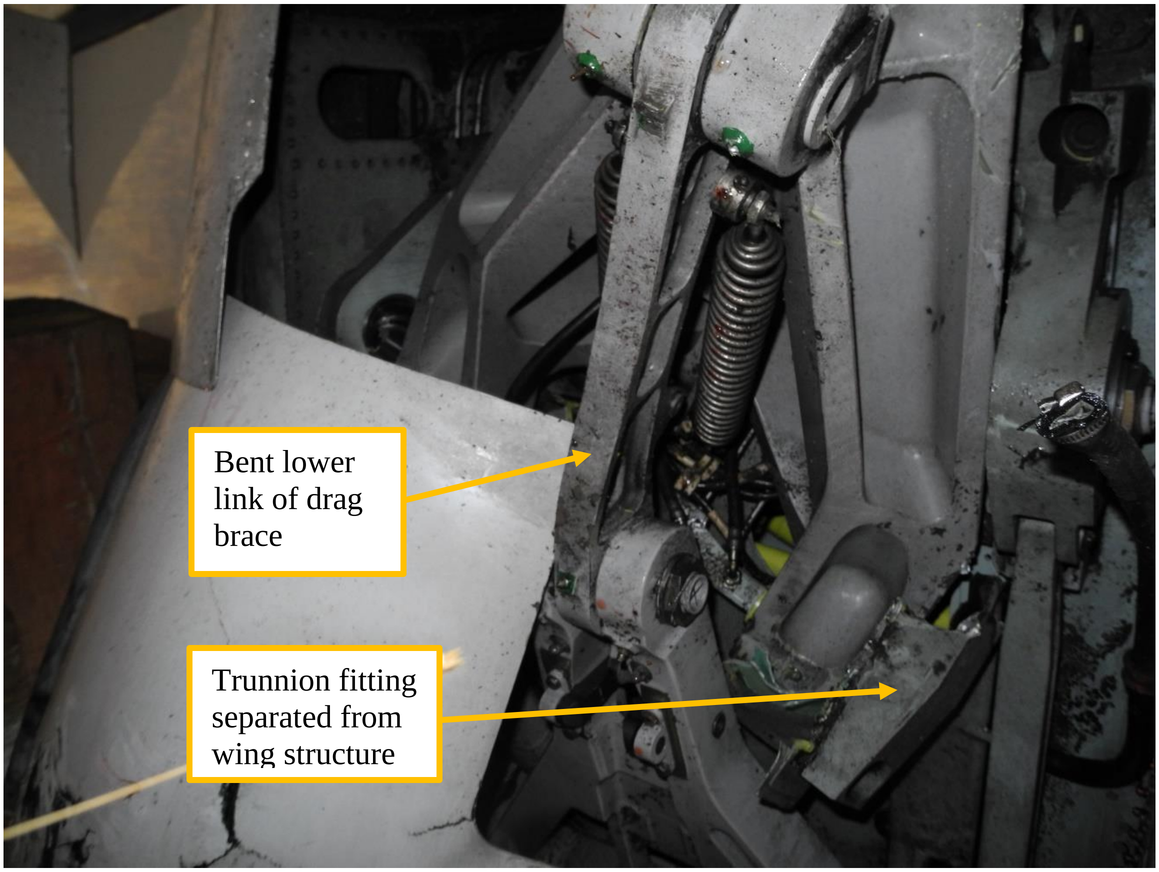


Figure 55 Left main gear bent and broken linkage


Figure 56 Left main gear drag brace

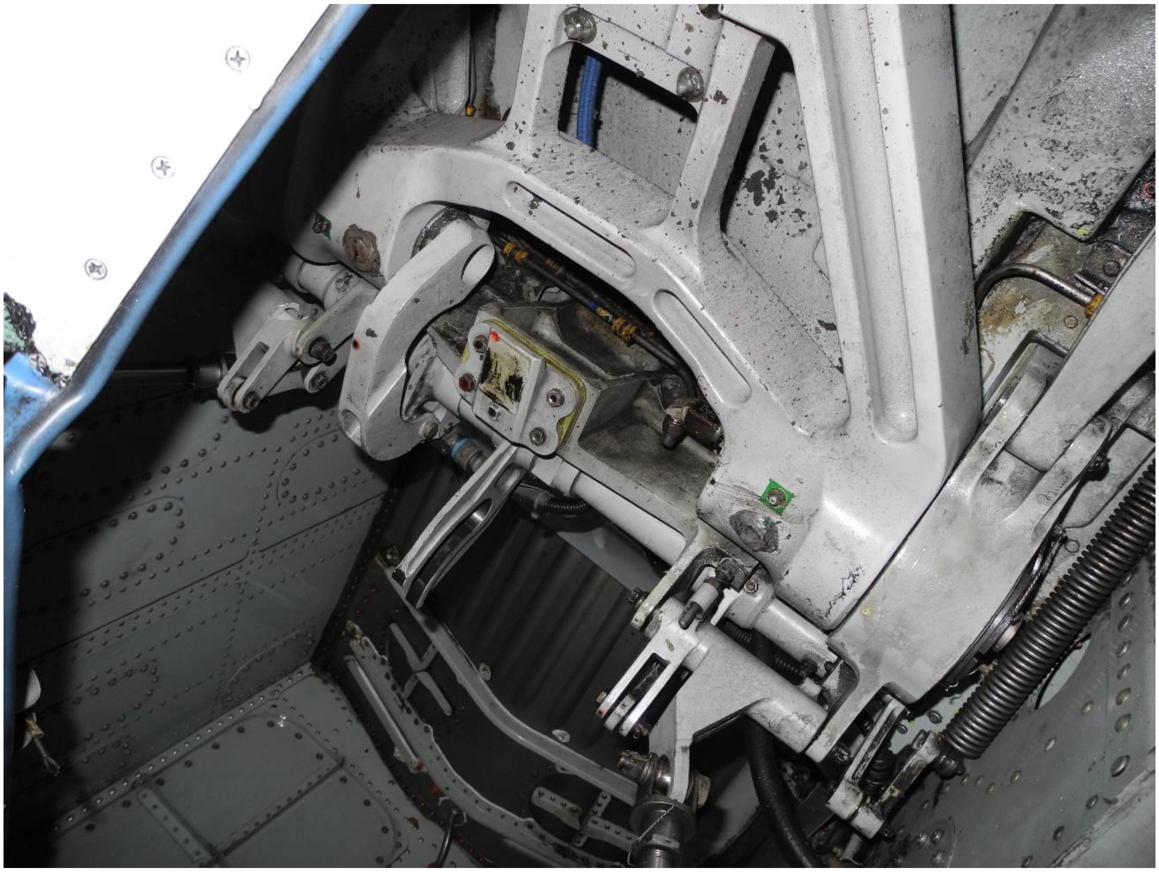


Figure 57 Left main gear upper drag brace

10.0 Nose Gear

The nose gear was intact and supported the airplane post-accident in shallow water, Figures 58-59. To stabilize the airplane the nose was supported by a strap attached to a crane. The left tire was punctured and deflated. The right tire appeared to be partially inflated but could not be measured prior to transporting. The taxi light was detached and damaged. During recovery the wheels got turned 180 degrees and the inboard sidewall of the right tire impacted the loose taxi light, Figures 60-62. The final condition of the tire was deflated. The pin was placed in the gear and the nose was supported by the gear.

Figure 58 Nose gear and tires

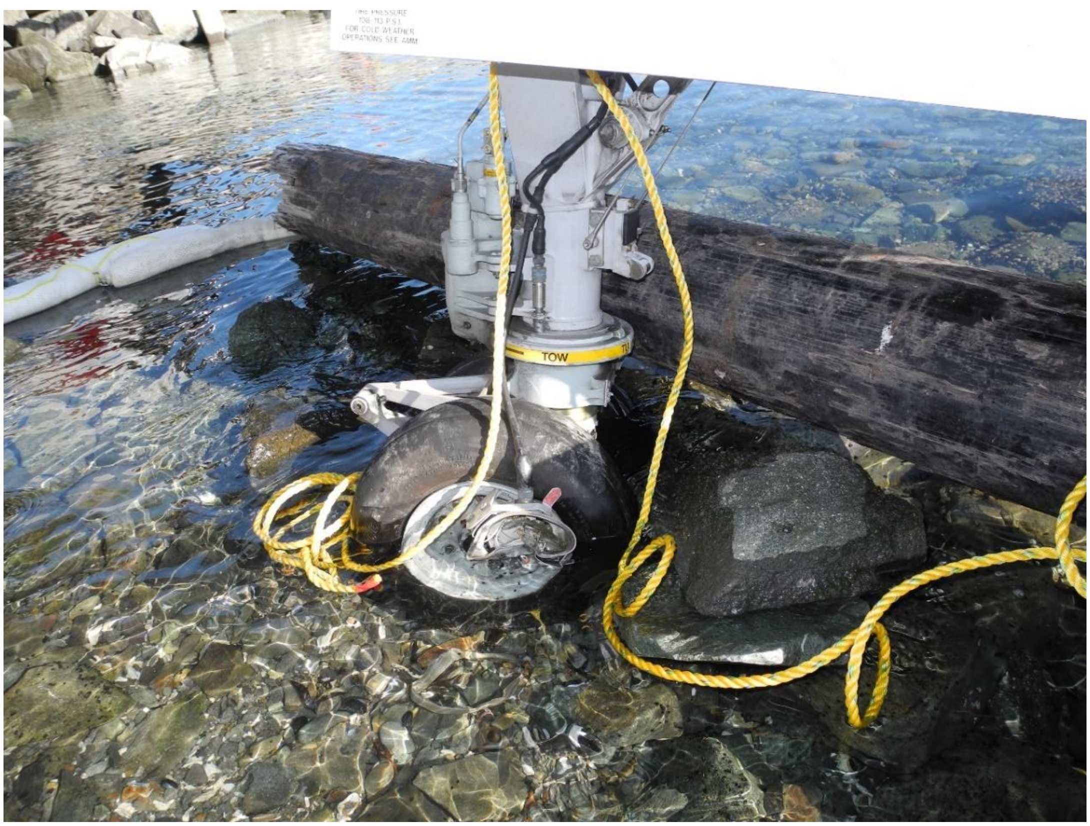


Figure 59 Nose gear and tires

Figure 60 Nose gear and tires after recovery

Figure 61 Punctured left tire

Figure 62 Nose gear and tires, right tire in contact with the light

11.0 Appendices

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

July 1, 2020

Wheel Speed Transducer Wiring Examination – PenAir Saab 2000 accident

DCA20MA002

A. ACCIDENT

Operator: PenAir
Aircraft: Saab 2000
Location: Dutch Harbor, AK
Date: October 17, 2019
Time: 1740 ADT

B. SYSTEMS GROUP

Group Chairman Steven Magladry
National Transportation Safety Board
Washington, DC

Member Gideon Singer
Swedish Accident Investigation Authority
Stockholm, Sweden

Member Jan Erik Andersson
Saab
Linkoping, Sweden

Member Jan Pettersson
Saab
Linkoping, Sweden

Member Ulf Andersson
Saab
Linkoping, Sweden

C. SUMMARY

On October 17, 2019, about 1740 Alaska daylight time, PenAir flight 3296,[1] a Saab 2000, N686PA, overran the runway while landing at the Thomas Madsen Airport (DUT), Unalaska, Alaska. The airplane was making its second landing approach when it touched down on runway 13 and overran the runway passing through the airport perimeter fence, crossing a road, and then pitching down over shoreline rocks. The airplane came to rest with the main landing gear wheels at the top of the rocks and the nose wheel in the water. Of the 39 passengers and 3 flight crew on board, 1 passenger was fatally injured, 4 passengers sustained injuries, and 37 passengers and flight crew were uninjured. Visual meteorological conditions prevailed. The airplane was substantially damaged. The airplane was operating as a regularly scheduled passenger flight in accordance with the provisions of 14 *Code of Federal Regulations* Part *121* from Ted Stevens International Airport (ANC), Anchorage, Alaska to DUT.

The left main gear was damaged in the accident, and the damage fractured the wheel speed transducer wire harnesses and detached them from the bulkhead fittings in the wheel well. The team removed a portion of the left outboard and left inboard wheel speed transducer wire harnesses. On June 20, 2020 the NTSB and a representative from PenAir returned to Dutch Harbor to document and removed the right gear wheel speed transducer wire harnesses and recover the remaining pieces from the left gear. These parts were shipped to the NTSB group chairman. On July 1, a video conference examination of all the recovered wheel speed transducer wire harnesses was performed by the group chairman and team members from Saab and the Swedish accident investigation authority. The following summarizes the examination findings.

D. DETAILS OF THE INVESTIGATION

The #1 and #2 wheel speed transducer wire harnesses recovered initially were laid out on a table, measured and photographed, Figures A1-A4. The total length of #1 was approximately 104 inches, #2 was approximately 51 inches. This dimension included the portion of the connector which was cut when the wheel speed transducers were removed on-scene. According to the landing gear manufacturer's drawing the total length should be 2775 +10/-0 mm or 109.25 +0.4/-0 inches. The #1 harness fractured end was cut earlier to try to determine the wire numbers, but it was found that there were no wire numbers. There was 1 black wire, 1 white wire, and 1 white non-conducting filler wire for a total of 3 wires. According to the landing gear manufacturer's instructions the AIR 134485 drawing states 1 small filler wire, the AIR 134484 states filler, but does not specifically designate the number.

[1] The airplane was owned and operated by Peninsula Aviation Services Incorporated d.b.a. PenAir.

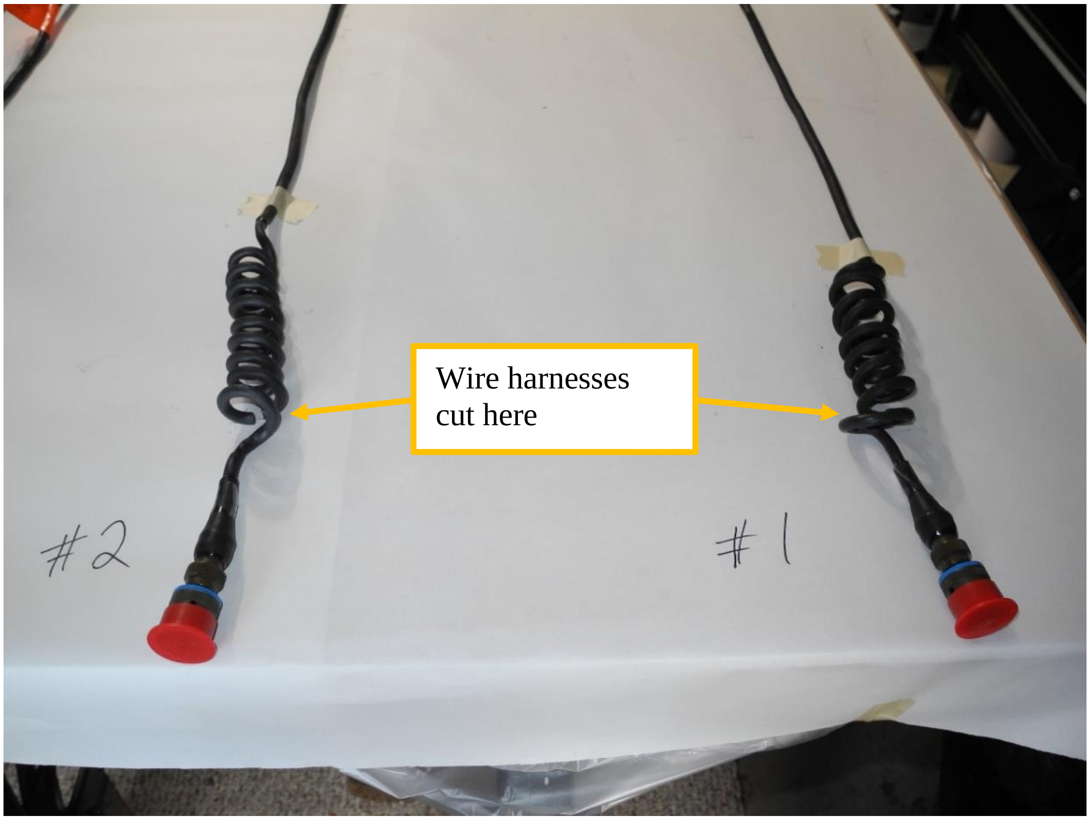


Figure A163 #1 and #2 wire harness segments with cut connector ends.


Figure A2 #1 and #2 wire harness segments

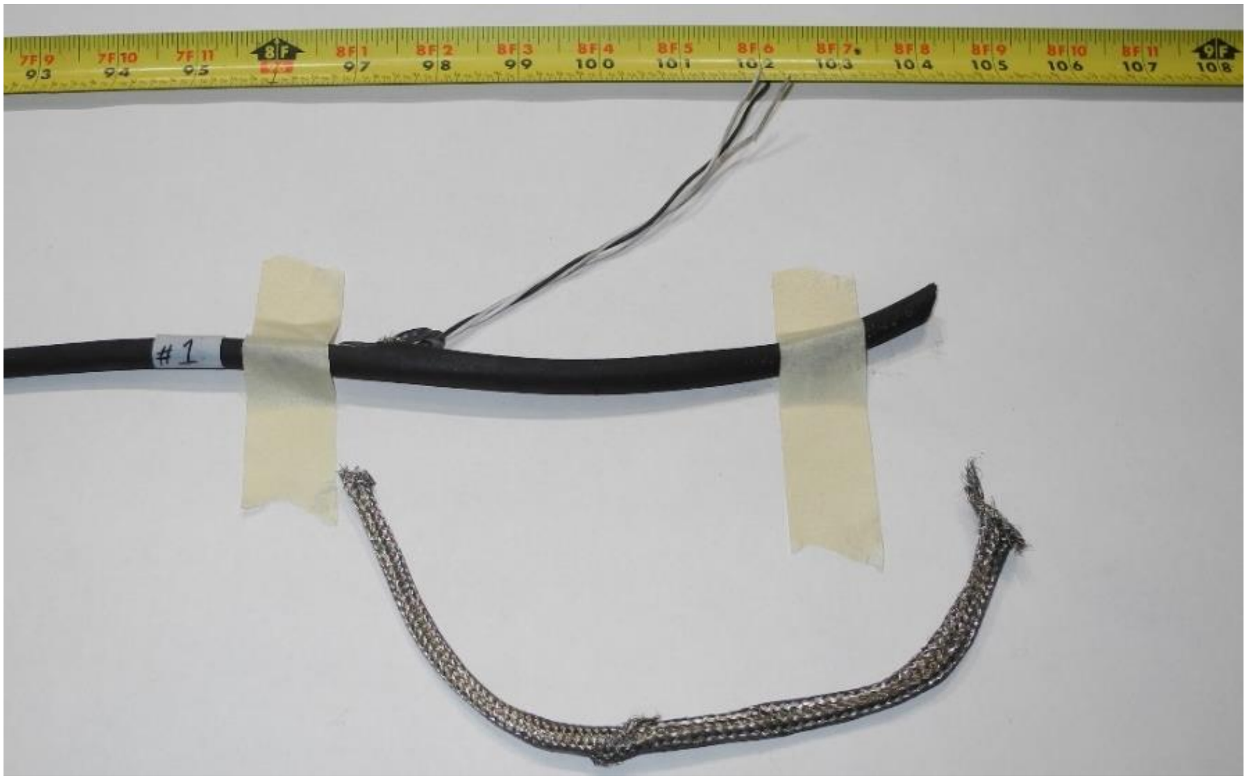


Figure A3 #1 wire harness fractured end showing 3 total wires

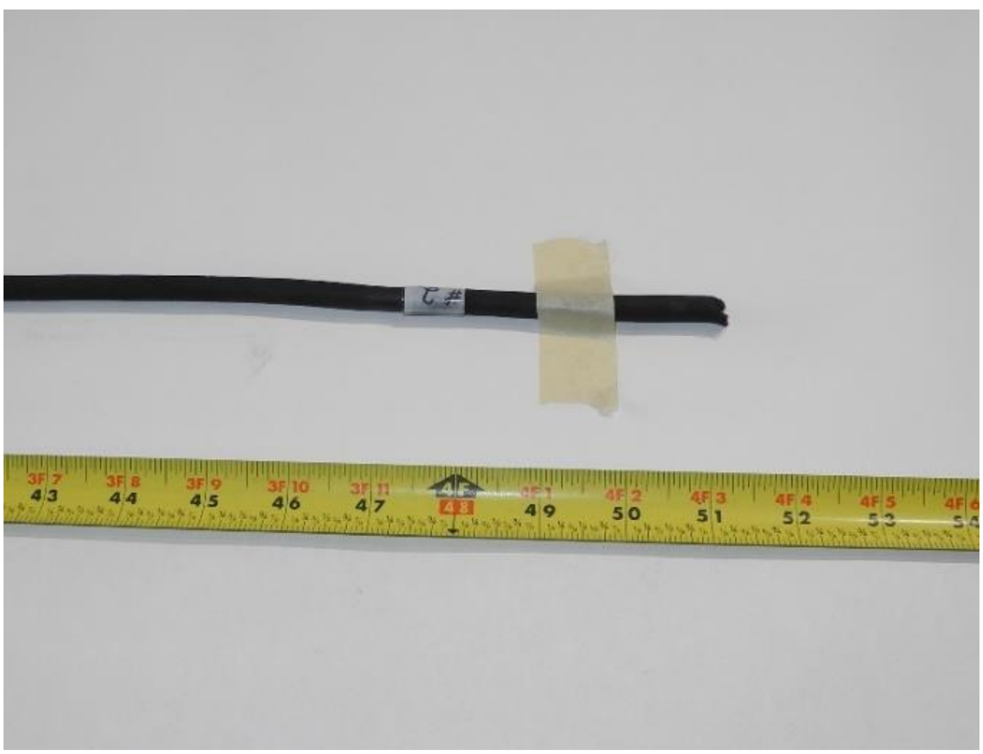


Figure A4 #2 wire harness fractured end

The shipping container was opened and the wire harness labelled #4 was removed, indicating it was removed from the #4 wheel, Figures A5-A6. The connector part number was MS27467T9B35P, the label closest to the connector was cleaned and it was 5/6GA-P4. The harness was laid out and it measured approximately 112.5 inches.

Figure A5 #4 wire harness

Figure A6 #4 wire harness connector

The wire harness labelled #3 was removed, Figures A7-A8. The connector part number was MS27467T9B35PA. The label was cleaned but could not be read. The harness was laid out and it measured approximately 112.5 inches.

Figure A7 #3 wheel speed transducer wire harness

Figure A8 #3 wheel speed transducer wire harness upper connector

A harness segment was removed, which came from the left gear, Figures A9-A10. The segment had two yellow P clamps attached and it was almost completely fractured in one location. The segment measured approximately 2’ 6” and will be referred to as the “Long segment” hereafter. The cable had two non-conductor white filler wires, one white wire, and one black wire, for a total of 4 wires, Figure A11.

Figure A9 Long segment of wire harness

Figure A10 Long segment of wire harness

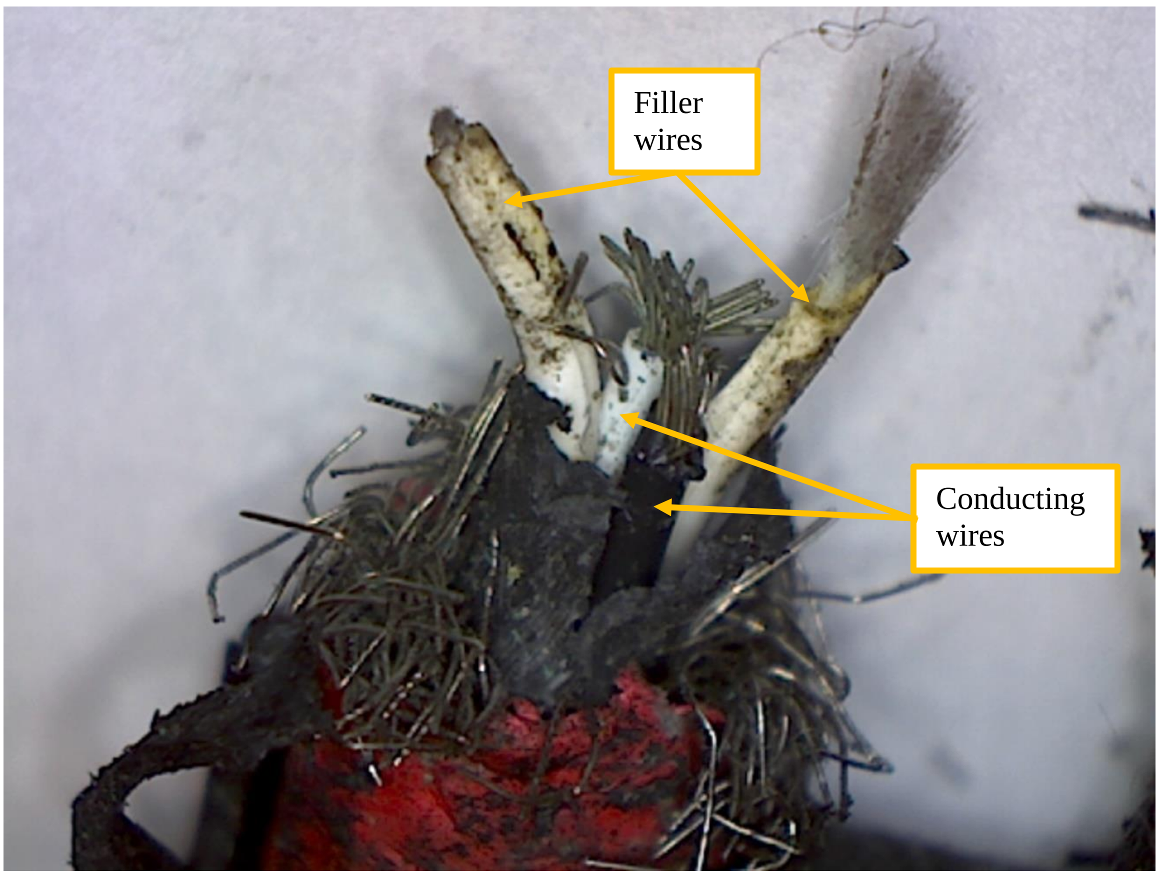


Figure A11 Long segment wire details

A harness segment was removed, which came from the left gear, Figures A12-A14. The cable segment had a portion of a connector attached and two wires with pins attached. The harness label read 5/6 GA-P4. One of the wires, the white, had separated. The wires had labels, 3 (white) and 4 (black). The wire segment was approximately 6.5 inches long, and will be referred to as the “Short segment” hereafter.

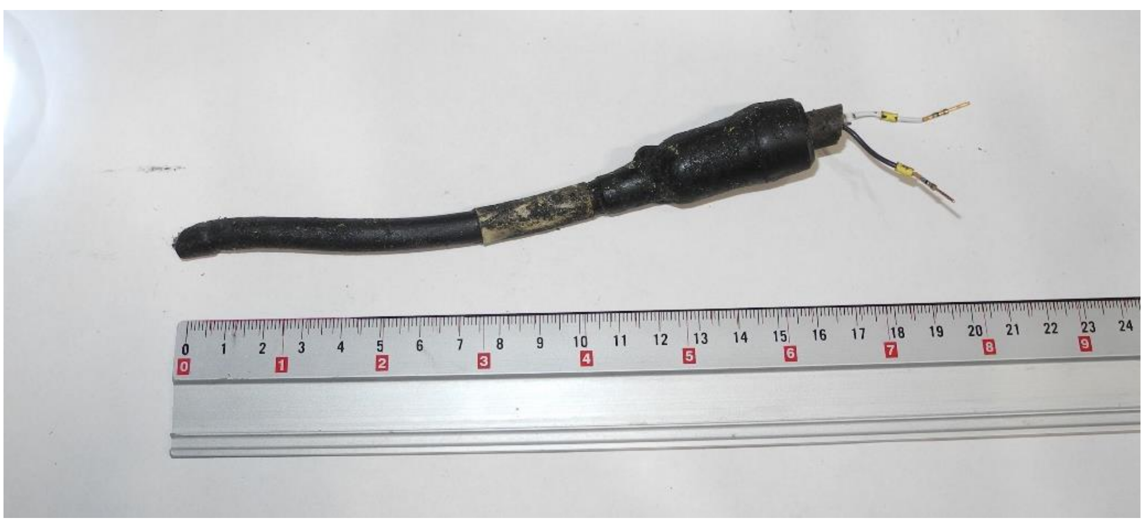


Figure A12 Short segment with connector portion and pins

Figure A13 Short segment label info

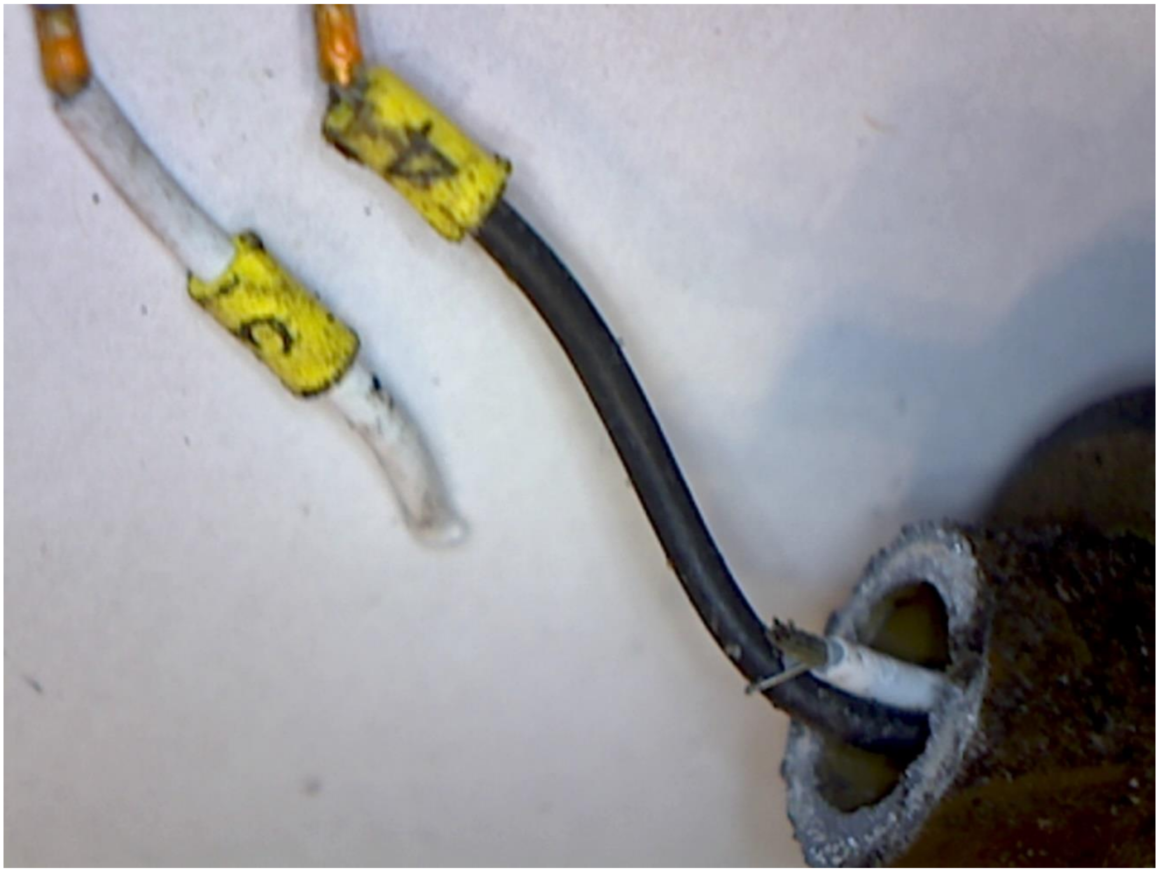


Figure A14 Short segment wire numbers

The connector labelled "#1 left upper position" was removed, Figures A15-A17. This was the connector attached to the upper bulkhead fitting in the wheel well. The connector number was MS27467T9B35P. The connector was missing pins 3 and 4.

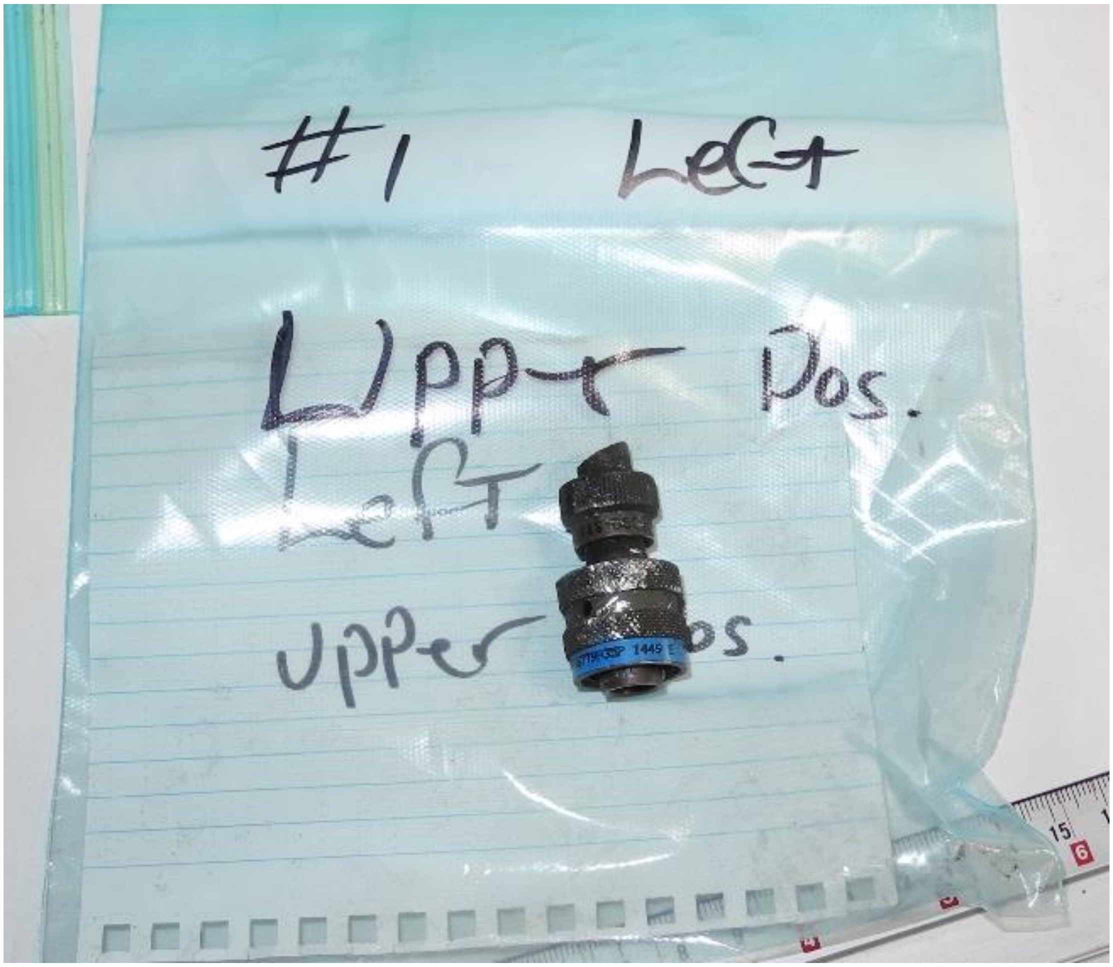


Figure A15 Upper connector portion

Figure A16 Upper connector part number

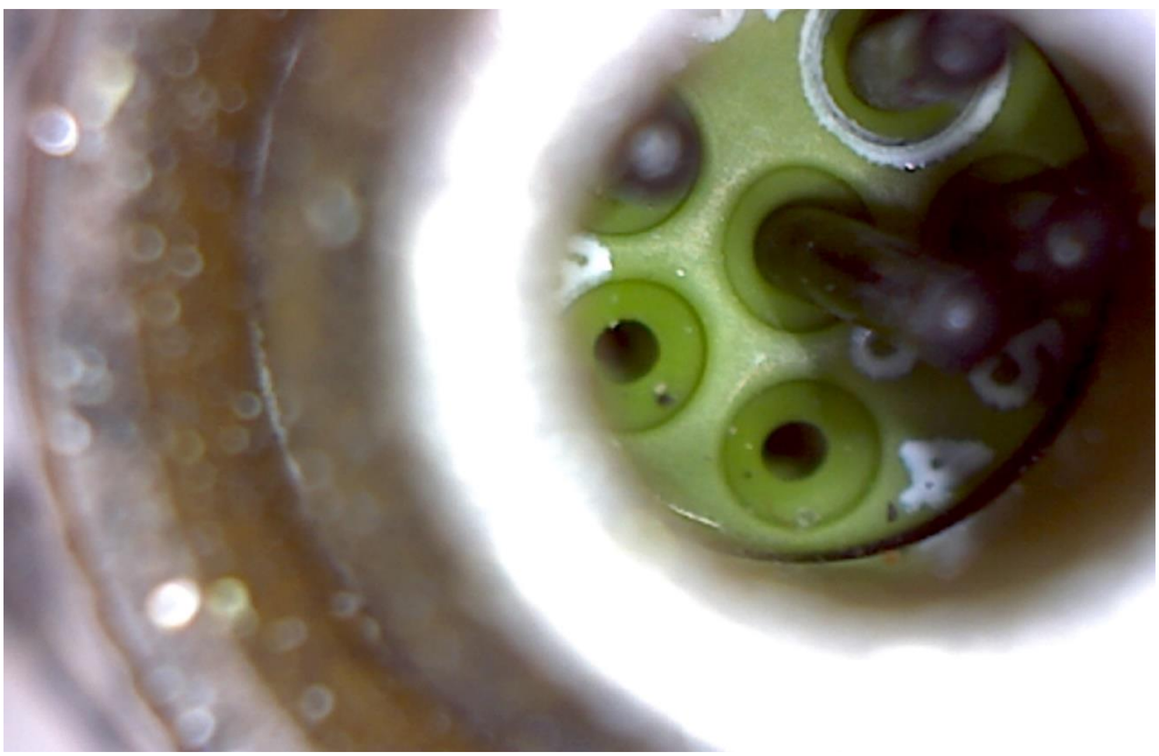


Figure A17 Upper connector pins missing

The connector labelled "#1 left lower position" was removed, Figures A18-A20. This was the connector attached to the lower bulkhead fitting in the wheel well. The connector number was MS27467T9B35PA. The connector had a white and black wire segment still attached. The black wire had a #4 label attached.

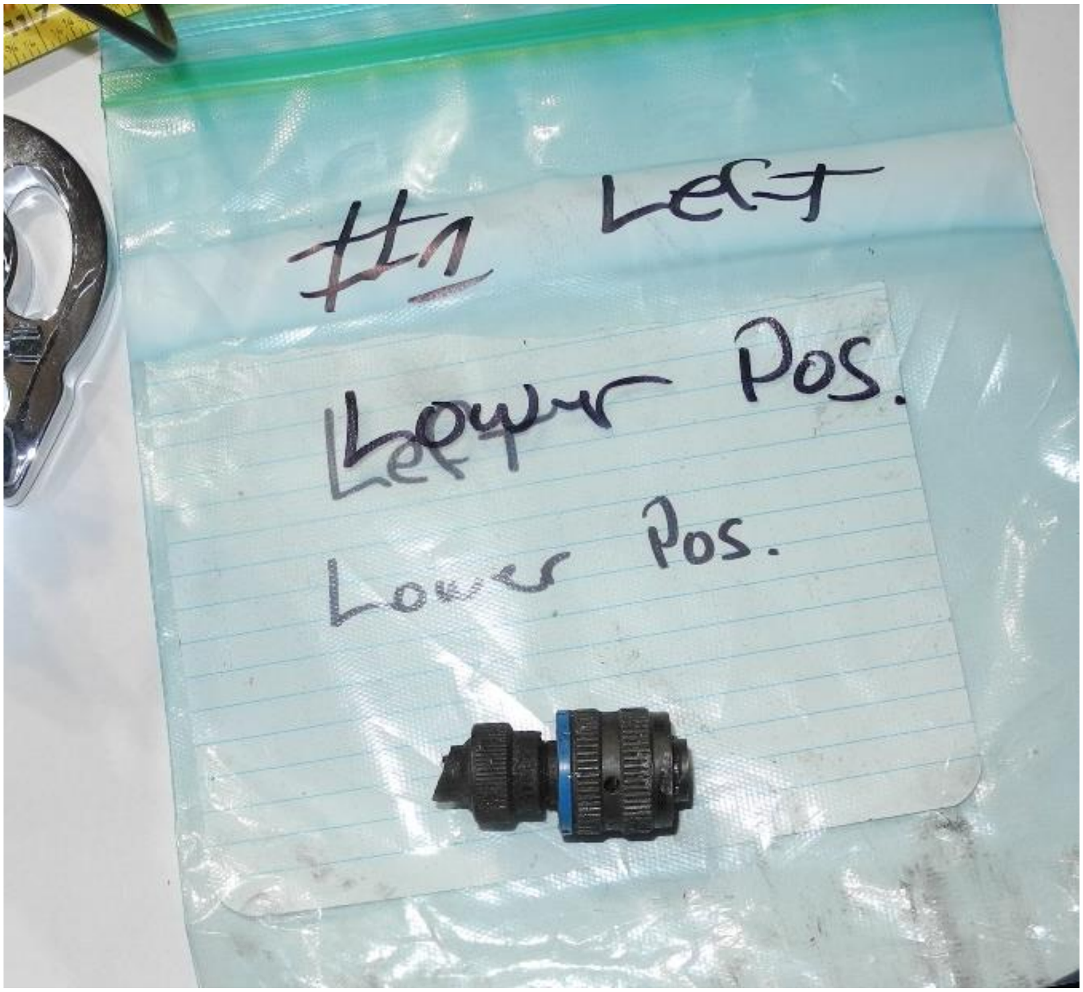


Figure A18 Lower connector portion

Figure A19 Lower connector part number

Figure A20 Lower connector wires still attached

The short segment was placed adjacent to the #1 wire harness segment fractured end, Figure A21. The two appear to have similar contours.

Figure A21 #1 wire harness fracture end (left) and short segment fracture end (right)

The upper connector portion was placed adjacent to the short segment connector end, along with the #4 harness end, Figure A22. The short segment had the two wires which this connector was missing. The two together form a 45-degree elbow like the elbows on the #3 and #4 wire harnesses. It appeared this elbow fractured along the brazed joint of the elbow.

Figure A22 Fracture surfaces of connectors formed 45 degree elbow

The following additional examination steps were performed by the NTSB after the live video conference:

Dimensional Study

As indicated earlier the manufacturer's requirement for overall length of the wire harness was 109.25 +0.4/-0 inches. The #3 and #4 harnesses measured over 112 inches. It was likely this additional length was a result of the coiled sections becoming elongated over time. To eliminate this ambiguity, measurements were taken from a reference point where the coil segment transitions to the rest of the harness, Figure A23. The manufacturer's drawing showed this dimension should be approximately 101 inches, Figure A24. The harnesses were measured from this reference point to the end:

#4 = 101.75 inches
#3 = 101.25 inches
#2 = 70 inches, the total of the #2 harness segment + long segment.
#1 = 101.5 inches, the total of the #1 harness segment + (short segment + upper connector) (93.5 + 8 inches) see Figure A25.

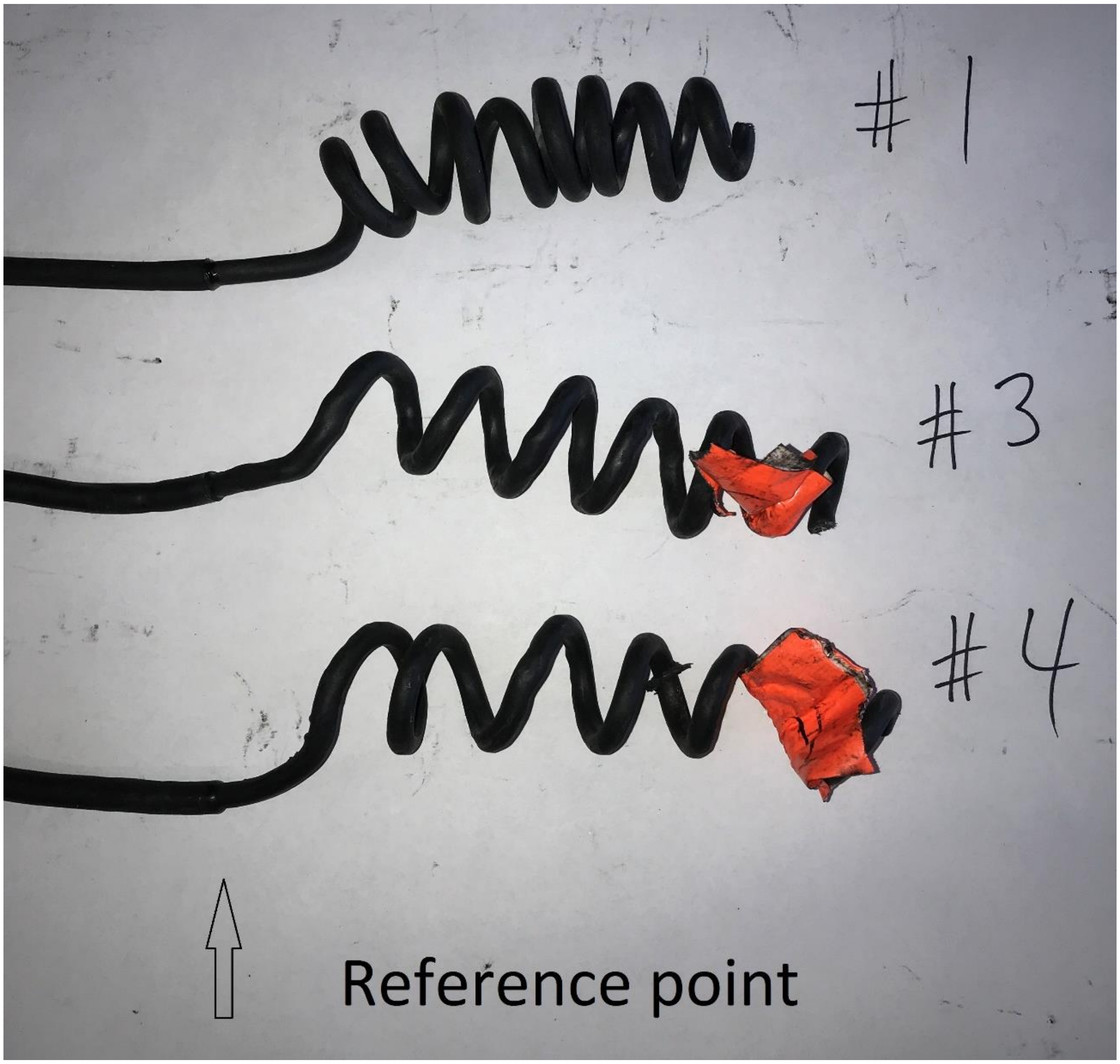


Figure A23 Elongated coils and reference measurement point

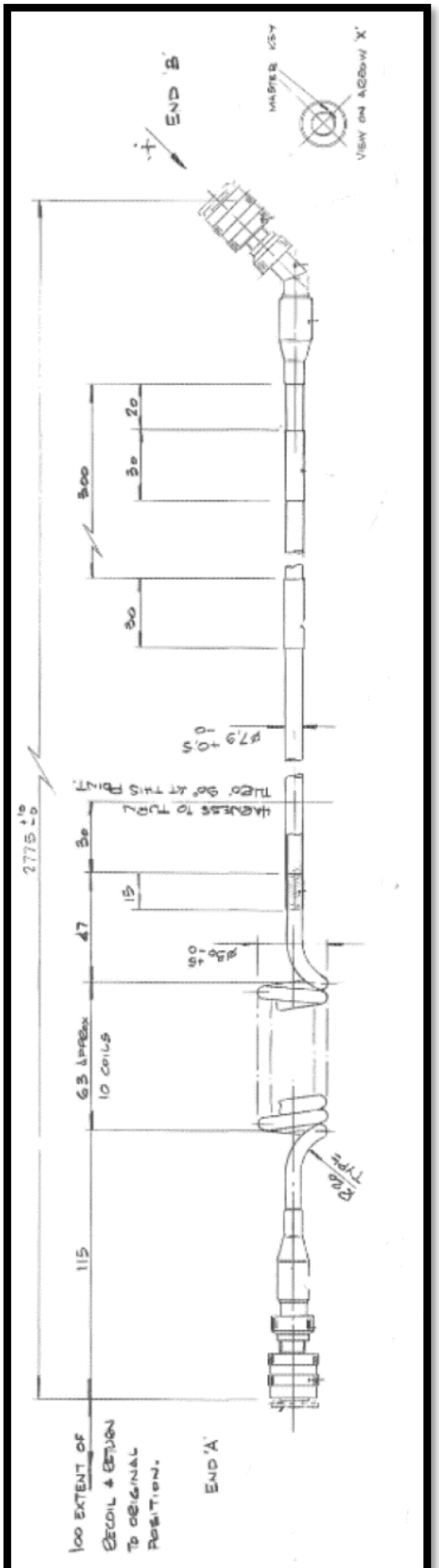


Figure A24 Harness drawing

Figure A25 Short segment with upper connector dimension

It was established above that the long segment had two conductor wires and two filler wires. Approximately 1 inch was cut from the #2 harness near the middle, Figure A26. The cut section was opened and there were 4 wires present, two conductor wires and two filler wires, Figures A27-A28.

Figure A26 #2 harness with small segment cut out of middle

Figure A27 Disassembled #2 harness cut section

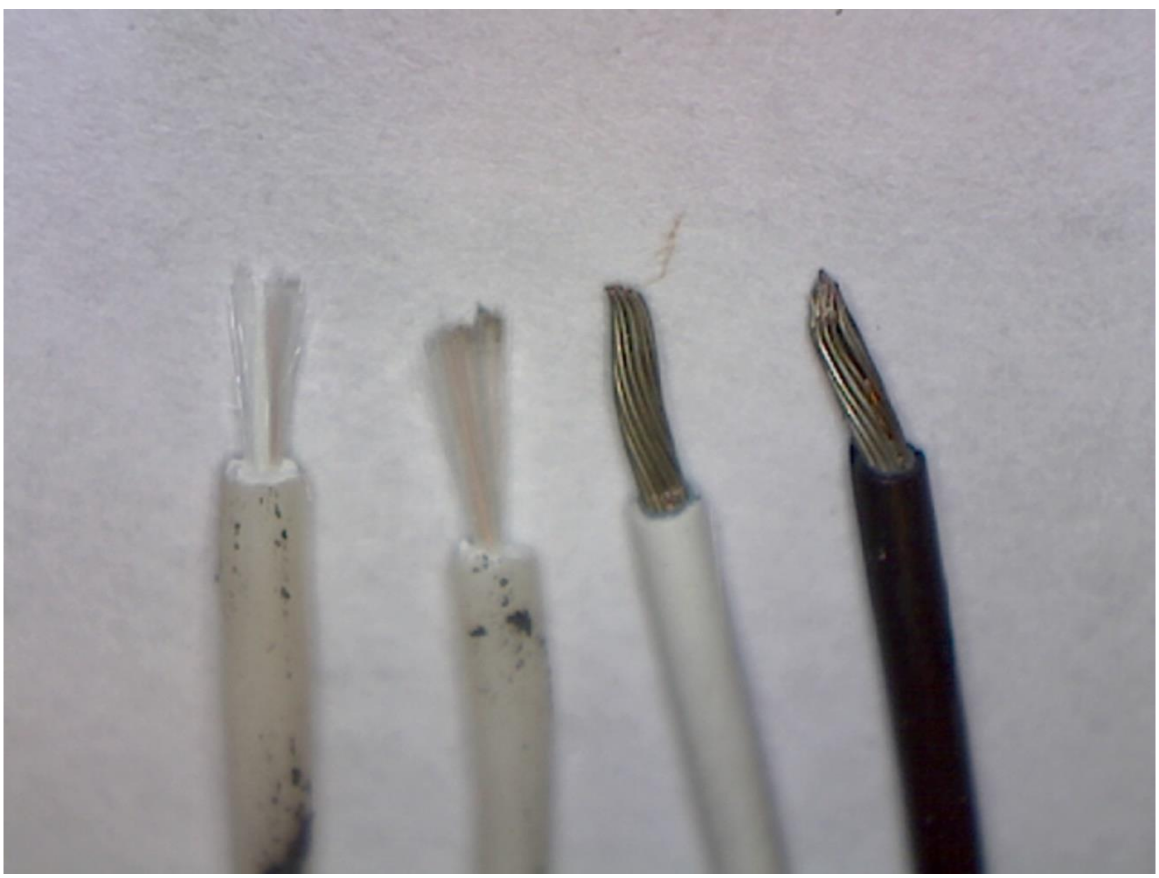


Figure A28 Magnified view of #2 harness wires

Approximately 1-inch was cut from the middle of the short segment below the label. The cut section was opened and there was 1 black wire, 1 white wire, and 1 non-conducting wire for a total of 3 wires, Figures A29-A30. This matches the number of wires in the #1 harness segment, Figure A3

Figure A29 Short segment with 1 inch segment cut from middle, shows 3 total wires

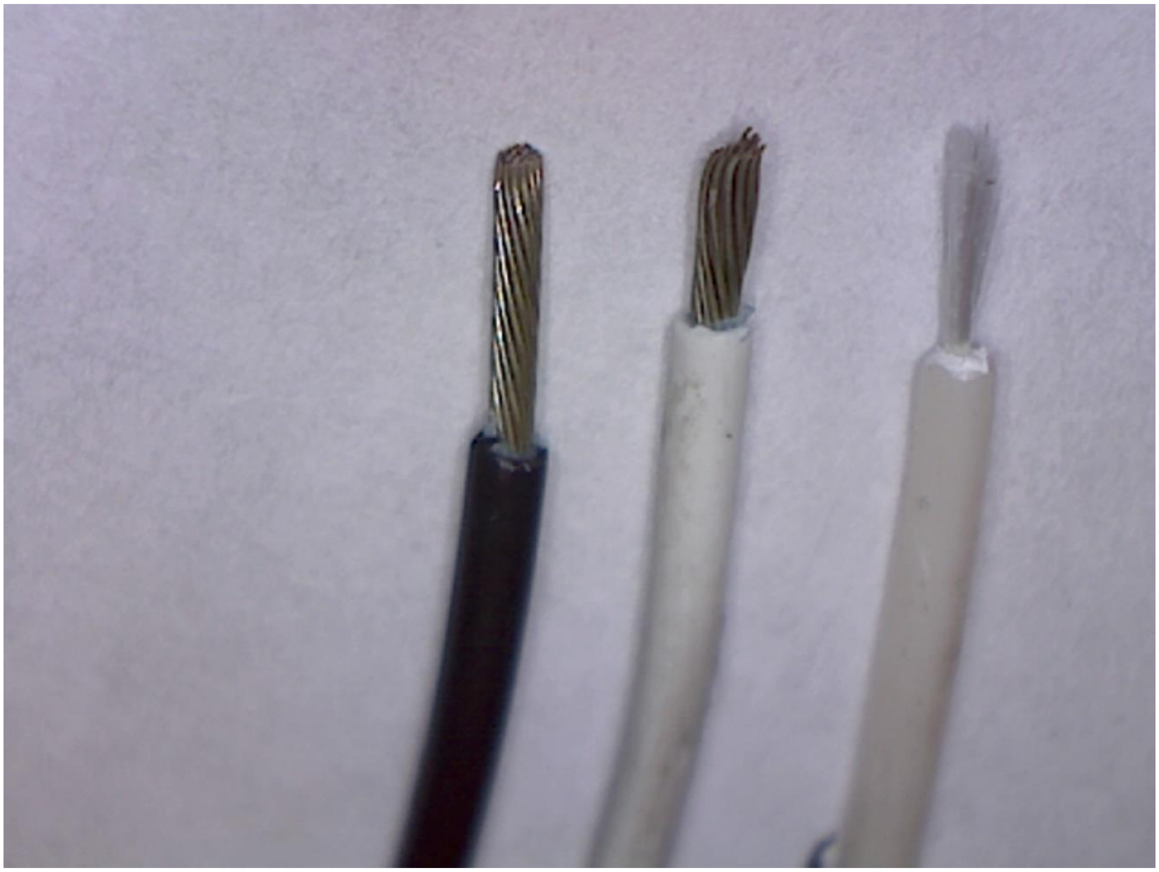


Figure A30 Short segment wire details.

MAINTENANCE MESSAGE N686PA-T.MTM 20:05 19NOV19
WRITE OPTION: ALL LEGS THROUGH LEG 00953
MDC ASSEMBLY CPN: 622-9818-122 DISKETTE CPN: 831-0547-021
A/C STRAPPING CODE: 0001 S2000 MDC SOFTWARE VERS: 0016

MESSAGE	LEG	TIME	DATE
-------------------	-----	-----	-------
R FADEC (A)	953	1:40	18-Oct-19
L FADEC (A)	953	1:40	18-Oct-19
34#ADC INVALID DATA	953	1:40	18-Oct-19
76#FADEC FAIL RESET	953	1:40	18-Oct-19
76#ALT FADEC DISCR	953	1:40	18-Oct-19
76#PMU ARINC	953	1:40	18-Oct-19
34#ADC ARINC	953	1:40	18-Oct-19
24#GEN RELAY	953	1:40	18-Oct-19
24#AC BUS TIE	953	1:40	18-Oct-19
29#HYD PRESS LO	953	1:40	18-Oct-19
61#SYNCHROPHASE DIS	953	1:40	18-Oct-19
77#TRQ LANE DIFF	953	1:40	18-Oct-19
61#MASTER PROP SYNC	953	1:40	18-Oct-19
76#PLA	953	1:40	18-Oct-19
61#PROP SPEED SENS	953	1:40	18-Oct-19
52#AFT S-DOOR	953	1:40	18-Oct-19
INBD A-SKID	953	1:40	18-Oct-19
OUTBD A-SKID	953	1:40	18-Oct-19
32#L WHEEL SPD XDCR	953	1:40	18-Oct-19
INBD A-SKID	953	1:40	18-Oct-19
32#ANTI SKID CTL	953	1:40	18-Oct-19
INBD A-SKID	953	1:40	18-Oct-19
32#ANTI SKID CTL	953	1:40	18-Oct-19
30#W+ST R AIR VLV	953	1:16	18-Oct-19
31#FDR NOT OK	952	21:02	17-Oct-19
30#W+ST R AIR VLV	952	20:40	17-Oct-19
R BLD	950	18:44	17-Oct-19
36#PACK VLV FAULT	950	18:44	17-Oct-19
R BLD	948	15:32	17-Oct-19
36#PACK VLV FAULT	948	15:32	17-Oct-19
36#BLD AIR FAULT	948	7:27	17-Oct-19
36#L+R PACK VLV CLS	948	7:27	17-Oct-19
49#APU BLD VLV	948	7:27	17-Oct-19
R BLD	948	7:27	17-Oct-19
36#PACK OVTEMP	948	7:27	17-Oct-19
30#WING BOOT DEFL	948	7:27	17-Oct-19

RIGHT PROP D-ICE	948	0:01	1-Jan-80
LEFT PROP D-ICE	948	0:01	1-Jan-80
34#DOUBLE TMP INPUT	948	0:01	1-Jan-80
30#WING BOOT DEFL	948	5:31	17-Oct-19
30#W+ST R AIR VLV	948	5:26	17-Oct-19
30#STAB BOOT DEFL	948	5:25	17-Oct-19
30#WING BOOT DEFL	948	5:25	17-Oct-19
30#WING BOOT DEFL	948	5:23	17-Oct-19
R BLD	947	4:11	17-Oct-19
36#PACK VLV FAULT	947	4:11	17-Oct-19
79#ENG OIL PR SW	947	4:10	17-Oct-19
R BLD	947	4:10	17-Oct-19
36#PACK VLV FAULT	947	4:10	17-Oct-19
28#FUEL UNBALANCE	947	3:57	17-Oct-19
R BLD	946	1:45	17-Oct-19
36#BLD VLV FAULT	946	1:45	17-Oct-19
49#APU BLD VLV	946	1:45	17-Oct-19
36#L+R PACK VLV CLS	946	1:45	17-Oct-19
L BLD	946	1:44	17-Oct-19
36#BLD VLV FAULT	946	1:44	17-Oct-19
49#APU BLD VLV	946	1:44	17-Oct-19
36#L+R PACK VLV CLS	946	1:44	17-Oct-19
79#ENG OIL PR SW	946	1:44	17-Oct-19
L BLD	946	1:43	17-Oct-19
36#BLD VLV FAULT	946	1:43	17-Oct-19
49#APU BLD VLV	946	1:43	17-Oct-19
36#L+R PACK VLV CLS	946	1:42	17-Oct-19
49#APU BLD VLV	946	1:42	17-Oct-19
R BLD	946	1:40	17-Oct-19
36#PACK VLV FAULT	946	1:40	17-Oct-19
R BLD	946	1:37	17-Oct-19
36#PACK VLV FAULT	946	1:37	17-Oct-19
28#FUEL UNBALANCE	946	0:59	17-Oct-19
31#DCU CAUTION	946	0:59	17-Oct-19
28#FUEL UNBALANCE	946	0:55	17-Oct-19
28#FUEL UNBALANCE	946	0:51	17-Oct-19
R BLD	944	23:28	16-Oct-19
36#PACK VLV FAULT	944	23:28	16-Oct-19
R BLD	943	21:14	16-Oct-19
36#PACK VLV FAULT	943	21:14	16-Oct-19
28#FUEL UNBALANCE	943	20:52	16-Oct-19
30#W+ST R AIR VLV	943	19:09	16-Oct-19
30#W+ST R AIR VLV	943	18:54	16-Oct-19
R BLD	941	17:49	16-Oct-19
36#PACK VLV FAULT	941	17:49	16-Oct-19

28#FUEL UNBALANCE	941	17:08	16-Oct-19
28#FUEL UNBALANCE	941	17:08	16-Oct-19
28#FUEL UNBALANCE	941	17:07	16-Oct-19
28#FUEL UNBALANCE	941	17:06	16-Oct-19
28#FUEL UNBALANCE	941	17:05	16-Oct-19
28#FUEL UNBALANCE	941	17:03	16-Oct-19
28#FUEL UNBALANCE	941	17:01	16-Oct-19
28#FUEL UNBALANCE	941	17:00	16-Oct-19
28#FUEL UNBALANCE	941	16:59	16-Oct-19
28#FUEL UNBALANCE	941	16:59	16-Oct-19
R ENG	941	16:53	16-Oct-19
73#ENG FUEL TEMP LO	941	16:53	16-Oct-19
R BLD	941	16:53	16-Oct-19
36#PACK VLV FAULT	941	16:53	16-Oct-19
R BLD	941	16:53	16-Oct-19
36#PACK VLV FAULT	941	16:52	16-Oct-19
35#CREW OX PRESS LO	941	0:00	1-Jan-80
R BLD	941	4:23	16-Oct-19
36#PACK VLV FAULT	941	4:23	16-Oct-19
79#ENG OIL PR SW	940	2:49	16-Oct-19
R BLD	940	2:48	16-Oct-19
36#PACK VLV FAULT	940	2:48	16-Oct-19
R BLD	939	0:46	16-Oct-19
36#PACK VLV FAULT	939	0:46	16-Oct-19
R BLD	939	0:46	16-Oct-19
36#PACK VLV FAULT	939	0:46	16-Oct-19
R BLD	938	22:52	15-Oct-19
36#BLD VLV FAULT	938	22:52	15-Oct-19
49#APU BLD VLV	938	22:52	15-Oct-19
36#L+R PACK VLV CLS	938	22:52	15-Oct-19
49#APU BLD VLV	938	22:51	15-Oct-19
36#L+R PACK VLV CLS	938	22:51	15-Oct-19
36#BLD AIR FAULT	938	22:39	15-Oct-19
36#L+R PACK VLV CLS	938	22:39	15-Oct-19
49#APU BLD VLV	938	22:39	15-Oct-19
R BLD	938	22:38	15-Oct-19
36#PACK VLV FAULT	938	22:38	15-Oct-19
R BLD	938	22:36	15-Oct-19
36#PACK VLV FAULT	938	22:36	15-Oct-19
R BLD	938	22:33	15-Oct-19
36#PACK VLV FAULT	938	22:33	15-Oct-19
R BLD	937	18:14	15-Oct-19
36#PACK VLV FAULT	937	18:14	15-Oct-19
R BLD	937	18:13	15-Oct-19
36#PACK VLV FAULT	937	18:13	15-Oct-19

28#FUEL UNBALANCE	937	17:31	15-Oct-19
R ENG	937	17:02	15-Oct-19
73#ENG FUEL TEMP LO	937	17:02	15-Oct-19
R BLD	937	17:02	15-Oct-19
36#PACK VLV FAULT	937	17:02	15-Oct-19
R BLD	937	17:01	15-Oct-19
36#PACK VLV FAULT	937	17:01	15-Oct-19
34#GPWS INOP	937	0:01	1-Jan-80
RIGHT PROP D-ICE	937	0:01	1-Jan-80
LEFT PROP D-ICE	937	0:01	1-Jan-80
34#DOUBLE TMP INPUT	937	0:01	1-Jan-80
34#GPWS INOP	937	0:00	1-Jan-80
RIGHT PROP D-ICE	937	0:00	1-Jan-80
LEFT PROP D-ICE	937	0:00	1-Jan-80
34#DOUBLE TMP INPUT	937	0:00	1-Jan-80
31#FDR NOT OK	937	1:26	15-Oct-19
R BLD	937	1:16	15-Oct-19
36#PACK VLV FAULT	937	1:16	15-Oct-19
34#GPWS INOP	937	1:12	15-Oct-19
RIGHT PROP D-ICE	937	0:00	1-Jan-80
LEFT PROP D-ICE	937	0:00	1-Jan-80
34#DOUBLE TMP INPUT	937	0:00	1-Jan-80
49#APU OVSP TEST	937	22:44	14-Oct-19
RIGHT PROP D-ICE	937	0:00	1-Jan-80
34#DOUBLE TMP INPUT	937	0:00	1-Jan-80
30#W+ST R AIR VLV	937	21:58	14-Oct-19
30#W+ST R AIR VLV	937	21:58	14-Oct-19
L ENG	936	21:12	14-Oct-19
79#ENG OIL PR SW	936	21:12	14-Oct-19
R BLD	936	21:12	14-Oct-19
36#PACK VLV FAULT	936	21:12	14-Oct-19
34#GPWS INOP	935	0:00	1-Jan-80
RIGHT PROP D-ICE	935	0:00	1-Jan-80
LEFT PROP D-ICE	935	0:00	1-Jan-80
34#DOUBLE TMP INPUT	935	0:00	1-Jan-80
28#FUEL UNBALANCE	935	18:08	14-Oct-19
30#W+ST R AIR VLV	931	15:40	14-Oct-19
28#FUEL UNBALANCE	930	14:37	14-Oct-19
28#FUEL UNBALANCE	930	14:36	14-Oct-19
28#FUEL UNBALANCE	930	14:17	14-Oct-19
L FUEL QTY	930	2:59	14-Oct-19
L FUEL QTY	930	2:57	14-Oct-19
28#FUEL QTY LO	930	2:57	14-Oct-19
L FUEL QTY	930	2:56	14-Oct-19
28#FUEL QTY LO	930	2:56	14-Oct-19

L FUEL QTY	930	2:55	14-Oct-19
28#FUEL QTY LO	930	2:55	14-Oct-19
32#ANTI SKID CTL	928	23:54	13-Oct-19
R BLD	927	21:24	13-Oct-19
36#PACK VLV FAULT	927	21:24	13-Oct-19
28#FUEL CON VLV	927	20:59	13-Oct-19
28#FUEL UNBALANCE	927	20:53	13-Oct-19
28#FUEL UNBALANCE	927	20:52	13-Oct-19
34#DOUBLE TMP INPUT	927	0:00	1-Jan-80
31#FDR NOT OK	927	19:03	13-Oct-19
76#BETA SWITCH	927	18:59	13-Oct-19
L FADEC (B)	927	18:59	13-Oct-19
L FADEC (A)	927	18:59	13-Oct-19
76#PMU INVALID DATA	927	18:59	13-Oct-19
30#W+ST R AIR VLV	927	18:45	13-Oct-19
49#APU BLD VLV	925	17:35	13-Oct-19