NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594
10/25/2022

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

DCA20LA013

A. INCIDENT

Location:	Chicago, IL USA
Date:	November 11, 2019
Time:	07:42 CST
Aircraft:	Embraer EMB 145 LR, N619AE
Airline:	Envoy Air Inc.

B. SYSTEMS GROUP

Chairman:	Adam Huray National Transportation Safety Board Washington, DC
Member:	Patrick Lusch FAA Washington, DC
Member:	Paulo Ribeiro Embraer Ft Lauderdale, FL
Member:	Ed Delehant Envoy Air Inc Irving, TX
Member:	Chris Heck Air Line Pilots Association McLean, VA

C. SUMMARY

On November 11, 2019, at about 0742 CST, American Eagle flight 4125, operated by Envoy Air, an EMB 145 LR, N619AE, experienced a right main landing gear collapse after the aircraft departed runway 10L while landing at Chicago O'Hare International Airport (KORD), Chicago, Illinois. There were no injuries to the 41 passengers and crew onboard and the airplane received substantial damage. There was blowing snow at the time of the accident. The flight was

operating under 14 CFR part 121 as a domestic passenger flight from Piedmont Triad International Airport (KGSO), Greensboro, North Carolina.

D. AIRCRAFT DESCRIPTION

Operator:	Envoy Air Inc (Envoy)
Registration number:	N619AE
Aircraft Serial Number:	145101
Aircraft Manufacturer:	Embraer
Model:	EMB 145 LR
Aircraft Year:	1998
Total Time:	45984
Total Cycles:	41846

E. DETAILS OF THE ON-SCENE INVESTIGATION

The aircraft was moved to a maintenance hangar provided by Envoy. On-scene recovery, documentation, and testing was performed by Envoy. A local FAA FSDO representative provided on-scene assistance when requested. The NTSB, Embraer, and Air Line Pilots Association did not travel to the aircraft.

E.1 Aircraft Condition

Figure 1: Aircraft Resting Position Following Runway Departure (Courtesy of Envoy)

The right main landing gear collapsed and damaged the landing gear itself, the upper wing skin, and Rib 4 between Spar II and Spar III. Rib 4 is considered primary structure by Embraer and was fractured. Minor damage to the wing where the wing contacted the ground was also observed. The No. 2 main gear tire had a slash mark that stretched across 4 of the 5 treads. The airport reported that two taxiway lights were damaged during the excursion.

E.2 On-Scene Aircraft Examination and Testing

Maintenance personnel made three attempts to download the Central Maintenance Computer without success (memory was blank). The Number 1 Return Differential Pressure Indicator was popped out; however, the associated filter was inspected and found to be clean. The Brake Control Unit (BCU) was removed prior to any aircraft testing and set aside for future non-volatile memory (NVM) download (see section G.6). A certified BCU was then installed in the aircraft for aircraft testing.

E.2.1 Nose Wheel Steering System Description and Examination

E.2.1.1 Nose Wheel Steering System Description

The nose wheel steering (NWS) system permits moving the nose wheels when the landing gear is down and locked and the airplane is on the ground. The NWS system is electronically controlled and hydraulically operated. It is powered by the Number 1 hydraulic system. The nose wheel steering system is comprised of the following components (see Figure 2):

- Tiller (steering handwheel)
- Rudder pedal potentiometer
- Control wheel disengage pushbuttons
- External steering disengagement switch
- Feedback potentiometer
- Load potentiometer
- Steering Electronic Control Module
- Hydraulic manifold assembly
- Steering actuating cylinder
- Feedback unit sensor (7 degree position sensor)

The nose wheel steering is controlled by the rudder pedals and/or the tiller. The commanded displacement is measured by a potentiometer, which transmits the signal to the Steering Electronic Control Module (SECM). The SECM monitors each potentiometer signal individually for a short or open circuit. If a short or open circuit is detected the SECM will send a signal to disengage the nose wheel steering. If the input signals are valid the SECM will process them and send nose wheel steering command signals to the hydraulic manifold assembly. The hydraulic manifold assembly provides hydraulic pressure to the steering actuator to move the nose wheel in the commanded direction. A feedback potentiometer on the nose landing gear transmits nose wheel displacement information back to the SECM. A load potentiometer sends a constant signal load to the SECM when the tiller is not engaged to provide precision zero centering adjustment to the nose wheel.

The nose wheel steering can be commanded to a maximum angle of 71 degrees when using the tiller, 5 degrees when using the rudder pedals, or 76 degrees using both tiller and rudder pedals. A proximity sensor connected to the feedback unit sensor disengages the system if the nose wheel is rotated beyond 7 +/-1 degrees when the tiller is not engaged. If the NWS system disengages in this manner, the system can be reengaged by engaging the tiller when speed is below 25kts. The steering system may also be manually disengaged through switches located on either control wheel provided the tiller is not engaged. If the NWS system is disengaged for any reason while the aircraft is on the ground a caution aural alert will sound, the master caution light will illuminate, and the message "STEER INOP" will display on the EICAS. The system allows for the nose wheel to free caster any time the nose landing gear is on the ground and the NWS is disengaged.

This aircraft was equipped with an external steering disengagement switch which allows ground personnel to disengage steering prior to towing operations. The disengagement switch inhibits the steering actuation commanded by the steering handle and the rudder pedals. A caution message is displayed on the EICAS whenever the steering system is disengaged by the external switch. The NWS system is also automatically disabled when the aircraft is airborne. Nose wheel centering when weight is off wheels (strut extended) is mechanically provided by a cam.

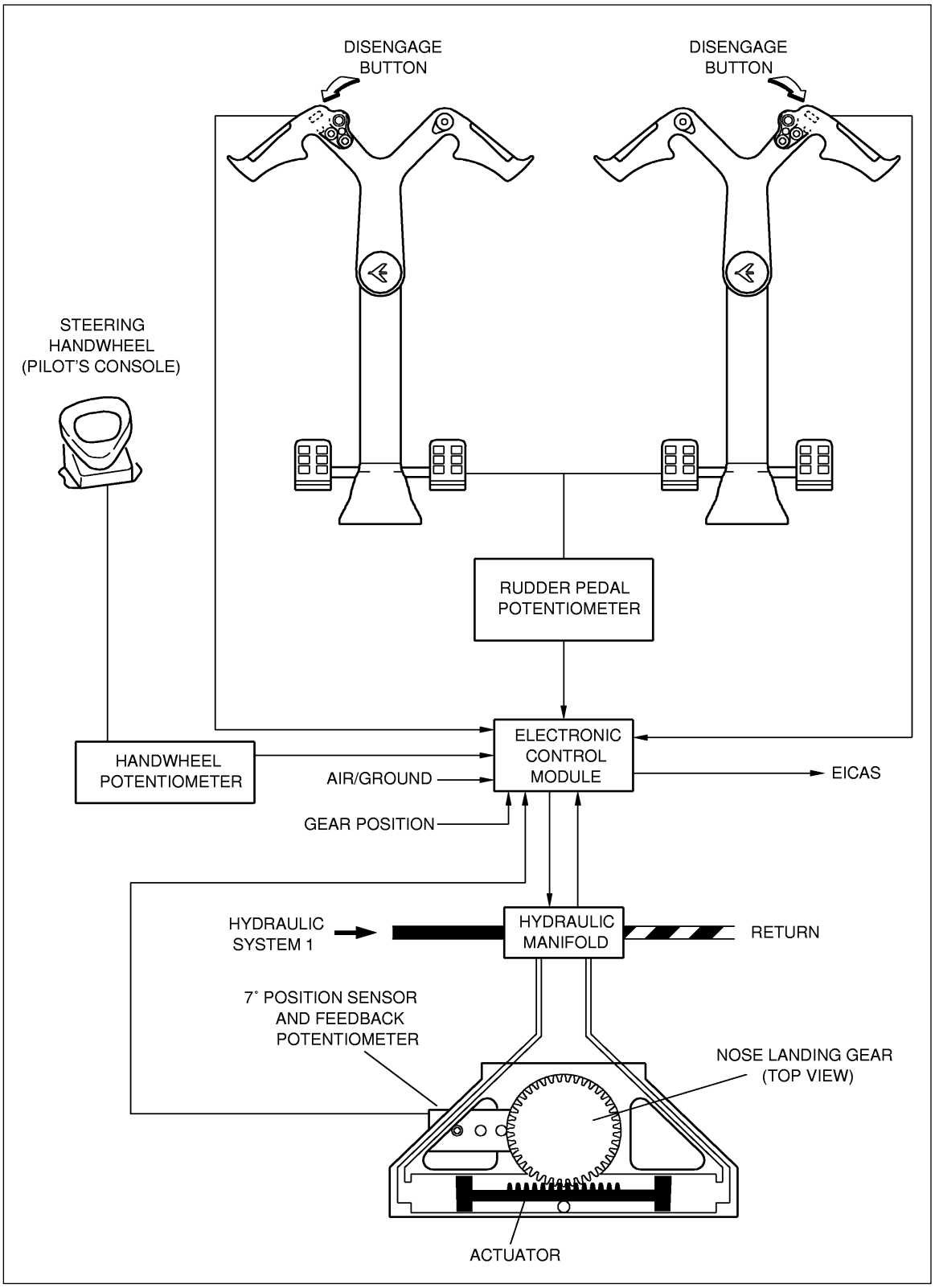

Figure 2. Nose Wheel Steering System Schematic (Courtesy of Embraer)

E.2.1.2 Nose Wheel Steering System Examination

Figure 3: Nose Landing Gear Following Runway Departure

The nose wheel strut was deflated prior to all nose wheel steering checks being accomplished. Prior to deflation, the strut measured 40 psi when the strut was fully extended. With strut compressed the strut height was found to be approximately 6 inches.

The aircraft was placed on jacks and the nose landing gear was verified to be straight and correctly seated in the centering cam. The steering disengage button on the pilot and copilot's yokes were tested per the Embraer 145 Aircraft Maintenance Manual (AMM), task 32-50-00-700-801-A, and found to operate normally.[1] In addition, the reset logic that does not allow engagement of the tiller nose wheel steering above 25 kts was tested per AMM task 32-50-00-700-801-A and found to operate normally.

The load potentiometer resistance was checked per AMM task 32-50-05-700-801-A. At electrical connector P7189 the measured resistance between pins 39 and 40 was 2426 Ohms and the measured resistance between pins 41 and 40 was 2409 Ohms, with a difference of 17 Ohms. The AMM required a difference 30 Ohms or less. During this test maintenance discovered that wires W101-0485-24, W101-1046-22, AND W101-6979-22 were broken at their connection to the P7189 connector. These wires were related to the ADC 2 functional test switch, EICAS test

[1] The revision of the AMM referenced throughout this report is Revision 64, dated June 28, 2019.

switch, and the baggage smoke detector test switch, respectively.

The handwheel potentiometer resistance was checked per AMM task 32-50-01-700-801-A. At electrical connector P7005 the measured resistance between pins A and B was 2638 Ohms and the measured resistance between pins B and C was 2650 Ohms, with a difference of 12 Ohms. The AMM required a difference 30 Ohms or less.

The feedback unit potentiometer resistance was checked per AMM task 32-50-07-700-801-A. With the nose landing gear at 0 degrees, at electrical connector P0051, the measured resistance between pins 1 and 2 was 2587 Ohms and the measured resistance between pins 2 and 3 was 2628 Ohms, with a difference of 41 Ohms. The AMM required a difference of 30 Ohms or less. The resistance value exceedance represents 0.2% increase in the voltage signal output from the feedback potentiometer to the SECM control circuit. This may result in a nose wheel command that would cause a slight nose wheel deflection from neutral, depending also on the combined input errors from the other command potentiometers and any error resulting from the Steering Manifold Assembly. In any case, according to Embraer, any nosewheel steering offset created by the observed feedback unit potentiometer resistance values would be a constant offset (not a sudden nose wheel input), and the crew would be able to correct the offset by applying additional steering input.

The rudder pedal potentiometer resistance was checked per AMM task 32-50-02-700-801-A. Envoy stated the following reading was taken at the P0052 connecter instead of the P7034 connector that is called out in the task, but that the reading was electrically identical. At electrical connector P0052, the measured resistance between pins K and D was 2679 Ohms and the measured resistance between pins D and E was 2667 Ohms, with a difference of 12 Ohms. The AMM required a difference of 30 Ohms or less.

Envoy stated that there were no anomalies noted with the general operation of the nose wheel steering during the on-scene examination. The nose landing gear bay was inspected with no indications of a turned nose gear identified. The following nose wheel steering components were removed for additional testing: Steering Electronic Control Module, hydraulic manifold assembly, feedback potentiometer assembly, rudder pedal potentiometer assembly, and the Brake Control Unit (see section G of this report):

E.2.2 Brakes

The braking system was checked in accordance with the AMM, Section 32-41-00. No faults were found. The #1 brake forward wear indicator extended 0.531 inches and the aft wear indicator extended 0.562 inches beyond the hexagonal insert of their respective wear indicator sleeves. The #2 brake forward wear indicator extended 0.656 inches and the aft wear indicator extended 0.718 inches beyond the hexagonal insert of their respective wear indicator sleeves. The #3 brake forward wear indicator extended 0.625 inches and the aft wear indicator extended 0.656 inches beyond the hexagonal insert of their respective wear indicator sleeves. The #4 brake forward wear indicator extended 0.687 inches and the aft wear indicator extended 0.718 inches beyond the hexagonal insert of their respective wear indicator sleeves. The AMM requires brake replacement when the wear indicator is flush with the hexagonal insert of the wear indicator

sleeve. For the component examination of the Brake Control Unit see section G.6 of this report.

E.2.3 Tires

All tires were inspected. There was no sign of rubber reversion, flat spotting, or any abnormal wear found on any tire. The No. 2 main gear tire had a slash mark that stretched across 4 of the 5 treads. The airport reported that two taxiway lights were damaged during the excursion.

E.2.4 Rudder

The rudder system passed an operational test per AMM 27-23-00-700-804-A with no faults found.

E.2.5 Spoilers

The spoiler system was subjected to an operational test per AMM 27-63-01-700-801. There were no faults found suspected of contributing to the accident. Testing revealed that the pitch trim would not nose back down after the speed brake was closed as expected. The spoiler control unit was removed and replaced and the trim correctly functioned in both directions. According to Embraer the reported fault would not have affected spoiler performance on landing. Review of the FDR shows the spoilers operated as expected.

E.2.6 Thrust Reversers

The thrust reversers passed an operational test per AMM 78-31-01-700-801-A with no faults found.

E.2.7 Circuit Breakers

Envoy reported that only the FDR and CVR circuit breakers were found to be open in the flight deck following the event.

F. MAINTENANCE RECORDS

A review of aircraft maintenance history for 60 days prior to the accident was performed. The following notable discrepancies were found (summarized for readability):

09/12/2019 - Spoiler fail on EICAS– replaced relays and ground spoiler valve, replaced BCU and wheel speed transducers during troubleshooting, due to BCU and wheel speed transducers troubleshooting a brake system functional check was performed and passed in accordance with AMM 32-41-00.
09/16/2019 - #3 and #4 tires worn to limits and replaced
09/17/2019 - Hydraulic system 1 low – fluid transfer from system 2 to system 1
09/24/2019 - Hydraulic system 1 fail and engine 1 hydraulic pump fail. Replaced hydraulic pump and EDP pressure switch.
09/29/2019 - Hydraulic system 1 reservoir low – serviced hydraulic system

09/29/2019 - #1 and #2 main gear and both nose tires tire worn – tires replaced
10/02/2019 - Hydraulic #1 system low - performed hydraulic transfer per ETN-EM-29-023
10/06/2019 - Removed and reinstalled # 3 wheel as a precautionary action
10/09/2019 - Found debris on the #2 thrust reverser – cleaned and inspected
10/11/2019 - Right hand main landing gear shock strut requires servicing - serviced
10/14/2019 - Left inboard spoiler actuator leaking and low hydraulic system 1 quantity – replaced ground spoiler actuator
10/14/2019 - #3 tire worn – removed and replaced #3 main landing gear wheel assembly and performed carbon inspection on brake assembly
10/14/2019 - Right hand strut requires servicing – serviced strut
10/16/2019 - Right main strut really compressed with little chrome showing - performed full service of right-hand main landing gear shock absorber
10/16/2019 - Hydraulic system 1 needs service – serviced both hydraulic systems
10/19/2019 - Nose gear pulls left at all speeds during taxi – performed adjustment of the feedback unit potentiometer in accordance with EMB 145 AMM 32-50-07. Ops checked good.
10/21/2019 - During taxi out performed steering check and right rudder at full deflection disengaged steering. - Removed and replaced 7 degree proximity switch in accordance with AMM 32-50-06-04 and performed adjustment/test in accordance with AMM 32-50-06-05 subtask 720-003-A. Ops check good.
10/23/2019 - #4 tire worn – replaced tire
10/25/2019 - Hydraulic system 1 and 2 low – serviced both hydraulic systems
10/25/2019 - Hydraulic fluid leak found in right hand wheel well - replaced right hand speed brake actuator
11/01/2019 - Hydraulic system 2 requires servicing – serviced hydraulic system 2
11/06/2019 - Hydraulic system 1 approaching amber range – performed transferring of hydraulic system
11/10/2019 - Found #2 main wheel dust cover damaged – replaced wheel dust cover
11/10/2019 - #2 tire worn – replaced tire

Envoy reported that there were no deferred items per the Minimum Equipment List at the time of the accident.

G. COMPONENT EXAMINATIONS

G.1 Nose Wheel Steering Electronic Control Module (SECM)

Manufacturer: Parker
Part Number: 308560-1013G
Serial Number: 0553
Date of Manufacture: 3Q98

The SECM is an electronic system consisting of a cover plate, circuit card assembly, and two connectors. The SECM receives electronic inputs from the nose wheel steering commands and feedback components and outputs an electrical signal to the hydraulic manifold assembly to command the steering actuator. The SECM also relays system status information. The unit does

not record any data in NVM.

The SECM was examined at the Parker facility in Irvine, CA on December 16, 2021. The examination was attended in person by the NTSB and virtually by the other participants.

The SECM was visually inspected and appeared to be in good physical condition. The unit was functionally tested in accordance with Chapter 2 “Testing and Fault Isolation” of the Abbreviated Component Maintenance Manual 32-50-11, Rev 7 dated Nov 5, 2015. The test included three phases, one at room temperature, one at 0 (+/- 5) degrees Fahrenheit, and one at 158 (+/- 5) degrees Fahrenheit. The unit passed all sections of the test.

Parker had no records of repair for this unit.

G.2 Nose Wheel Steering Manifold Assembly

Manufacturer: Parker
Part Number: 308570-1007
Revision: A1
Serial Number: 0301B
Date of Manufacture: 4Q99

The nose wheel steering manifold assembly is an electrohydraulic unit that provides fluid pressure to the actuator that controls the steering of the nose wheel. The manifold supports and contains an electrohydraulic servo valve, solenoid, three check valves, a bypass valve, an electrical connector, a filter, and a compensator.

The NWS manifold assembly was examined at the Parker Commercial Flight Controls Division Repair Station in Ogden, UT on September 20, 2021. This examination was attended virtually by all participants.

An external visual inspection was performed, and the unit appeared to be in good physical condition. The C1 and C2 control ports were blocked off by a plastic bag with zip ties, allowing for some residual fluid to leak out of the ports. The electrical connector pins were straight and clean. The unit was connected to the test bench. During setup, when there was 3000 psi hydraulic pressure applied to the pressure port but no electrical command input to the unit, it was observed that the C2 output port pressure increased to approximately 2,400 psi and the C1 output port pressure stayed at 0 psi. According to Parker, they would have expected the C1 and C2 output delta to be closer to 0 psi when there was no electrical command input. When the electrical command was applied to provide full pressure to the C1 port, the C1 port pressure went to 3,000 psi and the C2 port pressure went to 0 psi as expected. Pressure increasing at the C2 port of the manifold assembly would result in the nose wheel turning to the right at the aircraft level. It is noted here that electrical inputs to the nose wheel steering would normally be expected while the nose wheel steering is active, whether from the rudder pedals, tiller, or load pot. Nonetheless, the group decided to stop further testing until the electrohydraulic servo valve (EHSV) P/N 308598-1003D, S/N 684A, which is a subcomponent of the manifold assembly, could be removed for separate investigation to try to understand this observation. The manifold assembly

was repackaged and placed in a secure storage location until a later date when the EHSV could be removed.

On November 9, 2021, a second virtual examination was performed. The manifold assembly (with original EHSV still installed) was tested for dielectric and insulation resistance and the manifold met specifications. The EHSV (S/N 684A) was removed from the manifold and a metal shipping plate was installed over all 4 O-rings to seal the EHSV. No FOD or debris were noted in the 4 fluid ports of the EHSV and the O-rings appeared to be intact. The removed EHSV was secured for future testing (see section G.3).

EHSV P/N 308570-1011, S/N 467, was removed from certified stock and installed on the manifold assembly. A functional test was performed on the manifold assembly per the Component Maintenance Manual 32-50-15, Rev 12, dated October 4, 2021. Proof pressure testing was not performed. The unit (with replaced EHSV) passed all performed tests.

Parker provided the following service history for the manifold assembly:

Date	Reason For Return	Repair Result
8/6/2003	Vibration coming from NLG	No Fault Found
11/8/2006	Rework to B in serial number	Manifold upgraded to 0301B. EHSV 684A installed.
7/23/2007	Noise in valve	No Fault Found
3/8/2013	Excessive noise heard during taxi	No Fault Found
3/15/2018	Possible steering manifold is bypassing fluid	No Fault Found, cleaned and inspected 3 check valves.

Envoy records show that the manifold assembly was installed on the event aircraft on October 13, 2018.

G.3 Electrohydraulic Servo Valve (EHSV)

Manufacturer: HR Textron (Woodward HRT)
Part Number: 22253282-103
Serial Number: 684A
Date of Manufacture: 4Q2006

The electrohydraulic servo valve (EHSV) is a three position, four-way type valve. The EHSV receives electrical signals from the SECM. A torque motor within the EHSV responds to the electrical signals and hydraulic fluid is ported to the commanded steering actuator cylinder chamber.

The EHSV was removed from the manifold assembly during the examination of the manifold assembly at Parker on November 9, 2021 (see section G.2). The EHSV was examined at the Woodward HRT facility in Santa Clarita, CA on December 15, 2021. The NTSB, FAA, and Parker attended this examination in person while the other participants attended virtually. The

EHSV was made by HR Textron, who was later purchased by Woodward Inc. and is now known as Woodward HRT.

The EHSV was visually examined. The unit appeared in good condition with only minor dings and scratches observed. A blocker plate was installed over the hydraulic ports following the removal of the EHSV from the manifold assembly. This plate was removed prior to testing and examining the unit.

Functional testing was performed on the EHSV per the manufacturer's Acceptance Test Procedure HR72700412, Rev D, dated June 18, 2009. Steps 4.5 (Insulation Resistance), 4.8 (Flow Gain), 4.9 (Internal Leakage), 4.10 (Pressure Gain), 4.11 (Null Bias), 4.12 (Hysteresis), and 4.13 (Threshold) were performed. The unit met the as-new acceptance test limits for all performed tests except for the flow gain test. The Flow vs Input Current plot showed a slight exceedance of the as-new flow gain envelope between approximately the +2mA to +3mA range. The slight increase of hydraulic fluid flow could result in a small increase in the speed of the nose wheel deflection in the commanded direction over this input current range, but would not cause a change to the nose wheel commanded direction or result in an uncommanded nose wheel turn. Woodward HRT stated that this degree of flow gain exceedance is typically caused from wear induced backlash between the feedback wire pin and the spool pin slot, and is common on units with a significant amount of service hours. Later teardown of the EHSV revealed flat spots on the ends of the feedback wire pin and corresponding marks on the spool pin slot typical of in-service wear and a rotating spool.

The torque motor cover was removed and a small spec of foreign object debris (FOD) was found adhered to the armature near the top of the air gap in the right (C2) side (see Figure 4). The FOD was removed using adhesive tape and was submitted to the NTSB materials lab for identification. EDS spectra and fracture morphology revealed the FOD was consistent with an organic material such as an amorphous polymer. The source for the FOD was not identified. The plots for pressure gain, flow gain, and internal leakage were rerun following the removal of this FOD. An additional test (not required by the ATP), labeled as a "noise test", was also rerun that compares the differential pressure versus time. The pressure gain plot and the noise test plot values changed as shown in Figures 5-8. According to Woodward HRT, the pressure gain, null balance, and hysteresis observed in both the before and after FOD pressure gain plots is acceptable and passed the as-new ATP requirements. Embraer further stated that any effects of the observed pressure gain plot shift along the x-axis could be nulled out at the aircraft level by adjustment of the feedback potentiometer. Woodward HRT stated the noise plots created both before and after the FOD removal were acceptable for a properly functioning unit.

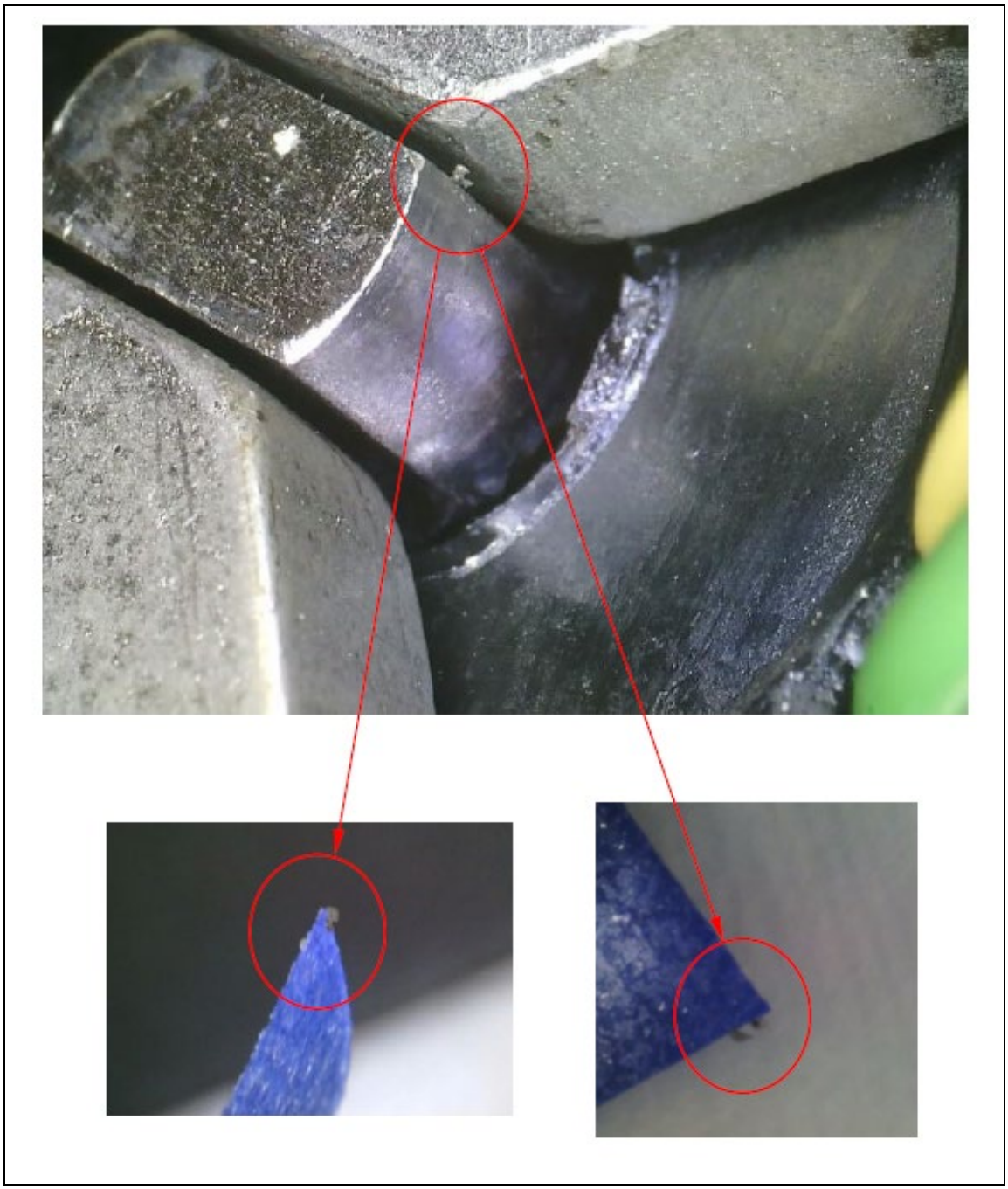

Figure 4: FOD Found on Armature

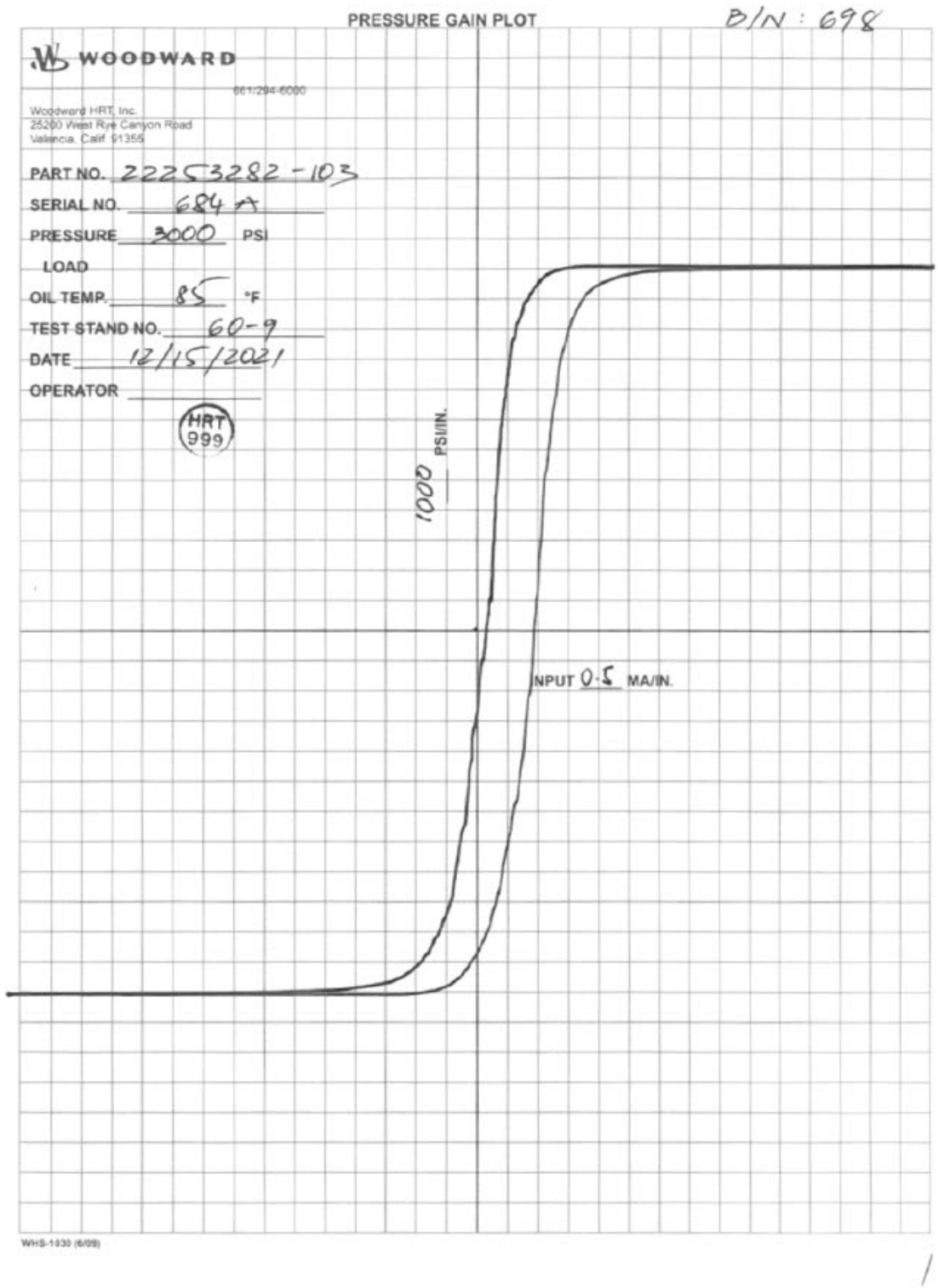

Figure 5: Pressure Gain Plot Before FOD Removal (Courtesy of Woodward HRT)
Figure 3 - Pressure Gain Plot with ATP scale (0.5 mA inch)

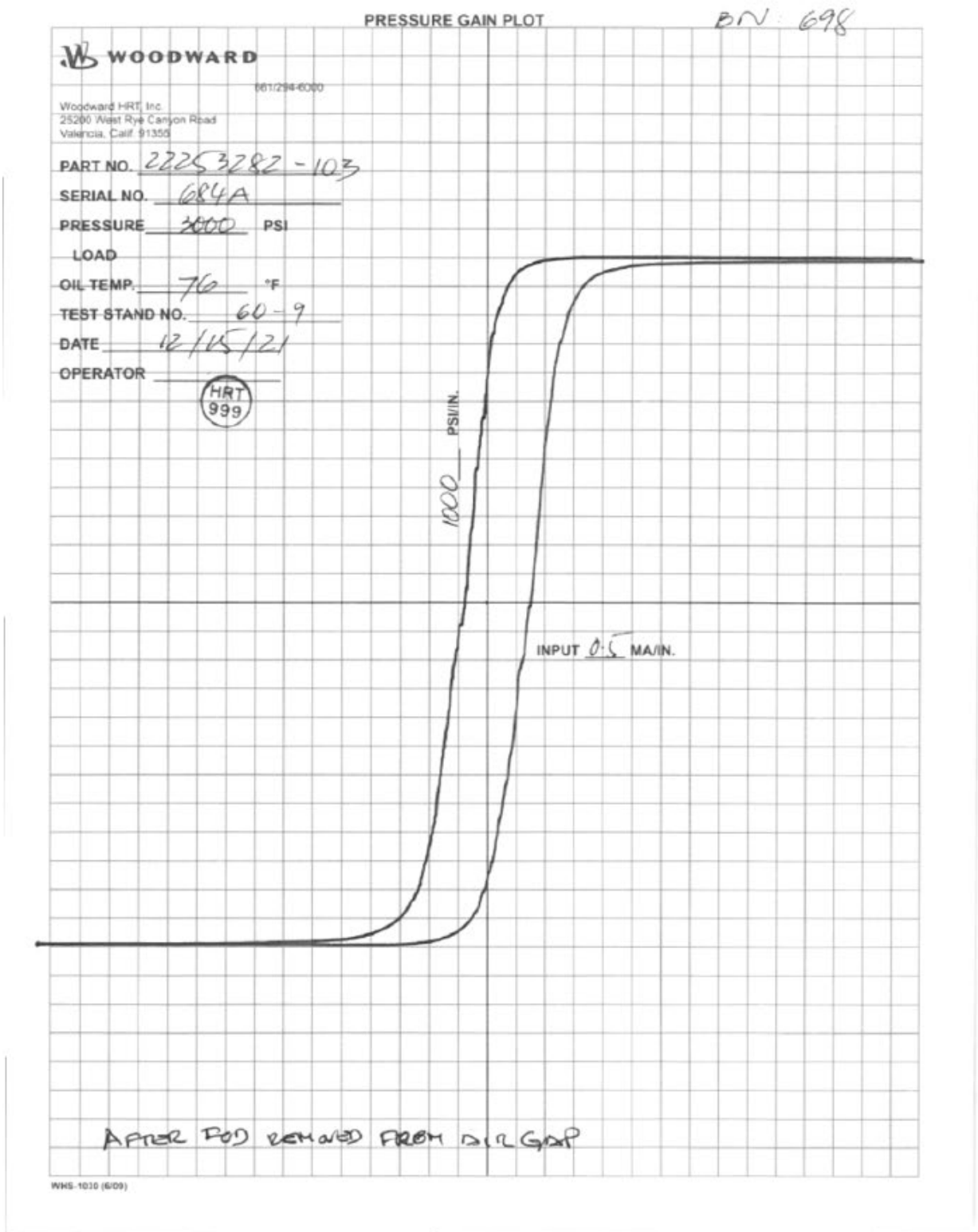

Figure 6: Pressure Gain Plot After FOD Removal (Courtesy of Woodward HRT)

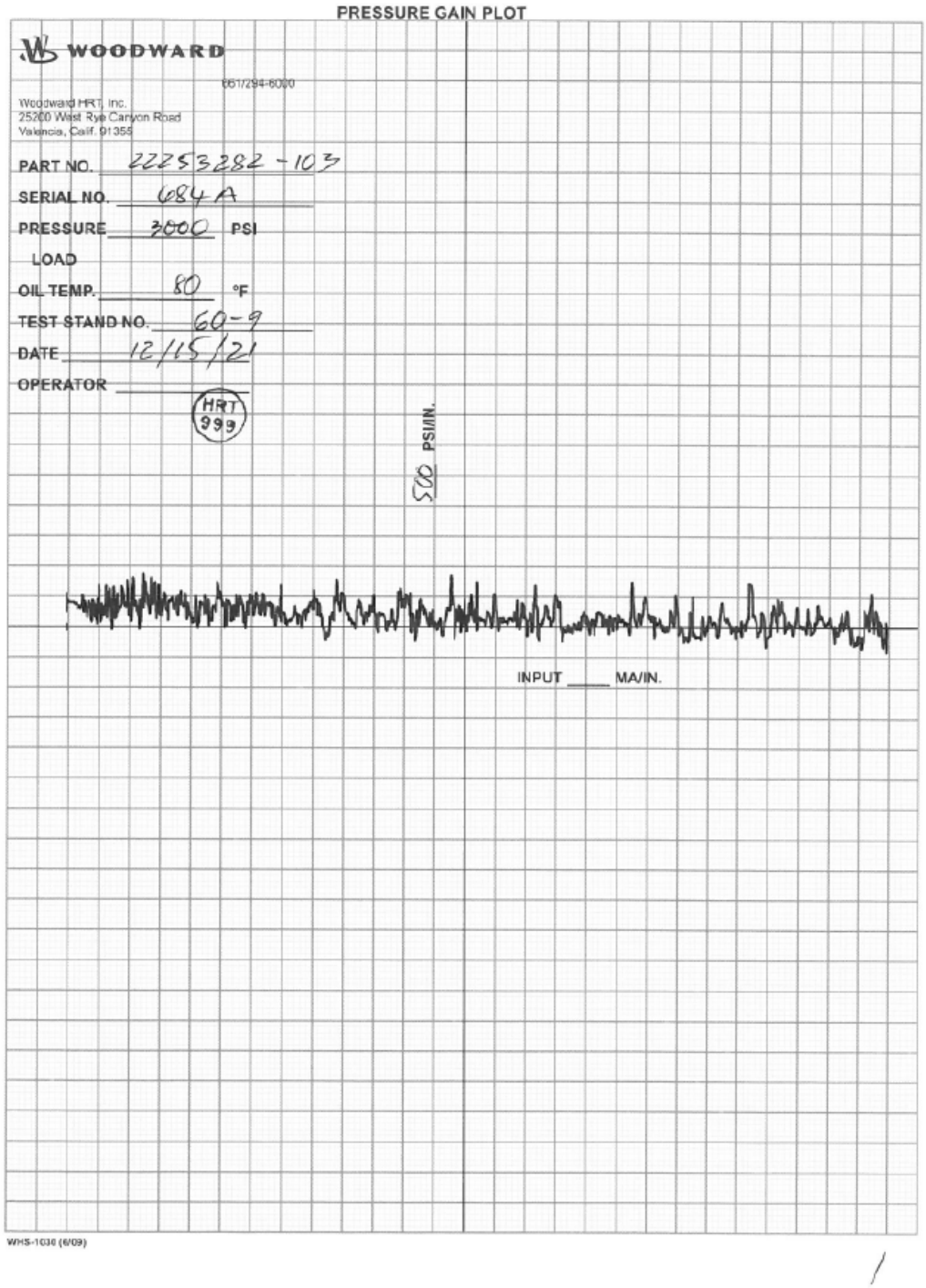

Figure 7: Noise Plot Before FOD Removal (Courtesy of Woodward HRT)

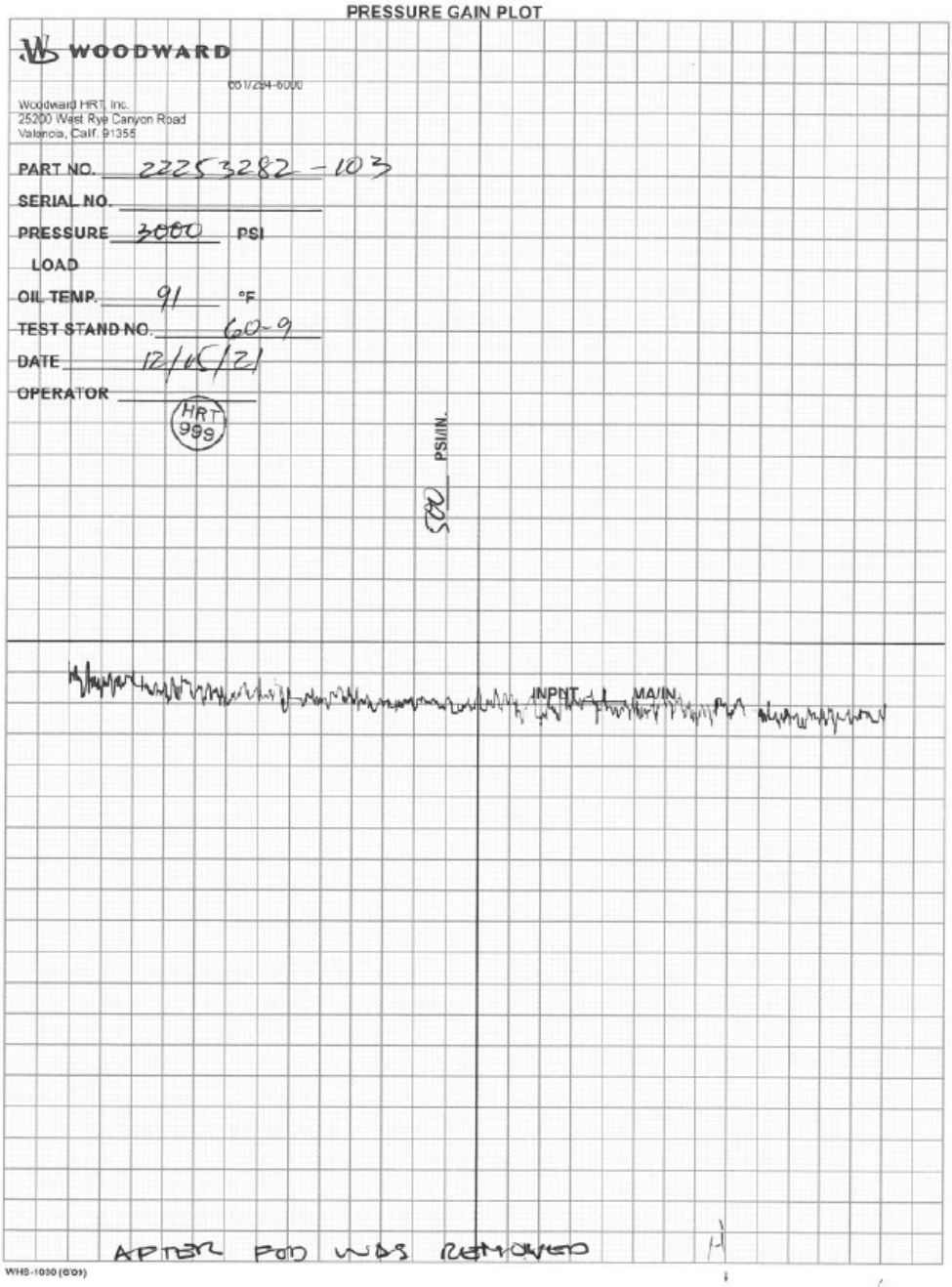

Figure 8: Noise Plot After FOD Removal (Courtesy of Woodward HRT)

Additionally, after the FOD was removed, the response of the unit to input pressure when no electrical current was applied was checked. 3000 psi pressure was applied with +8 mA input, the pressure and current was removed, and the pressure was re-applied. In this test the P1 measured 1200 psi and P2 was 1400 psi. Then pressure was applied with -8 mA input, the pressure and current was removed, and the pressure was re-applied. In this test P1 measured 200 psi and P2 was 2900 psi. As stated in Section G.2, electrical inputs to the nose wheel steering would normally be expected while the nose wheel steering is active.

Further disassembly of the unit revealed that the C1 and C2 filter seals (O-rings) were beginning to split on both the inner and outer diameters in the circumferential direction (see Figure 9). Examination of the seals under 40X magnification revealed that that while gaps in the seal material were observed due to the splitting, no material loss of the seal was identified.

Figure 9: Example of Circumferential Splitting on Inner and Outer Diameter of the C1 Seal

Due to the unavailability of required tooling, the critical dimensions for the filter bore and the filter orifice plugs as specified in Woodward HRT document DV1719 were measured at a later date under the witness of the FAA. All measured dimensions except for the "A" filter orifice plug inboard land diameter were found to be within the document requirements. The "A" filter orifice plug inboard land diameter measured 0.2078 inch, while the requirement was 0.2088-0.2093 inch. An undersized plug land will increase the gap between the land and the filter bore. Per the manufacturer, as this gap increases, so does the tendency of the corresponding orifice

filter seal to extrude. DV1719 is an inspection document authorized by Embraer Service Bulletin 145-32-0099 (current revision 03, dated April 8, 2005) to address premature deterioration of O-ring seals within the EHSV. The document requires the inspection of dimensions related to the filter bore diameter, the distance from the edge of the housing to the edge of the k-cut edge break, and the orifice plug land diameters. An "A" suffix is applied to the end of valve serial numbers that have been screened and meet the requirements of DV1719. The accident EHSV serial number was stamped with the "A" suffix.

Parker records show that this EHSV was installed on nose wheel steering manifold assembly S/N 0301B on 11/8/2006 and was not removed until this investigation.

G.4 Feedback Unit Potentiometer Assembly

Manufacturer: Liebherr
Part Number: 1170A3500-02
Serial Number: 01140
Date of Manufacture: 03.03

The feedback unit potentiometer assembly is a rotary potentiometer, assembled with a shaft, gear, and support ring in a two-part housing. The potentiometer is installed with a cap and electrical connector on the top part of the housing. Its function is to give an electrical signal relative to the angular position of the strut wheel axle.

The feedback unit potentiometer assembly was examined at the Liebherr facility in Saline, MI on May 2, 2022. This examination was attended virtually by all participants. The unit was unpackaged and visually inspected with no major defects found. The unit was subjected to the testing procedures as described in the Component Maintenance Manual 32-21-12, Rev 4, dated May 28/13. The unit passed all tests. A graph of voltage output was created as the gear was turned over its full operational spectrum. The graph was linear with no voltage spikes noted.

Liebherr provided the following service history for the feedback unit potentiometer assembly.

Date	Reason For Return	Repair Result
12/7/2010	Pulls to the right	Unit repaired and tested IAW CMM 32-21-12 R2 Mar 01/06
9/21/2012	Grinding noise intermittent	Repaired unit per CMM 32-21-12 R3 10-4-12
8/21/2018	Abnormally excessive constant nosewheel vibration when nose wheel is positioned just right of center	Inspected, repaired, and tested I/A/W CMM # 32-21-12 Rev #4, 05/28/2013. Modified from PN: 1170A3500-01 to PN: 1170A3500-02 per SB 145-32-0110 Rev #2, 04/30/2008. ECRS-00-001 has been completed.

G.5 Rudder Pedal Potentiometer Assembly

Manufacturer: Betatronix
Part Number: 13BF7184
Serial Number: 1500
Date of Manufacture: 98-08

The rudder pedal potentiometer is installed on the pilot's pedal mechanism. It sends electrical signals to the SECM that are proportional to the rudder pedal movement.

The examination of the rudder pedal potentiometer was conducted by Betatronix at their facility in Ronkonkoma, NY on May 11, 2022. This examination was attended virtually by all participants. The unit was constructed in the Hauppauge, NY facility in 1998.

This assembly consisted of a few structural brackets, a gear connected to the potentiometer shaft, and wires that were attached to the potentiometer leads on one end and a cannon plug on the other end. A visual inspection of the assembly did not reveal any anomalies.

The potentiometer was removed from the rest of the rudder potentiometer assembly. The unit was then tested in accordance with the Acceptance Test Procedures ATP-1000/7184, Rev B, dated 3/16/11. Test 1.1 labeled "Dimensions per outline drawing" was not completed. The unit passed all performed tests per the acceptance test procedure with no anomalies noted.

Following the examination, the potting around the potentiometer was removed so that the serial number and date code of the potentiometer could be identified.

Betatronix had no records of repair for this unit and stated that the potentiometer is not a repairable component.

G.6 Brake Control Unit (BCU)

Manufacturer: Crane
Part Number: 42-951-6
Serial Number: 550
Date of Manufacture: 06-00

The BCU contains the circuitry to control, monitor, and test the brake system's components. The BCU receives signals from the pedal position transducers, wheel speed transducers, and brake pressure transducers and commands the brake control valves to modulate required pressure to the wheel brakes. The unit contains fault history in non-volatile memory.

The examination of the BCU was conducted at the Crane facility in Burbank, California on July 11, 2022. The NTSB participated in this examination virtually. A visual external inspection was performed and the unit appeared in good condition. All connector pins appeared straight and clean.

The BCU was connected to test set "Hydro-Aire 299-047" and the unit was powered on. The eeprom memory download option was selected from the test bench computer and all data within both channels (outboard and inboard) were downloaded. The data contained one page for the outboard channel and one page for the inboard channel. A page is created when a fault or failure occurs. The page will contain the fault or failure identification as well as associated system status information. There is no date or time stamp associated with pages or faults/failures.

The one recorded outboard channel page and the one recorded inboard channel page contained the same "Test Setup Error", "Right Velocity Transducer", "DC test(bias) Failure", and "Right Wheelspeed Transducer Fault" messages. Both occurred when the left and right wheel speed velocity was 0, the gear up switch was "up", the hydraulic status switch was "off", the gear handle switch was "down", and the left and right squat switches were "air". According to Crane, the "Test Setup Error" message suggests these pages were recorded during maintenance because it is only reported during the operator-initiated test, and not the continuous wheelspeed transducer test. In addition, Crane reported that had a right wheelspeed transducer failure occurred when the gear was put to the down position during flight, it would have resulted in a BRAKE DEGRADED message being displayed on EICAS.

A functional test was performed in accordance with Component Maintenance Manual 32-43-50 Rev 6, dated November 19, 2010. The source procedure was TP42-951-6 dated March 14, 2008. The unit passed all portions of the test.

Crane provided the following repair history for the BCU:

DATE	CUSTOMER_PROBLEM	TROUBLESHOOTING_TEXT
12/15/2000	Brakes are grabbing/loaner unit	
5/24/2005	Repair-Inbound INOP message.	No fault found, pass verification test per TP42-951-3, also manual software FD299-04710-08.00
5/18/2007	Modification MOD to -5 SB: 42-951-1-32-3	Failed verification test, LVDT 3 RS232 10% inbd sn 998. After mod sn 998, no fault found. Mod both cards, sn 998 and 1000 per routing sheet PN 42-951-5. No valley circuit cards. Sn 998 and 1000 had VR41, VR42, and Q5 leads no clinch. Also replaced, K1 and K2 Relays and recal +5 and +18 volts per CP 42-951145.
2/16/2009	Return reason: POS only spoiler fail message.	Inboard card failed LVDT test.
4/14/2011	Intermittent braking on roll out	Passed test AS 42-951-5. Modified to 42-951-6. Reprogramed U9 on both cards.

4/13/2018	A23 - Removal Reason: BRAKE DEGRADED msg on EICAS. Maintenance Provider Notice: Routine repair – perform maintenance in accordance with current OEM and applicable specifications.	Pretest functional per TP-42-951-6: OK Opened for visual inspection. No discrepancies were found. Retest unit after visual inspection: test passed. Cleaned up dirty unit and touch up paint on scratched housing. Final functional test per TP-42-951-6 : all test passed.

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