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

September 30, 2015

Systems Group Chairman's Factual Report of Investigation

DCA15MA029

A. ACCIDENT

Operator: Sage Aviation LLC
Aircraft: EMB500, N100EQ
Location: Gaithersburg, MD
Date: 12/8/2014
Time: 10:41 AM

B. SYSTEMS GROUP

Chairman Steven Magladry
National Transportation Safety Board
Washington, DC

Member Daniel Marimoto
Embraer
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C. SUMMARY

On December 8, 2014, about 1041 Eastern Standard Time (EST), an Embraer EMB-500 Phenom 100, N100EQ, impacted terrain and three houses about 0.75 miles short of runway 14 while on approach to Montgomery County Airpark (GAI), Gaithersburg, Maryland. The pilot and two passengers were fatally injured and three occupants in one house were also fatally injured. The 14 CFR Part 91 flight originated from Horace Williams Airport, Chapel Hill, North Carolina, and was operating on an instrument flight rules (IFR) flight plan.

The NTSB Systems Group Chairman arrived on the accident scene 12/8. The systems group convened 12/9 and completed the on-scene activities 12/10. Some members of the systems group performed an examination of the trim actuators at the salvage facility on August 11, 2015. The following is a summary of the systems group findings.

D. DETAILS OF THE INVESTIGATION

1. Stall Warning and Protection System Description

The SWPS (Stall Warning and Protection System) performs two main functions. The first one is to provide situational awareness in an impending aircraft stall condition, and the second one is to prevent the aircraft from entering a potentially hazardous stall condition. The first main function is achieved by means of two features:

- An aural warning, designed to be unambiguous, to inform the crew that the aircraft is approaching the stall condition;
- A visual indication on the airspeed tape in both Primary Flight Displays (PFD) intended to provide the crew with low-speed awareness.

The second main function is achieved by means of stick pusher activation, in which a Stick Pusher Actuator (SPA) causes the aircraft to pitch down, away from a stall condition.

The primary components of the SWPS are the angle of attack (AOA) sensors, the dual channel stall warning and protection computer (SWPC), and the SPA.

The AOA sensors, mounted on each side of the forward fuselage, consist of two swept vanes that measure the direction of local airflow. The vane is connected to two independent resolvers, generating electrical outputs to the SWPC.

The SWPC performs the processing and monitoring to provide the related indications, failure annunciation, and activation of the SPA. Each channel of the SWPC receives information from the independent resolvers (two for each AOA sensor) about its respective AOA and sends the average of the resolvers signals and subsystem validity to the opposite channel in order to compute the compensated AOA (average). This is designed to compensate for the sideslip influence in the AOA measurement.

The pitching-down function is provided by means of the SPA. The SPA is a rotary electromechanical actuator connected to the elevator control system by means of a steel cable. When activated, the actuator moves the control column forward in order to deflect the elevator to 9.0 ± 1.0 degree, trailing edge down. However, the crew has authority to move the control column forward beyond such limit. The SPA activation commands the control wheel pitch downward with around 150 lbf. The intent of the high force is so the pilot does not mistake the SPA activation from any other input, such as aerodynamic forces..

With the flaps positioned at Full, and with no wing and stabilizer de-ice activated, the aural stall warning is designed to occur at greater than or equal to 21 degrees AOA. The stick pusher is designed to activate at greater than or equal to 28.4 degrees.

Accident Airplane Information

The accident airplane stick pusher actuator P/N 260926250-0101, and both angle of attack sensors P/N 100117-4, S/N 142875-08, S/N 168 were recovered and retained by the NTSB. The SWPC was not recovered on scene due to fire damage in the area. The SWPC P/N C-100106-2, S/N 239 was later recovered from the wreckage during the August 11, 2015 visit to the salvage facility.

2. Flaps

The airplane has one flap (Figure 1) on each wing and they are operated by the Flap Selector Lever (FSL) in the flight compartment. The FSL position is sent electrically to the Flap System Control Unit (FSCU). The FSCU sends an electrical signal to Flap Linear Actuator (FLA) which moves the flap surface. A Flap Position Sensor Unit (FPSU) on each flap provides position information to the FSCU. The FLA is an end-to-end dual load path fail safe actuator with a no-back brake to provide irreversibility. Actuation is accomplished by a 28 V DC brushless motor, a spur gear train, and a ball screw assembly.

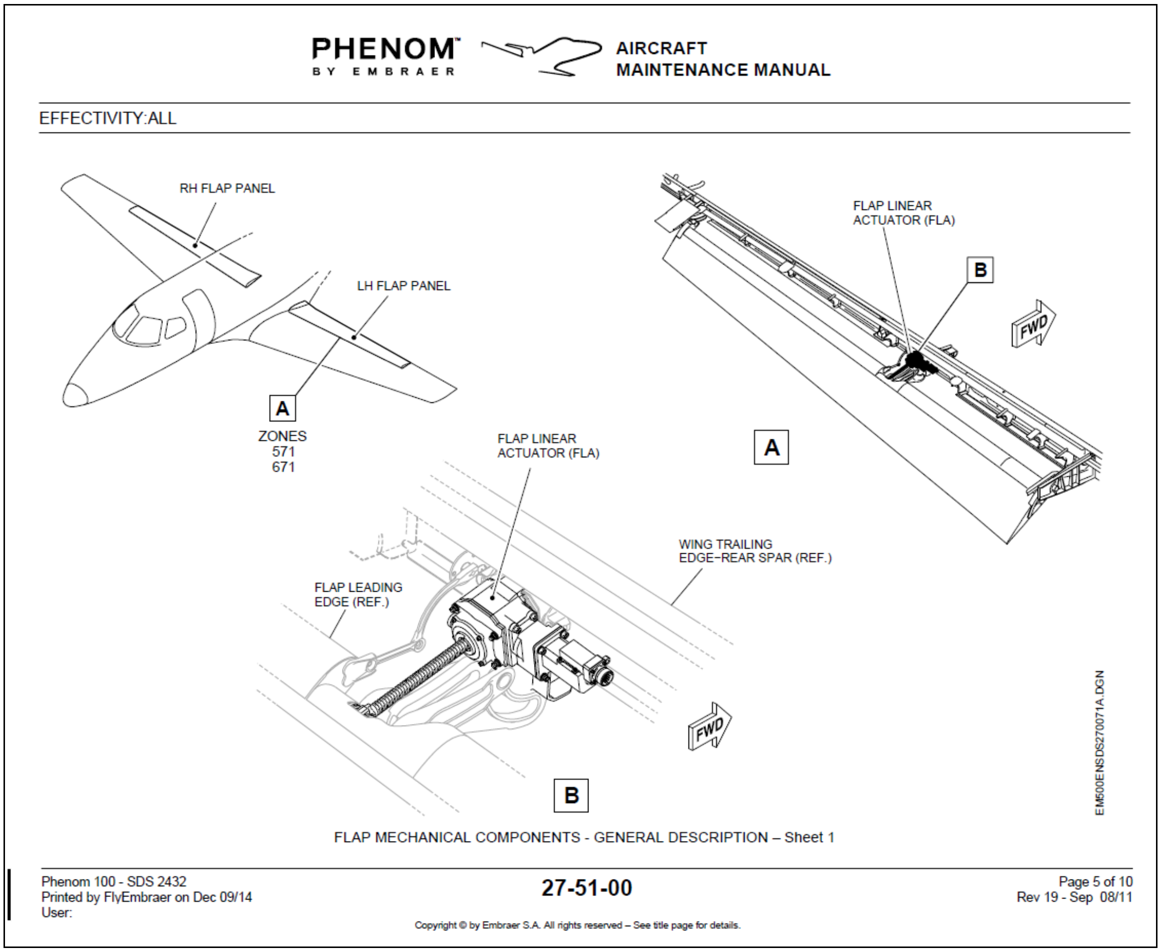

Figure 1 Flap System Components

Flap Operation Details

A dual discrete sequence of signals from the FSL defines a valid command to move the flap panel as determined by each FSCU channel. The command is compared between the left and right channel control electronics within the FSCU. Upon agreement of the FSL signals, each FSCU channel provides an enable signal to the opposite channel and a command within its own channel to disengage the power off electric brakes and activate the brushless DC motor. The activation of the brushless motor will either extend or retract the FLA ball screw consistent with the command. The FLA ball screw is driven at a constant speed by the brushless DC motor through a gear train to the new flap position. A dual channel FPSU directly connected to each flap panel through a two bar linkage provides redundant position feedback to FSCU. The FPSU data in conjunction with the Hall Effect sensor signals from the FLA motor is used by the FSCU for closed loop positioning of the flap panels. Once the flap panel selected position is achieved, the FSCU removes the motor drive command and reengages the FLA electric brake. The Flap Actuation System (FAS) operation is designed for fail safe operation. In the event of a failure, the FAS shuts down in a safe condition. Monitors within the FSCU perform health and status checks of the entire system and the individual components. Any detected fault condition will result in halting the system motion. The FLA electric brakes are engaged and motor drive is inhibited until the applicable reset condition is applied. The flap system performs a power up bit (built in test) and a continuous bit for monitoring and fault detection. Critical system faults such as asymmetry and uncommanded motion result in system lock out and are only resettable when FSCU control power is recycled and aircraft is on ground. If a failure occurs in one of the flap channels or an unsafe condition is detected by the FAS, the flap panel operation is halted and the EICAS (Engine Indication Crew Alert System) message "FLAP FAIL" is displayed. The FSL position versus flap degrees and maximum speed for each flap position is provided in Figure 2.

FSL DETENT	FLAP POSITION (Degrees)	PLACARD SPEED (kt)
0	0	None
1	10	200
2	26	160
3	26	160
FULL	36	145

Figure 2 Flap Positions

Accident Airplane Information

The flap handle was identified in the wreckage and found in the flap 0 position, however the area had extensive impact damage. The right flap was intact and still connected at its attach points. The flap actuator extension was 7.5 inches from bolt center to actuator housing. Embraer indicated that this extension corresponded to Full flaps extension. The left wing had substantial impact and fire damage. The left flap actuator was not identified in the wreckage. The FDR recorded the FSL and both FPSU positions.

3. Flight Controls

Control of the ailerons and elevators is through motion of the control yoke, and the rudder is through conventional pedals. These move a series of torque tubes, cable quadrants, cables, bell cranks, and push rods to mechanically actuate the surfaces.

a. Pitch Control Overview (Figures 3 and 4)

During normal operation, the pilot or the copilot commands the control yoke forward or rearward to move the elevators and achieve the desired pitch response of the aircraft. The control yoke travel is limited by the primary and secondary stops. The primary stops are on the tail and limit elevator surface deflection, the secondary stops are on the support for the forward torque tube and limit the yoke travel:

- When the yoke is pushed forward to the primary stop (73.4 ± 4 mm from neutral), the elevator surfaces moves 19 degrees ± 1 trailing edge down.
- When the yoke is pulled aft to the primary stop (104.7 ± 4 mm from neutral), the elevator surfaces moves 27 degrees ± 1 trailing edge up

The secondary stops are placed at 84.0 ± 4 mm forward, and 112.7 ± 4 mm aft.

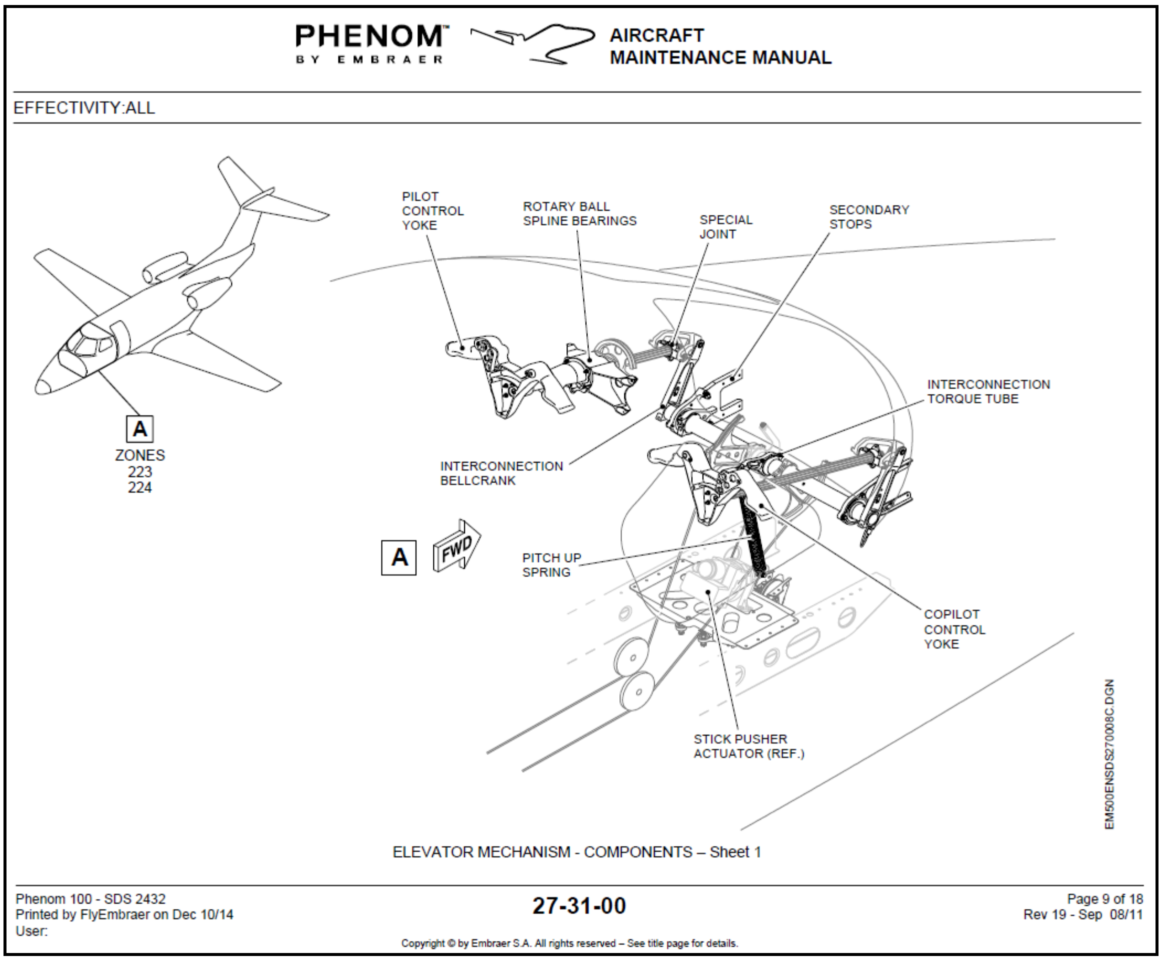

Figure 3 Pitch Flight Control

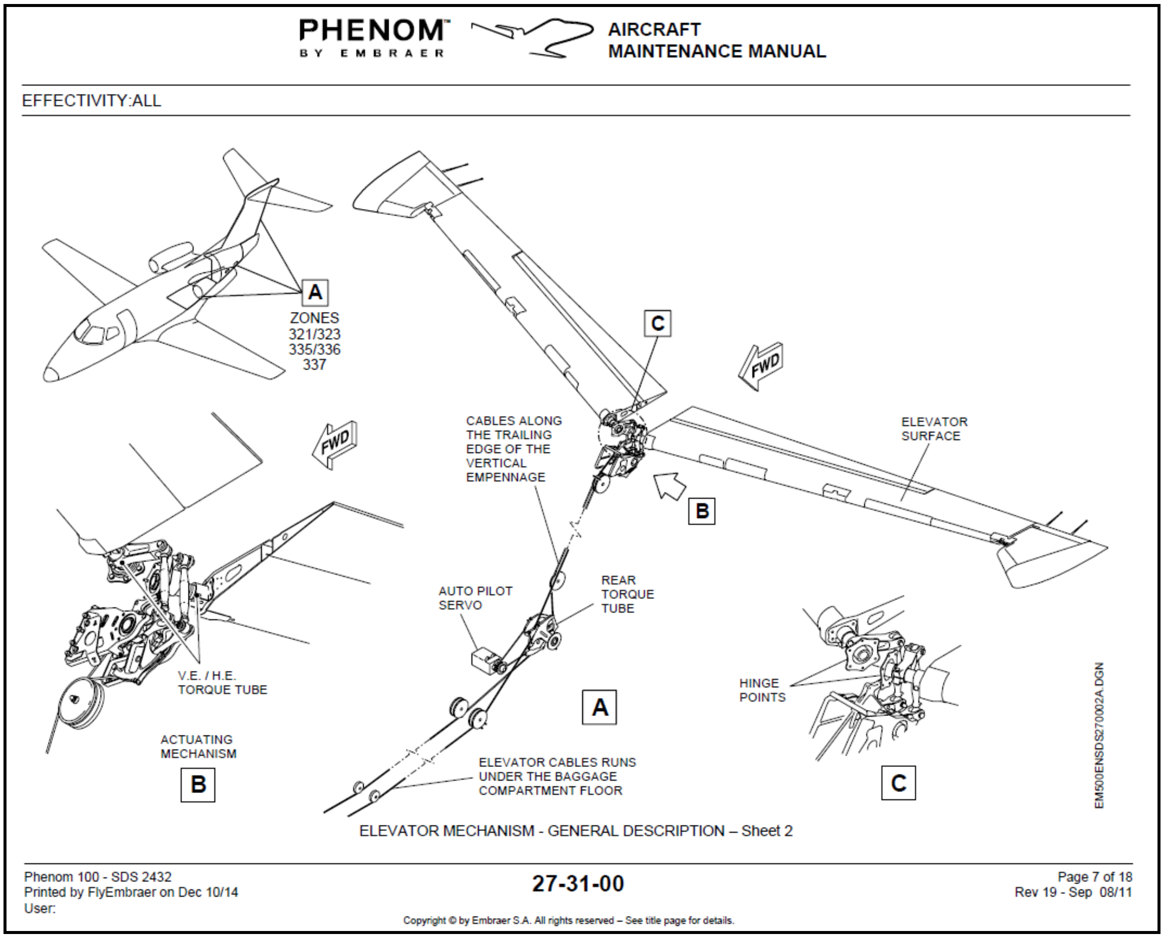

Figure 4 Pitch Flight Controls

Accident Airplane Pitch Control

The accident airplane cockpit had extensive impact damage and no pitch control linkage was documented. The vertical and horizontal stabilizer separated from the fuselage and no cable continuity could be determined. The yoke and elevator positions were not recorded on the FDR.

b. Roll Control Overview (Figure 5)

During normal operation, the pilot or copilot rotates the control wheel left or right to achieve the desired roll response of the aircraft.

- When the control wheel is commanded to full left (51 degrees), the left aileron surface moves up (25 degrees) and the right aileron surface moves down (15 degrees).
- When the control wheel is commanded to full right (51 degrees), the left aileron surface moves down (15 degrees) and the right aileron surface moves up (25 degrees).

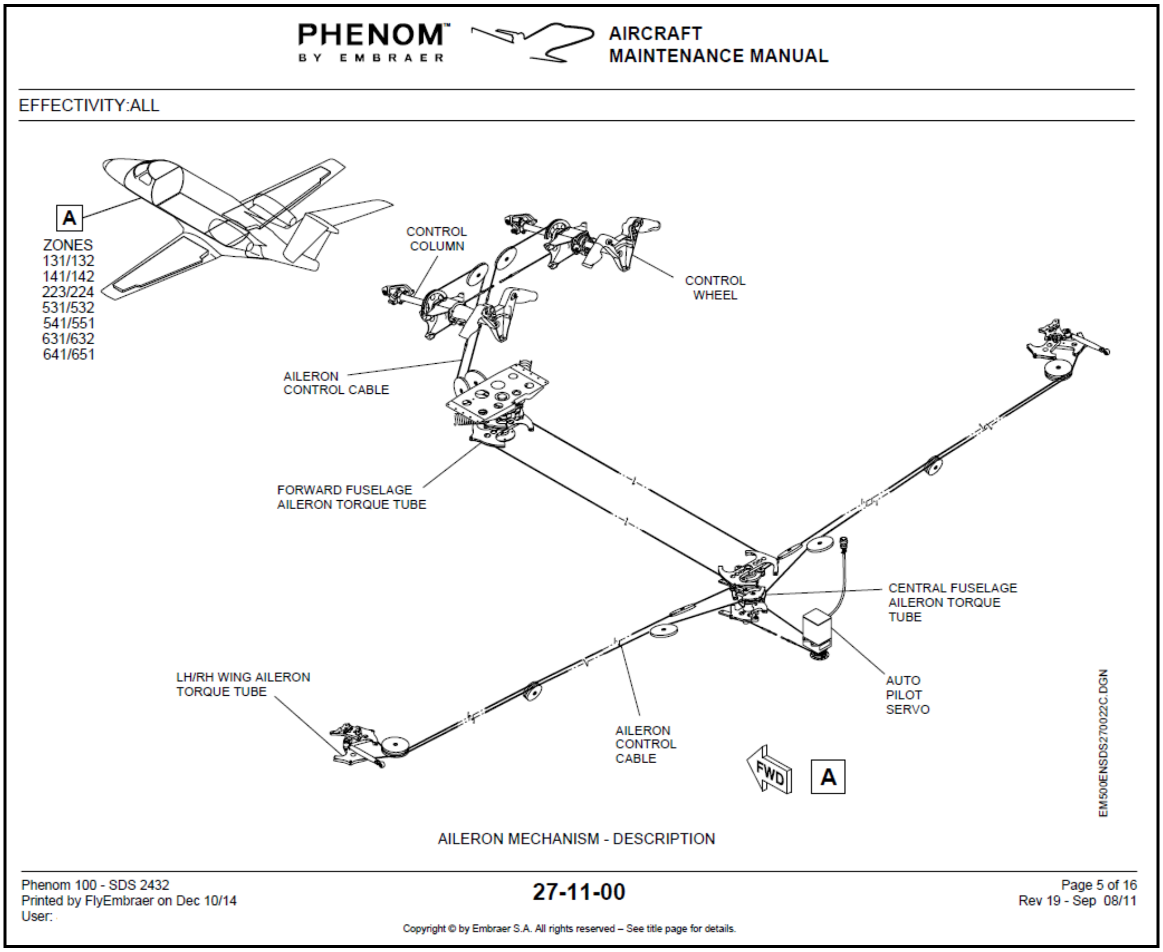

Figure 5 Roll Flight Controls

Accident airplane information

The accident airplane cockpit had extensive impact damaged and no roll control linkage was documented. The accident airplane's wings separated from the fuselage, so cable continuity could not be determined. The yoke and aileron positions were not recorded on the FDR.

c. Yaw Control Overview (Figure 6)

During normal operation, the pilot or copilot commands the rudder pedals forward and rearward to achieve the desired aircraft yaw response.

- When the left pedal (pilot or copilot station) is commanded in full forward direction (16.6 degrees) and the right pedal is driven in full rearward direction (12.9 degrees), the rudder surface moves left (27 degrees).
- When the right pedal (pilot or copilot station) is commanded in full forward direction (16.6 degrees) and the left pedal is driven in full

rearward direction (12.9 degrees), the rudder surface moves right (27 degrees).

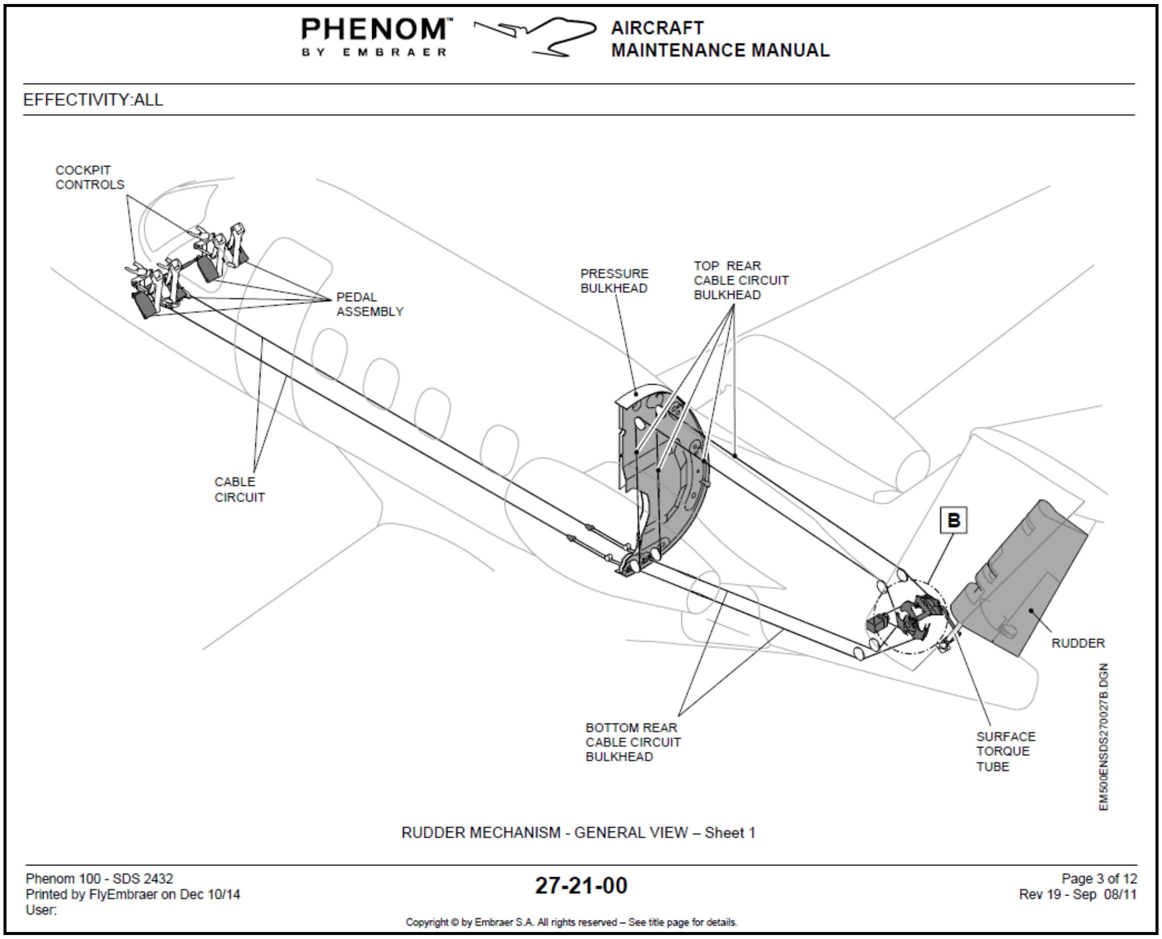

Figure 6 Yaw Flight Controls

Accident Airplane Information

The accident airplane cockpit had extensive impact damaged and no yaw control linkage was documented. The accident airplane's vertical stabilizer separated from the fuselage, so cable continuity could not be determined. The pedals and rudder positions were not recorded on the FDR.

4. Flight Control Manual Trim and Automatic Pitch Trim

a. Manual Trim

Manual trim is available for pitch, roll, and yaw through switches in the cockpit (Figure 7). For roll, yaw, and backup pitch trim, commands from the switches are sent to one of two trim actuator controllers (TAC). The TAC's are electrically connected to the applicable trim actuator near the trim tab. The trim actuator is connected to the trim tab through linkage.

Each trim actuator has a potentiometer to sense position. Each trim actuator is an irreversible dual-load path electromechanical actuator which converts the electrical power to mechanical linear motion. There is one trim actuator attached to the rudder tab, one for the left wing aileron tab, and one for each elevator tab, which are connected through pushrods to the small tab at the aft portion of each surface. The aileron trim actuator installation is shown in Figure 8, which is typical of the others.

The pitch trim system is based on two redundant operation modes, Normal and Backup. When operating in Normal Mode, manual trim is commanded by the pilot or copilot through the switches on control yoke. Switch signals are then processed by the avionics and sent to the TAC 1 which operates the actuator attached to the left elevator trim tab. The pitch trim system comprises a master and slave configuration so that when the LH (Left-Hand) actuator is operating it also back drives the actuator attached to the RH (Right-Hand) elevator trim tab through an interconnecting flex shaft.

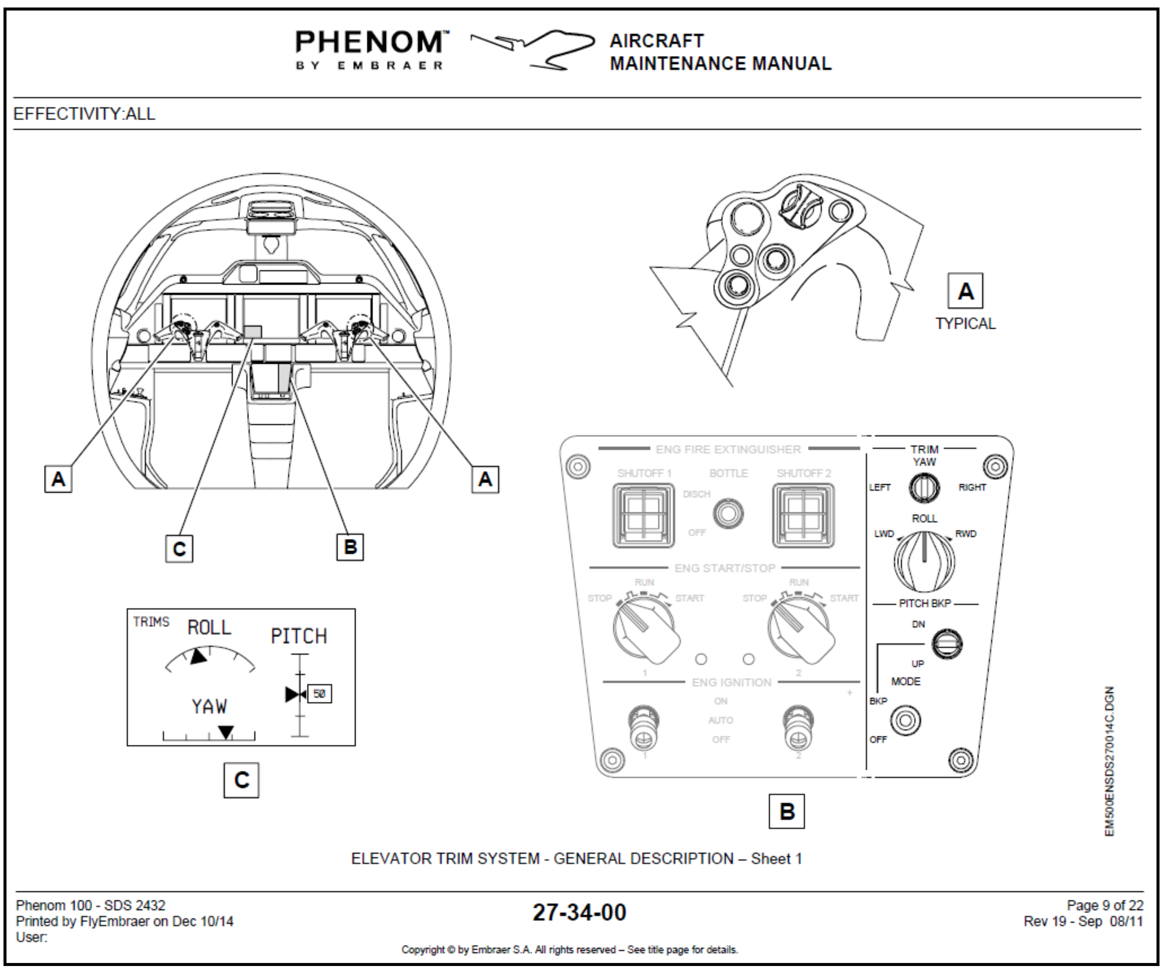

Figure 7 Trim Controls

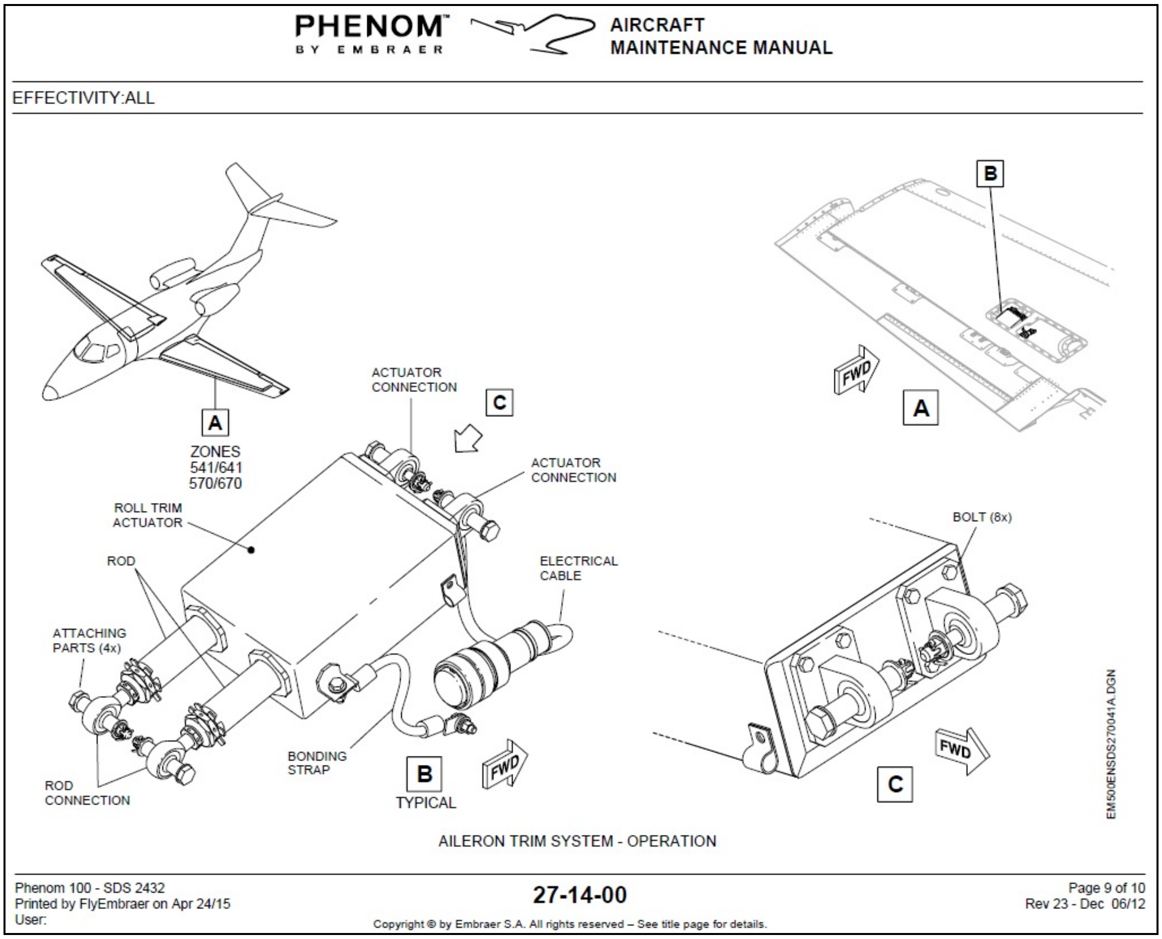

Figure 8 Aileron Trim Actuator Installation

b. Automatic Pitch Trim

The pitch axis is the only one that has an automatic trim function, which is active when the autopilot is engaged and is transparent to the crew.

The automatic pitch trim commands are processed in the Garmin Integrated Avionics Units (GIA) and respond to the primary autopilot pitch servo torque effort and flap motion.

The GIAs receive the primary pitch servo effort (torque) as produced by the primary pitch servo. When the automatic pitch trim is engaged, the pitch trim function outputs up or down commands from GIA 1 to the primary pitch trim system in order to reduce the average pitch servo effort.

Accident Airplane Information

The positions of the accident airplane aileron trim, rudder trim and elevator trim actuators were recorded on the FDR.

The trim actuator positions were measured by systems group members on August 11, 2015 at the salvage yard in Clayton, Delaware. Each was measured from the actuator body housing to the approximate center of the rod end fitting. The left wing aileron trim actuator extension was measured to be 3.19 inches. The rudder trim actuator extension was measured to be 2.59 inches. The left elevator trim actuator was measured to be 6.31 inches and the right was 6.26 inches.

Using manufacturing data, these dimensions where converted to the values which would be recorded on the FDR in volts[1].

- For the aileron trim, the aileron trim actuator position converted to volts was 4.81 V (FDR values: Neutral = 4.87V, full retract=2.41 V, Full Extend=7.57 V).
- For the rudder trim, the rudder trim actuator position converted to volts was 5.26 V (FDR values: Neutral = 5.17V, full retract=2.07 V, Full Extend=8.21 V).
- For the pitch trim, the pitch trim actuator positions converted to volts for the left actuator was 5.8V and the right value was 5.6V (FDR values: Neutral = 6.55V, full retract=2.27V, Full Extend=8.59V)

5. Autopilot

The autopilot function is performed by two Garmin Integrated Avionics Units, with inputs from a Guidance Panel, Air Data Computers, Attitude and Heading Reference System, and other discrete inputs. The GIA's send signals to autopilot servo actuators which are connected to the applicable mechanical flight control system through cables.

Monitors are implemented in the GIAs and in the servos which are designed to guarantee integrity of the software package, hardware, and systems, as well as the configuration of the systems. The monitors are classified as power-up, preflight, and continuous tests. The parameters are processed in both GIAs for autopilot (AP) system status annunciations, alerts, and engagement and disengagement logic processing. The AP is designed to disengage if a stall warning signal is receive from the SWPC.

The FDR recorded the last AP vertical navigation mode as Glidepath. The Glidepath mode is used to track the WAAS (Wide Area Augmentation System) based glidepath. When the Glidepath mode is armed, "GP" is annunciated in white in the AFCS status box. Upon reaching the glidepath, the AP transitions to the

[1] The FDR parameters for trim position are in volts. Here the measured actuator extension was converted to a value in volts that would be recorded on the FDR, according to system design.

Glidepath mode and begins to capture and track the glidepath. The AP will follow a vertical profile guidance based on specified altitudes (entered manually or loaded from the database) at waypoints in the active flight plan or direct-to (with vertical constraint).

Accident Airplane Information

Both GIA's were recovered from the wreckage. The units were examined by the NTSB lab. A report of the findings is available in the public docket.

6. Wing and Horizontal Stabilizer De-Ice Systems

The airplane was equipped with wing and horizontal stabilizer de-ice systems, in the form of de-icer boots, which cycle (inflate/deflate) in order to mechanically remove the formation of ice from the leading edges. Bleed air is routed from both engines through check valves, pressure regulated/relief valves, and water separators to provide conditioned air to the system. A low pressure switch monitors system supply pressure. A Controller activates Ejector Flow Control Valves to send air to the boots, and monitors system performance. The de-ice system is activated and de-activated in the flight compartment by the WINGSTAB switch on the Ice Protection Control Panel, Figure 9.

An ice detection system was installed on this model up to manufacture serial number 10. This airplane was serial number 82, so there was no ice detection system installed on this airplane

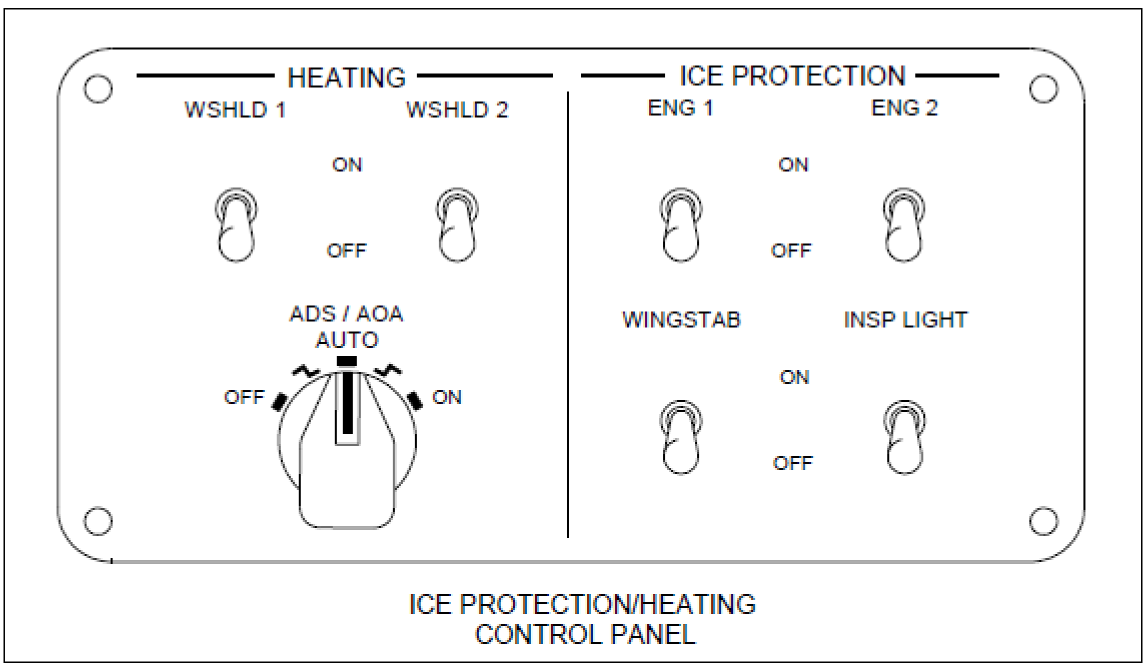

Figure 9 Ice Protection/Heating Control Panel

a. De-Ice Component Details

De-Icer Check Valves

The de-icer check valve is a spring-loaded flapper valve that, with its metal sealing surfaces, is designed to withstand high bleed air temperatures while providing a positive seal against engine bleed air back flow with minimum leakage. The valve is also designed for minimum pressure drop and flow resistance in the forward flow condition. Check valves are used on dual-engine aircraft in which pressurized bleed air from both engines is supplied to a pneumatic deicing system through a common manifold. The check valves provide positive seal against engine bleed air backflow in the event of loss of bleed air from one engine. This is designed to ensure that the pressure to the deicing system is maintained in the event bleed air is only available from one engine.

Pressure Regulator/Reliever

The pressure regulator/reliever is designed to receive inlet air pressure from an engine bleed air source and to provide a constant outlet pressure for de-icer inflation, over a wide range of flow rates and inlet pressures. Outlet pressure regulation is accomplished by means of a variable orifice which opens and closes to modulate the flow area. The orifice is formed by a poppet which moves relative to a fixed seat located in the regulator housing. The poppet is attached to a spring-loaded diaphragm which senses outlet pressure and closes the poppet in the event of high outlet pressure, and opens the poppet in the event of low outlet pressure. The regulator is equipped with an over-pressure relief valve, or reliever, which serves as a fail-safe device for venting excess pressure overboard in the event the regulating poppet fails in the open position. The reliever consists of a self-resetting spring-loaded ball, which opens at a preset pressure. The reliever is installed to one of the two outlet ports of the regulator housing.

Pressure regulator/reliever designed set points:
- Inlet pressure range: 22 to 320 psig
- Regulated outlet pressure: 20.0 ± 1.0 psig

Low Pressure Switch

The switch is located upstream of the EFCV (Ejector Flow-Control Valve)s and is used to monitor the system pressure and is designed to ensure a minimum pressure is being supplied to the FCVs.
Low pressure switch designed set points:
- Switch actuation pressure: 17.0 psig (maximum) ≥ 70 °F (21°C) 17.5 psig (maximum) < 70 °F (21 °C)
- Switch deactivation pressure: 15.0 ± 0.5 psig

Controller

The controller provides the command signals to the EFCVs. The controller operates in a 1 minute mode using the control switch. A single cycle mode can be initiated by momentarily toggling the control switch from the OFF position to the ON position and then back to OFF. This provides the pilot with immediate operation of the boot deicing system. Power input to the controller consists of 28 V DC. The controller will communicate status and fault messages to the Data Concentrator Unit via ARINC 429. The fault messages will indicate a pressure fault or a stepping fault. A timed pressure fault is one or a combination of the following:

- Failure of a pressure switch to close within 4 seconds of activation of its associated ejector flow control valve, indicating failure of the de-icer to inflate to operating pressure in proper time.
- Failure of a pressure switch to reopen within 4 seconds of deactivation of its associated ejector flow control valve, indicating failure of the de-icer boot to deflate in the proper time.
- A de-ice pressure switch is not open when the controller is not cycling.
- The low pressure switch is not open within 4 seconds after a valve is actuated.

Ejector Flow Control Valve (EFCV)

The aircraft has three EFCVs. There are two EFCVs for the wing deicing system and one for the horizontal stabilizer deicing system (AMM SDS 30-15-00/1). The EFCV controls the flow of air to and from the de-icer boots. It is a two-position, solenoid-operated poppet valve that provides system pressure (energized position) or vacuum to the pneumatic de-icers. When the solenoid valve is in the de-energized condition, the ejector section of the valve provides the vacuum necessary to maintain the deicing tubes in a deflated condition using a minimum amount of air flow. The vacuum generated is 5.0 psi at the inlet of 18 psig and 21 °C (70 °F).

De-Ice Pressure Switch

The aircraft has five de-ice pressure switches. They have the same part number, but one pressure switch is dedicated to the horizontal stabilizer deicing system (AMM SDS 30-15-00/1). The wing de-ice pressure switches are located at the inlets of both the inboard and outboard LH (Left-Hand) and RH (Right-Hand) chambers of the wing de-icer boots and downstream of the EFCVs. The pressure switches ensure a minimum pressure is being supplied to the deicers in a specific timing window. De-ice pressure switch designed set points:

- Switch actuation pressure: 15.0 ± 1.0 psig

- Switch deactivation pressure: 12.5 ± 1.5 psig

Wing Boot De-Icer

The wing de-icer boots are silver polyurethane-surfaced pneumatic deicers consisting of a smooth rubber and fabric blanket containing span wise deicing tubes. Each wing de-icer boot is a single boot with separate inflatable chambers, one for the inboard wing section and one for the outboard wing section. Each wing de-icer boot has an inboard and an outboard air connection for inflation. The LH and RH outboard chambers of the de-icer boot will inflate simultaneously. The LH and RH inboard de-icers will inflate simultaneously. The inflation pressure of the de-icer boot is 20.0 ± 1.0 psig.

Accident Airplane Information

The control panel was located in the wreckage. The panel was heavily damaged, and the switch position was not determined. None of the de-ice components were recovered from the wreckage. The FDR recorded numerous parameters related to this system.

Steven H. Magladry
Investigator
NTSB