

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



ERA23FA174

SYSTEMS

Group Chair's Factual Report

January 26, 2024

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A. ACCIDENT

Location: Gulf of Mexico
Date: March 30, 2023
Time: 1815 EDT
2215 UTC
Airplane: Cessna 525B, N869AC

B. SYSTEMS GROUP

Group Chair	Adam Huray NTSB Washington, DC
Group Member	Randy Ryhal FAA/FSDO Tampa, FL
Group Member	Haldan Gates Tamarack Aerospace Group Sandpoint, ID
Group Member	Ricardo Asensio Textron Aviation Wichita, KS

C. TAMARACK AEROSPACE ACTIVE TECHNOLOGY LOAD ALLEVIATION SYSTEM (ATLAS) FUNCTIONAL DESCRIPTION

The airplane was equipped with the Tamarack Aerospace Group Active Technology Load Alleviation System (ATLAS). The system modified the original airplane design by removing the original wing tip assemblies and adding wing extensions that included winglets and active aerodynamic surfaces known as TACSs (Tamarack Active Camber Surfaces) (see Figure 1). The system was designed to measure vertical accelerations on the airplane and automatically deploy each TACS to counteract the associated structural loads. The system operates independently of other airplane systems. This report section describes the general design and function of the system so that the reader is familiar with components and structure discussed in later sections of the report.

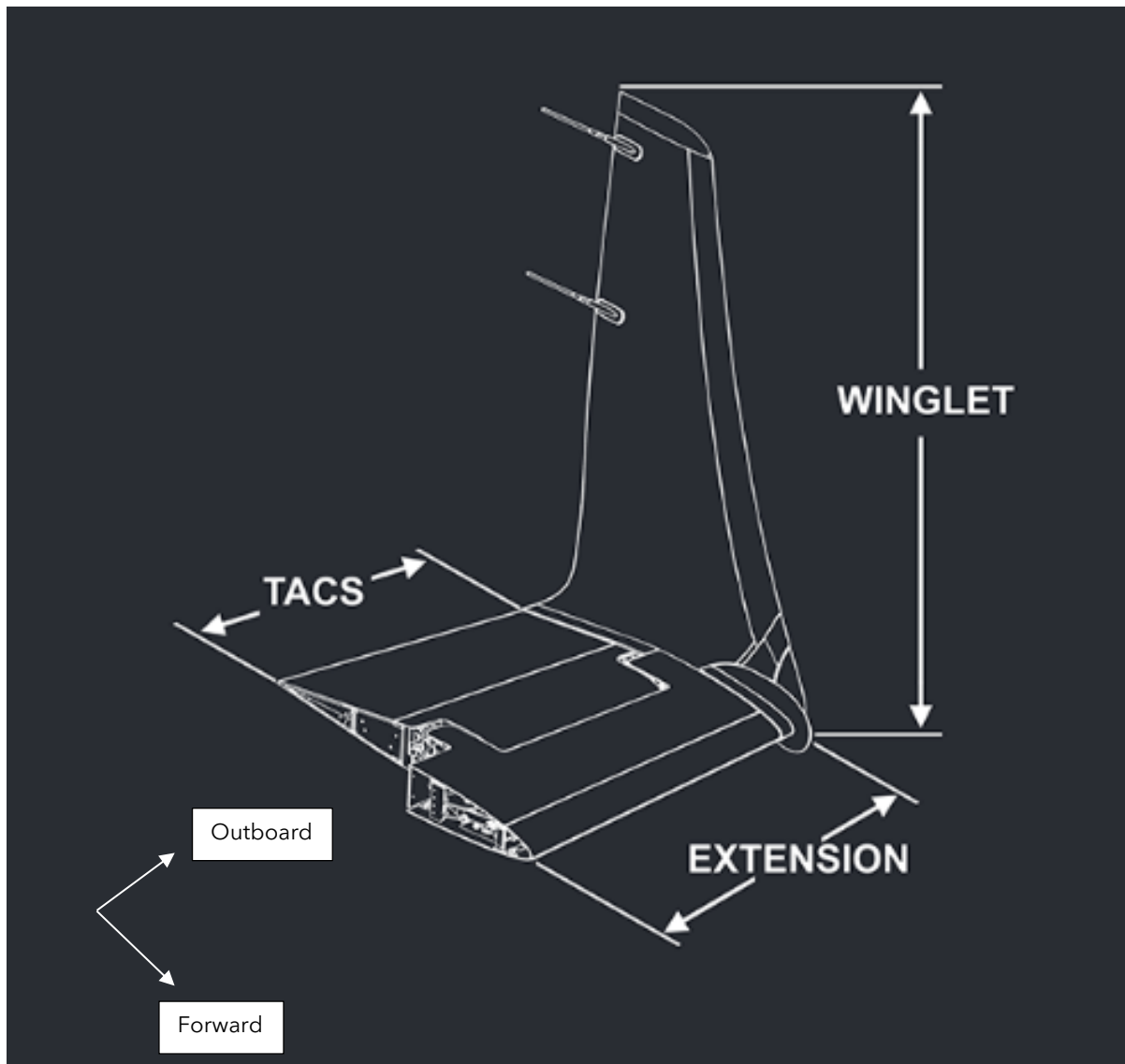


Figure 1. ATLAS wing extension, TACS, and winglet (left wing shown)(courtesy of Tamarack Aerospace Group).

The main components of the ATLAS system are the two wing extensions, two winglets, two TACS, two TACS Control Units (TCUs), an ATLAS Control Unit (ACU), an annunciator line replaceable unit (LRU), and an ATLAS INOP button located in the flight deck. See Figure 2 for ATLAS component locations.

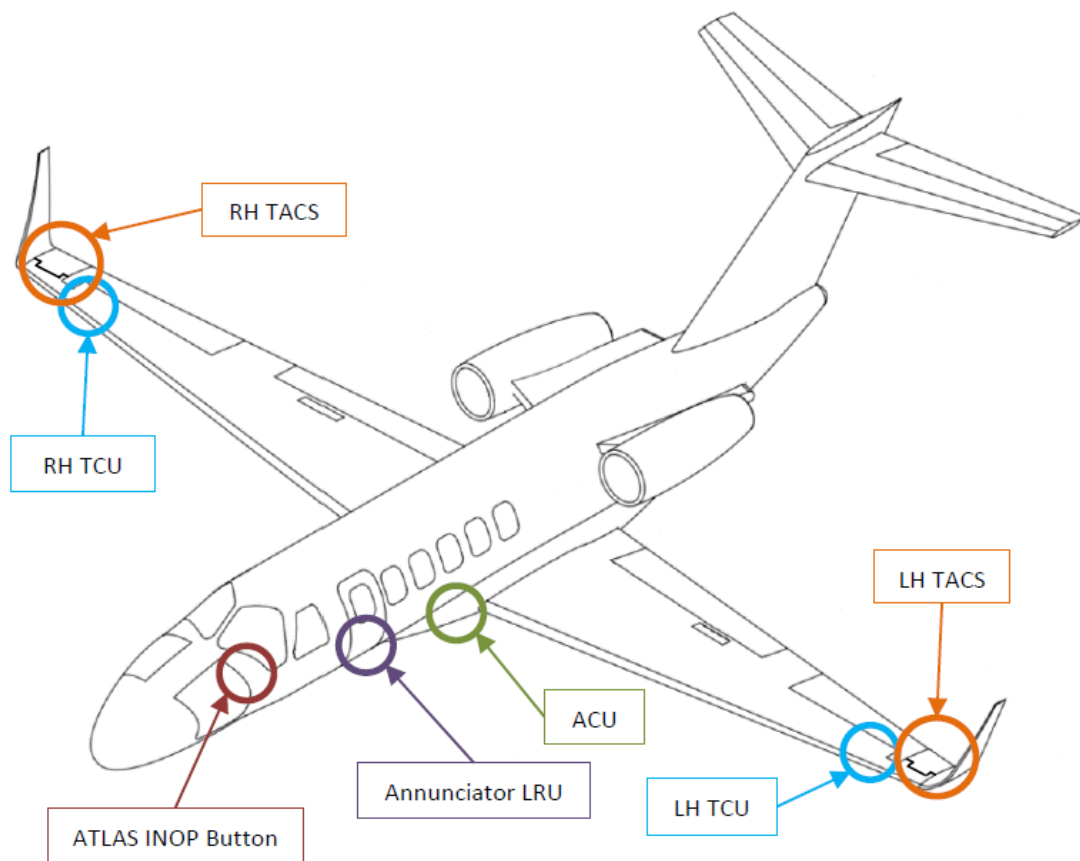


Figure 2. Approximate ATLAS component locations (courtesy of Tamarack Aerospace Group).

The annunciator LRU contains relays which will trigger the illumination of the ATLAS INOP button in the event of a system fault signal from the ACU or a loss of power from the ACU. The annunciator LRU was installed below the floor in the main cabin near the wing fuselage interface.

The ATLAS INOP button is a backlit button installed in the flight deck on the main instrument panel (see Figure 3.) The illumination of the ATLAS INOP button does not result in an aural annunciation. The button illuminates in the event of a fault condition and provides the flight crew with a primary means of resetting the system during a faulted condition. Per the Tamarack Airplane Flight Manual Supplement, Issue B, during the "Before Taxi Checklist" the crew should activate a built-in test feature by selecting the button three times in rapid succession. The built-in test exercises select portions of the system to identify latent failures in the system, including failures of the light-emitting diodes (LEDs) in the ATLAS INOP button. In addition, during powerup, the ATLAS system will perform a built-in test automatically,

without crew initiation.¹ A failure of the built-in test, or a self-detected failure during operation, will result in a latched illumination of the ATLAS INOP button unless it is a power fault. A power fault will result in the illumination of the ATLAS INOP button, but the button illumination will unlatch and the system will return to normal operation when power is restored.

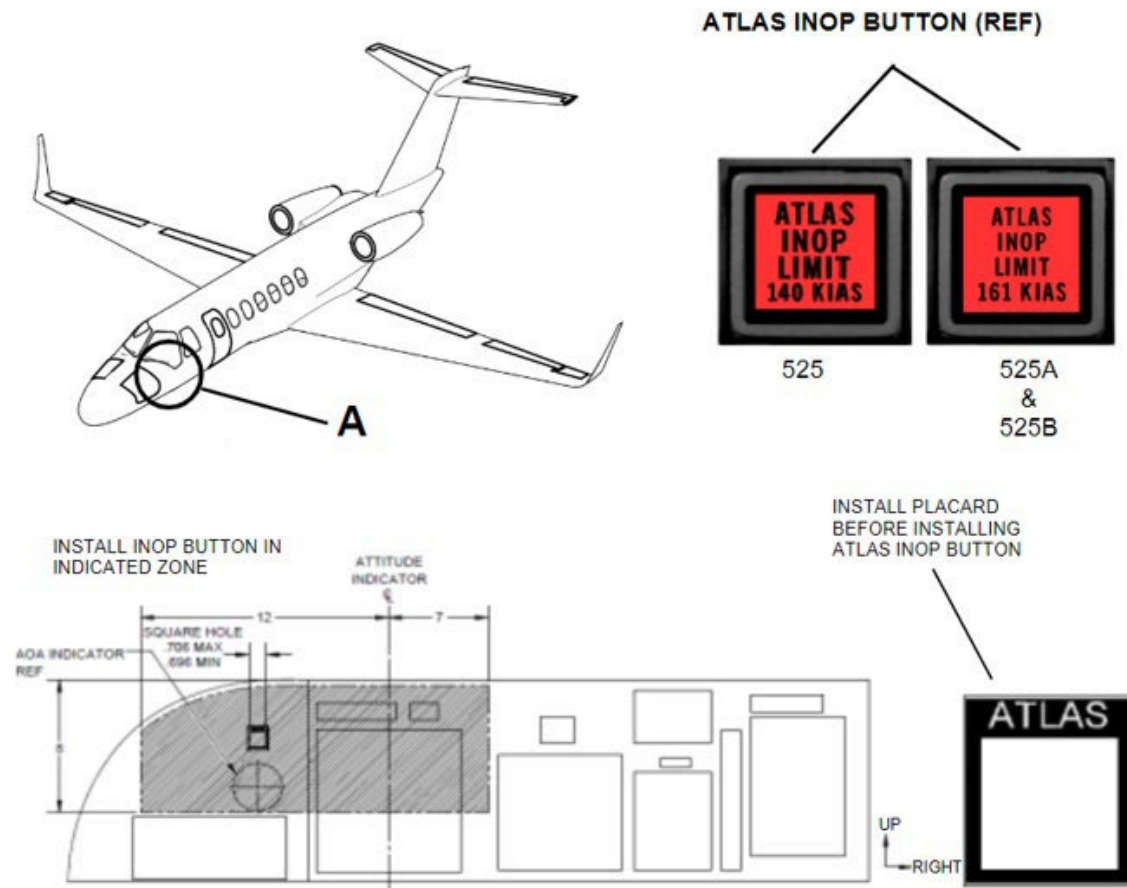


Figure 3. ATLAS INOP button installation description (courtesy of Tamarack Aerospace Group).

The ACU was mounted to the forward spar stiffeners close to the centerline of the airplane and the airplane's center of gravity. The ACU is an analog device and does not contain any software or non-volatile memory. The ACU contains two redundant accelerometers to measure acceleration along the vertical (Nz) axis. The ACU provides commands to the TCUs to actuate the TACSs symmetrically as required due to varying loading conditions and monitors system functions. The ACU monitors for various power faults, accelerometer differences, TCU reported faults, TCU oscillations, and TCU positions. Differences between the commanded and actual TCU positions and asymmetry between the left and right TCUs are included in the monitoring. In the event of a fault being detected the ACU will signal the TCU to

¹ Tamarack stated that the built-in test that occurs automatically during powerup is functionally identical to the crew-initiated test minus a sequence to test the LEDs in the ATLAS INOP Button.

depower the motor. When power is not applied to the TCUs, the units are free to move with an applied force of 10 lbs or less, allowing aerodynamic forces acting on the TACS to move the TACS to the neutral position.

Each wing has a TCU installed in existing airplane structure. A TCU contains a linear actuator, a motor controller, and two linear variable differential transducers (LVDTs). The TCUs are operated based on electrical commands received from the ACU. The ACU monitors the TCUs for faults and system operation. The TCUs have individual internal monitors for power faults, temperature faults, and position monitoring which includes, for example, differences between the two LVDT positions within one unit. In the event of a fault being detected the TCU would register the fault and communicate the fault to the ACU. In addition, the TCU receives commands from the ACU for positioning of the TACS and provides position feedback to the ACU. The TCUs are designed with a nominal stroke length of 1.58 inches and can travel between neutral and extend or retract positions in approximately 100 milliseconds. The system contains electronic limits to actuator travel, commonly referred to as "soft-stops" and hardware limits, commonly referred to as "hard-stops".

A TACS was attached to each wing extension through two hinges and was mass balanced. Each TACS was connected to a TCU via pushrods, a bellcrank and a walking beam (see Figure 4). Electronic stops (soft stops) are designed into the ATLAS system to allow for a nominal operational travel of the TACSs of 20° trailing edge up and 9° trailing edge down. Mechanical stops (hard stops) within the TCUs prevent the TACS from moving beyond 21° ±1° trailing edge up and 10° ±1° trailing edge down. Hard stops are also located in the bellcrank assemblies and prevent the TACS from moving beyond 21° ±1° trailing edge up and 10° ±1° trailing edge down. During normal powered operations the bellcrank should not contact the hard stops within the TCUs or at the bellcrank assembly due to the electronic limits within the system. The installation of the TACS additionally includes a leaf spring attached to the bellcrank which is designed to provide a small centering force for trailing edge up deflections of the TACS. The spring does not exert any force on the TACS at the neutral position or during trailing edge down deflections.

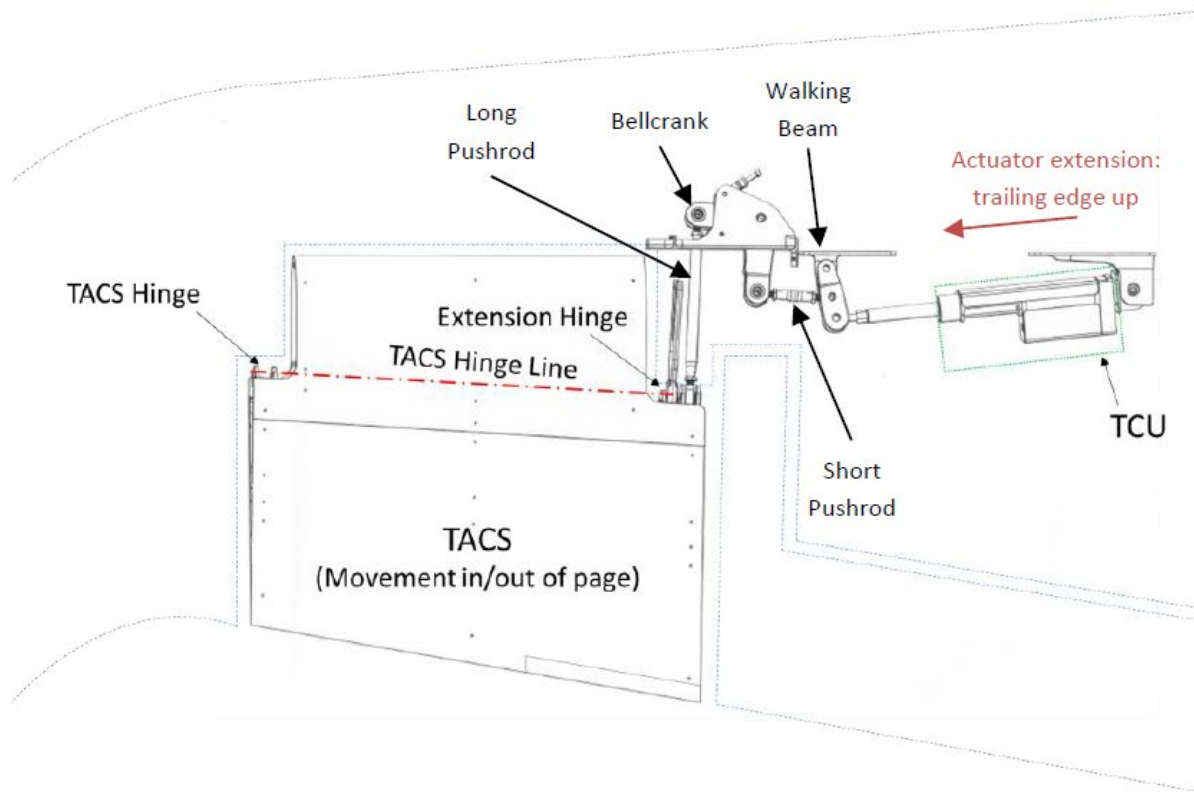


Figure 4. TACS control linkages (courtesy of Tamarack Aerospace Group).

D. DETAILS OF THE ON-SCENE EXAMINATION

The airplane, S/N 525B0001, was stored in a hangar at Tampa International Airport. The group arrived on 4/1/2023 to examine the airplane. It was reported that the left wing TCU push rod was moved prior to the arrival of investigators and therefore the original position of the push rod was unknown. It is also unknown if the right TACS was moved prior to the arrival of investigators.

1.0 Condition of Left Wing

The left wing extension, winglet, and TACS were all missing except for approximately 28 inches of the leading edge of the wing extension (see Figure 5). Approximately 7.5 inches outboard from the wing extension root, the forward spar (with leading edge skin still attached) was buckled, and the remaining structure started to bend downward. The top of the leading edge skin bent downward and gradually closed in on the lower skin as the skin went outboard. The entire leading edge skin for the wing extension was present. The outboard 3 inches of the leading edge skin was bent 90 degrees down and was partially severed. The leading edge of this section was flattened (approximately 1 inch wide at the outboard tip) compared to the rest of the leading edge, and there were scratches and gouges on the inside curvature of the skin including along the two edges of the flattened section. The

forward spar in this area was bent aft away from the leading edge skin and failed along a rivet line with any remaining outboard section of the forward spar missing. The wire harness from the strobe and navigation light was missing from the wing extension area but the wire protection tube was still present.



Figure 5. Picture of the left wing as found.

The wing extension aft spar (which attaches to the airplane mid spar) was fractured approximately 7 inches from the inboard end (see Figure 6, arrow A). The top cap of the aft spar was bent upwards, the bottom cap of the aft spar was bent slightly downwards, and the aft part of the spar web was bent aft. The production break upper closeout rib cap was bent with the aft portion bent downwards, the forward portion bent upwards, and the surrounding skin around the forward end separated and bent upwards consistent with the upward bend to the rib cap (see Figure 6, arrow B).

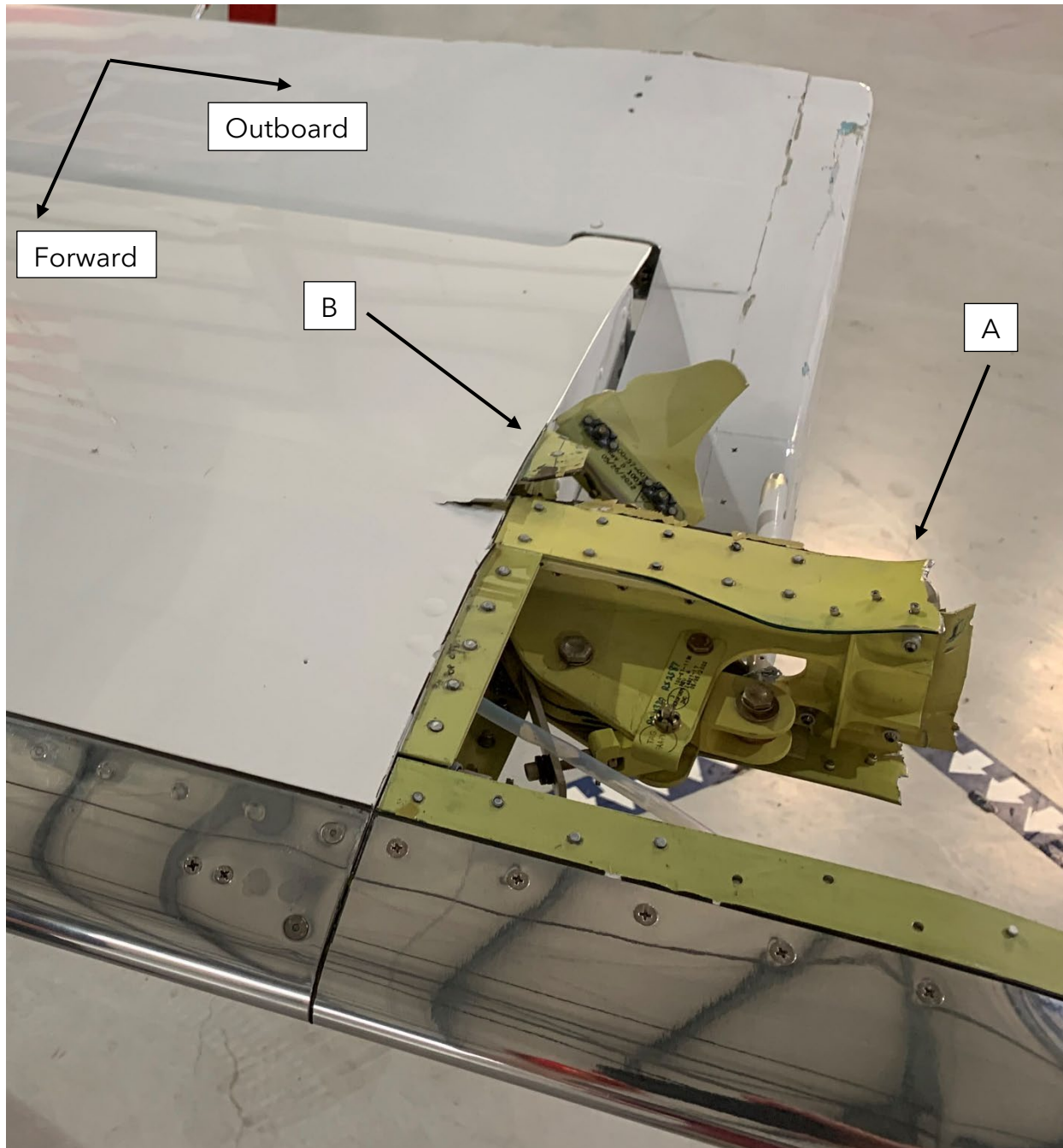


Figure 6. Left wing extension attachment area. Arrow A points to the remaining wing extension aft spar. Arrow B points to the damaged production break upper closeout rib cap.

The top of the wing had a line of chipped paint and residue marks starting at a point approximately 6 inches inboard of the wing extension attachment, and 9 inches aft of the leading edge. This line transitioned at approximately a 45 degree angle aft and inboard, to a point approximately 22 inches inboard of the wing extension attachment, and two inches forward of the aft edge of the wing (see Figure 7). From this point, another line of slight deformation and cracked paint traversed straight outboard to a point approximately 9 inches from the wing extension attachment (see

Figure 7, partially circled in red (note the entirety of this line of damage is difficult to see in the figure)). The bottom of the wing had a small residue mark near the aft side approximately in line with the outboard static wick on the aileron. The aileron had an upward impact mark on the bottom side of the trailing edge approximately 4.5 inches from the outboard end. This area was buckled and pressed up, with chipped paint. Cracking in the paint was present along the aileron outboard tip cap production break. The bottom forward side of the aileron tip cap had a 4 inch gouge with small dents centered approximately 3 inches aft of the leading edge of the tip cap. The outboard static wick was missing and the threaded portion of the wick base was missing. The wick base appeared to be slightly separated from the aileron at the forward and aft ends, and some paint was missing on the aileron trailing edge just aft of the wick base. Residue was located on the bottom of the aileron on the inboard side of this wick base, and the paint on the aileron trailing edge in this area was chipped. Nearly in line with this static wick base, approximately 6.5 inches forward of the aileron trailing edge, more residue and a chip in the paint was located at the leading edge/trailing edge aileron skin seam on the bottom side of the aileron. See Figure 8 for damage to the bottom side of the aileron and wing. The top side of the forward aileron surface had two dents. One was located approximately 20 inches inboard of the outboard side of the aileron tip cap, and approximately 10 inches forward of the trailing edge of the aileron. The other dent was located approximately 24 inches inboard of the outboard side of the aileron tip cap, and approximately 10 inches forward of the trailing edge of the aileron. The aileron trim tab was flush with the aileron surface.²

² Aileron and aileron trim tab movement is described in Section 4.0 of this report.

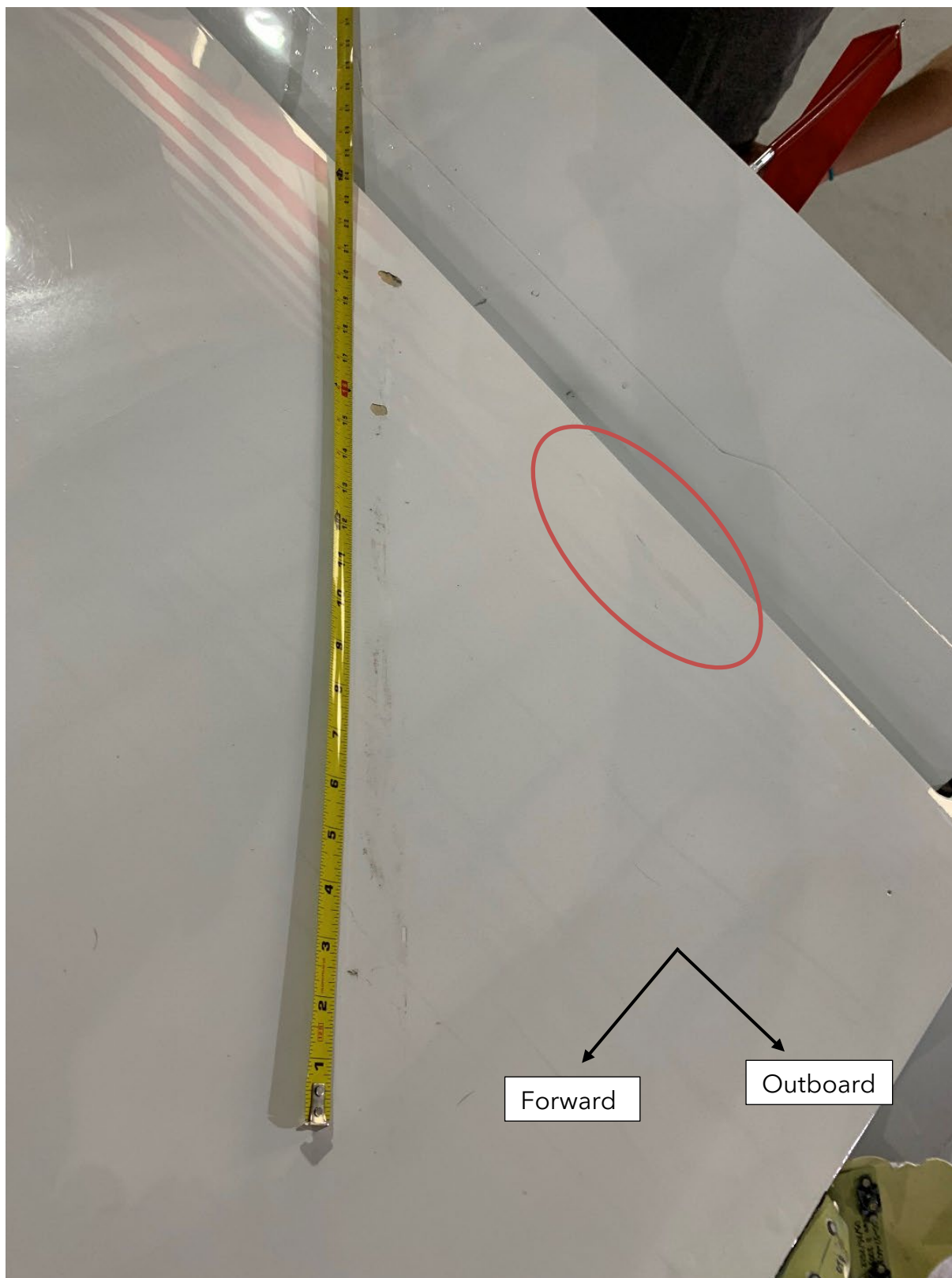


Figure 7. Chipped paint and residue in line on top surface of wing. Part of a second line of damage that runs in an inboard/outboard direction is circled in red (entirety of this line of damage is difficult to see in this picture).



Figure 8. Damage to the bottom side of the aileron and wing

Two small cracks were located along flap cove ribs (near the inboard edge of speedbrake and near the flap actuator).³ The cracks extended from the aft most rivet to the aft edge of the cove rib (see Figure 9, crack circled in red, for an example). A possible crack (unknown if it was only in the paint or if it was in structure) was found on the aft upper spar cap just inboard of the flap actuator, and extended upwards from a High-Lok fastener and ended just before the upper radius of the cap.

³ The flap coves are the areas on the aft side of the wings where the flaps tuck into when retracted.



Figure 9. Example of flap cove rib cracking near aft rivet (crack is circled in red)(picture location near Right Wing Station 106)(courtesy of Tamarack Aerospace Group).

2.0 Left Wing ATLAS Components

The access panel for the TCU was removed. The TCU was labeled as part number 100-37-0300-04, serial number 1389. The TCU remained securely attached to the wing mid spar with some allowable rotation which was considered normal. The TCU grounding point to structure was intact as well as the case bonding straps. The electrical connector to the TCU was intact with no obvious damage to the wiring. As previously stated, it was reported that the left wing TCU push rod was moved prior to the arrival of investigators and therefore the original positions of the push rod and connected linkages was unknown. In the as found position, the actuator ram tube extension measured 5 inches from the TCU actuator barrel to the center of the walking beam attach bolt. According to Tamarack this equates to approximately a TACS neutral position. All anti-rotation hardware on the TCU appeared to be present.

The TACS walking beam and all connections were secured and undamaged. The "short push rod" extending outboard from the walking beam remained intact with no obvious damage. The bellcrank was intact and the short and long push rods remained connected to it. The bellcrank was positioned between the TACS trailing edge up (forward) mechanical stop bolt and the trailing edge down (aft) mechanical

stop bolt. The gap was approximately 3/8 inch from the center of the trailing edge up stop bolt to the edge of the bellcrank and 3/16 inch from the center of the trailing edge down stop bolt to the aft edge of the bellcrank. According to Tamarack, this is consistent with a neutral position. The leaf spring remained intact, and the washers were slightly loose (consistent with a neutral or trailing edge down position). There were light contact marks on both sides of the bellcrank that were consistent with expected contact with the trailing edge up and trailing edge down stops during pre-flight checks.⁴ The "long push rod" extending aft from the bellcrank was fractured at the aft end eye bolt threads. The fracture demonstrated a cup like surface and the push rod had a slight bend outboard near the fracture. There was some scraping damage on the aft half of the push rod (see Figure 10). The TCU ram tube was moved by hand. The force required to move the ram tube felt normal and the movement sounded normal according to the Tamarack representative.



Figure 10. Picture of the "long push rod" with missing rod end and scraped paint.

⁴ Per the Tamarack Airplane Flight Manual Supplement, Issue B, the preflight inspection should include an exterior inspection for "TACS- CONDITION and MOVEMENT". Tamarack stated that in their experience most pilots interpret this inspection to cover the full travel of the TACS.

3.0 Right Wing ATLAS Components

The right wing TACS was inspected with no anomalies noted. Centering strips were installed on the trailing edge of the TACS. The TACS surface was found approximately 2-5/8 inch down measured from the trailing edge of the winglet to the outboard trailing edge of the TACS surface (see Figure 11). According to the Tamarack representative, this would be approximately full trailing edge down. As stated earlier in this report, when power is not applied to the TCUs, the units are free to move with an applied force of 10 lbs or less, and it is therefore unknown if the TACS position had changed prior to the arrival of investigators. The access panel for the TCU was removed. The TCU was part number 100-37-0300-04 and serial number 1385. The TCU remained securely attached to the wing mid spar with some allowable rotation which was considered normal. The actuator ram tube extension measured 4-3/8 inch from the TCU actuator barrel to the center of the walking beam attach bolt. According to Tamarack, this extension was consistent with the TACS in the as-found approximately full trailing edge down position. The TCU grounding point to structure was intact as well as the case bonding straps. The electrical connector to the TCU was intact with no obvious damage to the wiring. All anti-rotation hardware appeared to be present.

The walking beam and all connections were secure and undamaged. The "short push rod" remained intact and connected at both ends with no obvious damage. The "long push rod" was intact and remained connected at both ends. The bellcrank and mechanical stops could not be observed without disassembly of the wing extension.



Figure 11. Right wing with intact wing extension, winglet, and TACS. TACS is near the full down position.

The trailing edge of the TACS control surface was moved by hand with expected force and sound from the actuator. The TACS trailing edge was moved full up and measured 4-3/8 inches from the trailing edge of the winglet, and the TACS trailing edge was moved to full down measuring 2-5/8 inches from the trailing edge of the winglet.

Chipped/peeling paint was located on the aft portion of the right wing in line with the flap actuator (see Figure 12). There was slight chordwise deformation visible in some lighting conditions near this area also. Three small cracks similar to those noted on the left wing were located on cove ribs in the area of the inboard edge of speedbrake, area of the flap actuator, and the area of the inboard flap hinge. The cracks extended from the aft most rivet to the aft edge of the cove rib.



Figure 12. Chipped/peeling paint found on top side of right wing (courtesy of Tamarack).

4.0 Functional Tests

Functional tests of the ATLAS system were conducted. No circuit breakers, including the “ATLAS Main” circuit breaker, were found to be open on the left or right side circuit breaker panels in the cockpit. The broken “long push rod” was removed from the airplane. The airplane was turned on and powered by the battery with avionics off. The ATLAS light turned on briefly, but the ATLAS actuators did not move. The avionics were powered, and the ATLAS light came on briefly, the TCUs moved, and then the light extinguished. The ATLAS button was pressed three times to manually initiate the built-in test. The top half of the light briefly turned on, then the bottom half of the light turned on, then both turned on and then extinguished. Then the light came on again during the built-in test, then extinguished. The left TCU and remaining linkages were observed to move during this test. The right wing TACS also moved. The light extinguished at the end of the test indicating that the system had passed the built-in test with no faults detected.⁵ Following the test, the left wing bellcrank was between the stops approximately in the neutral position, and the right wing TACS was in a neutral position.

The control wheel was rotated in the cockpit. The ailerons moved freely with no anomalies noted (the “long push rod” was removed for this test – it is noted that

⁵ The missing winglet and removed TACS control rod would not be expected to cause the built-in test to fail because the TCU and ACU can still operate normally.

prior to removal the long push rod was in a position where it could have contacted the aileron tip cap). The aileron trim tab operated as expected. The elevators and elevator trim tabs, and the rudder and rudder trim tab, also operated as expected when initiated from the cockpit controls. The flaps were extended with no anomalies noted. The speedbrakes extended when the flaps were moved to the ground flaps position.

Textron Aviation reported that the airplane did not have an Aircraft Recording System (AReS) installed.

E. COMPONENT EXAMINATIONS

Representatives from the NTSB, FAA, Tamarack Aerospace, and Textron Aviation met at the Lee Air facility in Wichita, KS, on 5/16/2023, for the examination of the ACU and two TCUs removed from the event airplane. All units were stored in secure storage, and shipping boxes remained unopened, until the team arrived for the examination. All units were tested per Acceptance Test Procedure (ATP) document TAG-1100-0163, Rev F, dated March 23, 2021.

The Enhanced Ground Proximity Warning System (EGPWS) was also removed from the incident airplane during the on-scene examination. The EGPWS was subsequently sent to Honeywell for download of its non-volatile memory. Honeywell provided the results to the NTSB.

1.0 ATLAS Control Unit Functional Test

The following information was on the ACU label:

Part Number (P/N): 100-39-0100
Revision: D
Serial Number (S/N): 1135
Supplier Ident: 2X920

The ACU was removed from the shipping box. External inspection did not reveal any anomalies. The seal under the connector cover was intact and the connector pins were straight and clean. The ACU was connected to the test equipment and passed all portions of the ATP.

Tamarack initial build ATP Test Data Sheets for this unit were dated 10/20/22. Tamarack had no records of repair on file for this unit for the time period between initial build and the incident.

2.0 Left TACS Control Unit Functional Test

The following information was on the TCU label from the TCU installed on the left side of the event airplane:

P/N: 100-57-0300-04
Revision: F "SB1467/SB1480 TCU Compliant"
S/N: 1389
Supplier Ident: 2X920 MOD 1-4-5

The TCU was removed from the shipping box. External inspection did not reveal any anomalies except for a small dent approximately ¼ inch long on the bottom housing plate (note the bottom of the TCU installed on the left wing is the side with the label) and some scuffing on the edge of the bottom plate on the side opposite of the ram tube. The connector pins were straight and clean. The rod end from the ram tube was removed and the attach bolt on the opposite side from the ram was removed so that the unit could be placed in the test fixture. The TCU was connected to the test equipment and passed all portions of the ATP.

Tamarack initial build ATP Test Data Sheets for this unit were dated 10/04/22. Tamarack had no records of repair on file for this unit for the time period between initial build and the incident.

3.0 Right TACS Control Unit Functional Test

The following information was on the TCU label from the TCU installed on the right side of the event airplane:

P/N: 100-57-0300-04
Revision: F "SB1467/SB1480 TCU Compliant"
S/N: 1385
Supplier Ident: 2X920 MOD 1-4-5

The TCU was removed from the shipping box. External inspection did not reveal any anomalies. The connector pins were straight and clean. The rod end from the ram tube was removed and the attach bolt on the opposite side from the ram was removed so that the unit could be placed in the test fixture. The TCU was connected to the test equipment and passed all portions of the ATP.

Tamarack initial build ATP Test Data Sheets for this unit were dated 10/04/22. Tamarack had no records of repair on file for this unit for the time period between initial build and the incident.

4.0 Left TACS Control Unit Teardown

The left TCU (S/N 1389) was disassembled to look for any anomalies and to inspect for witness marks. The lid was removed. The retaining screw securing the connector card to the housing was secure (split washer was compressed) and had both the solid washer and split washer installed. The bottom housing plate was removed. The gap between the insulating spacers of the connector card and the insulating spacers of the TCU main circuit card pins was measured at 0.015 inch on the connector side and flush on the side opposite of the connector. Note this gap may have changed from the original condition as the connector card had to be pushed to one side to aid disassembly.

The main circuit board was removed from the lower housing plate. The entire linear actuator assembly was then removed. The ram guide and motor covers were removed. The ram tube appeared to be straight. The LVDT pistons and guide (yoke) were intact and straight. There was no indication that the yoke over-traveled or made contact with the housing.

The gears were disassembled and looked to be intact. The gear threads on the ball screw were in good shape with no evidence of thread stripping. The ball nut coating was intact on both the extension and retraction edges (consistent with the ball nut not contacting the housing under high energy). The housing stop on the ball nut retraction side had some circular contact/scuff marks consistent with the ball nut edge. Tamarack stated that the scuff marks were consistent with other units, and that the ball nut will contact this housing stop during the ATP backdrive test. The backdrive test is not under high energy but contact/scuff marks can still be created. In addition, Tamarack noted that the results of the ATP backlash test were consistent with a ball nut that had not impacted the housing under high energy, as this can cause damage that can increase the backlash in the unit. The housing on the ball nut extension side did not reveal any indications of the ball nut contacting the housing under high energy. Tamarack stated that the housing on the extension side is a different design than the housing stop on the retraction side, and that contact/scuff marks caused during the ATP back drive test are not normally seen on the extension side housing.

5.0 Enhanced Ground Proximity Warning System

The Honeywell Mark VIII EGPWS installed on the incident airplane was P/N 965-1206-011 and S/N 2191. The EGPWS was sent to Honeywell in Phoenix, AZ for download of the non-volatile memory. Honeywell reported that the download was successful and provided the data to the NTSB. The data showed that there were no faults recorded by the EGPWS for the incident flight leg. There was a "Mode 5 GS" (below glideslope) alert recorded in the data that occurred during the incident flight leg; however, this alert also appeared on many of the previously recorded flight legs

(including the previous three flight legs). The EGPWS will record various parameters for 20 seconds prior and 10 seconds after an alert occurs. The recorded alert occurred when the airplane was at approximately 270 ft radio altitude and near Tampa International Airport, and therefore the initiating event for this incident was not captured in the recorded data associated with this "Mode 5 GS" alert.

Submitted by:

Adam Huray
Aircraft Systems Investigator