----- SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT -------

1 ACCIDENT:

Location:	Memphis, Indiana
Date:	November 30, 2018
Time:	About 1028 EST
Aircraft:	Cessna Citation 525A
Serial Number:	525A0449
Registration:	N525EG

2 SYSTEMS GROUP:

Chairman:	Michael Bauer National Transportation Safety Board Washington, D.C.
Member:	Jeffrey Zimmer Federal Aviation Administration Westbury, NY
Member:	Henry Soderlund Textron Aviation Inc. Wichita, KS
Member:	Hal Gates Tamarack Aerospace Group Sandpoint, ID
Member:	Bennie Lee Lee Air, Inc. Wichita, KS

3 SUMMARY

3.1 Event Summary

On November 30, 2018, about 1028 eastern standard time, a Cessna 525A (Citation) airplane, N525EG, collided with trees and terrain near Memphis, Indiana. The airline transport certificated pilot and 2 passengers were fatally injured, and the airplane was destroyed. The airplane was owned and operated by EstoAir LLC under the provisions of 14 Code of Federal Regulations Part 91 as a business flight. Visual meteorological conditions prevailed for the flight which operated on an instrument flight rules flight plan. The cross-country flight departed Clark Regional Airport (JVY), Jeffersonville, Indiana, about 1025, with Chicago Midway Airport (MDW), Chicago, Illinois, as the intended destination.

3.2 Systems Group Summary

The systems group was initially formed on October 1, 2019 during the wreckage examination phase of the investigation, which was conducted at the wreckage storage facility at AMF Aviation, Springfield, Tennessee. The group documented the Active Technology Load Alleviation System (ATLAS) and associated systems from October 1- 2, 2019. The systems group chairman was not present at the accident site during initial investigative operations.

The systems group reconvened at Lee Air, Inc. in Wichita, Kansas to conduct teardown examinations of the Tamarack ATLAS system components from October 29-30, 2019, at which time Lee Air, Inc. was added to the systems group. The examination consisted of the left and right Tamarack Active Camber Surface (TACS) Control Units (TCU) and the ATLAS Control Unit (ACU). Prior to the examination in Wichita, the TCUs were inspected using computed tomography (CT). Details of CT imaging can be found in the Computed Tomography Specialist's Factual report.

An additional examination of the left TCU printed circuit board assembly (PCBA) was conducted at the NTSB materials laboratory. Inspections of the PCBA using the NTSB's scanning electron microscope (SEM) was performed from November 2019 to January 2020. Additional microscopic imaging and PCBA inspections were conducted in March and May 2020. During the inspections of March and May 2020, due to COVID-19 restrictions, the inspections were conducted by NTSB personnel only with the resulting imagery shared with the group.

This report contains the factual information related to the group's inspection and documentation of the aircraft's ATLAS system and additional systems as noted.

3.3 Acronyms

AAIB	Air Accidents Investigation Branch	KIAS	Knots Indicated Air Speed
ACU	ATLAS Control Unit	LE	Leading Edge
AD	Airworthiness Directive	LED	Light Emitting Diode
AGL	Above Ground Level	LH	Left Hand
AHRS	Attitude Heading Reference System	LLC	Limited Liability Company
AMOC	Alternate Means of Compliance	LRU	Line Replaceable Unit
AP	Autopilot	LVDT	Linear Variable Differential Transformer
AReS	Aircraft Recording System	MDW	Chicago Midway Airport
ATLAS	Active Technology Load Alleviation System	MMEL	Master Minimum Equipment List
ATP	Acceptance Test Procedure	MX	Maintenance
CAS, CAeS	Cranfield Aerospace Solutions	NTSB	National Transportation Safety Board
CF	Compact Flash	NVM	Non-Volatile Memory
CT	Computed Tomography	OUTBD	Outboard
DC	Direct Current	PCB	Printed Circuit Board
EAD	Emergency Airworthiness Directive	PCBA	Printed Circuit Board Assembly
EASA	European Union Aviation Safety Agency	REV	Revision
EGPWS	Enhanced Ground Proximity Warning System	RH	Right Hand
EST	Eastern Standard Time	SB	Service Bulletin
FAA	Federal Aviation Administration	SEM	Scanning Electron Microscope
FWD	Forward	STC	Supplemental Type Certificate
GND	Ground	TACS	Tamarack Active Camber Surface
GPS	Ground Position System	TAG	Tamarack Aerospace Group
INBD	Inboard	TCU	TACS Control Unit
INOP	Inoperative	TED	Trailing Edge Down
JVY	Clark Regional Airport	TEU	Trailing Edge Up

4 DETAILS OF THE INVESTIGATION:

4.1 Aircraft Information

Customer/Model Series:	Cessna Citation 525A (Citation CJ2+)
Aircraft Registration:	N525EG
Aircraft Serial Number:	525A0449
Manufactured Date:	2009

At the time of the accident, the aircraft had the following approximate flight hours and cycles.

Total Flight Hours:	3,306.5
Total Flight Cycles:	2,696

4.2 Aircraft Maintenance Information

The following maintenance information only contains entries that are related to flight controls and specifically to the roll (lateral) axis, and adjacent systems and aerodynamic surfaces related to an aftermarket winglet, wing extension, and load alleviation system which was installed on the airplane.

The aileron and aileron trim system was last checked on March 23, 2018 in accordance with the aircraft's maintenance manual procedures. The aileron trim bearings were replaced with no operational issues noted.

The aircraft was outfitted with the Active Technology Load Alleviation System (ATLAS) Active Winglets on May 27, 2018 in accordance with STC #SA03842NY.

The aileron trim tab lubrication was last checked on July 13, 2018 in accordance with the maintenance manual procedures, with no defects noted.

Both the left and right TCUs were removed and returned to Lee Air, Inc. in accordance with service bulletin CAS/SB1467 and reinstalled in their original locations on July 13, 2018.

The LH and RH winglet tip caps were repaired on November 20, 2018.

No additional maintenance write-ups or repairs related to the longitudinal flight controls, autopilot and ATLAS system were noted in the maintenance records dated between January 23, 2018 and the accident date.

The following table, Table 1, summarizes the landings and flight hours noted in the maintenance records at the time of selected entries.

Table 1 - Maintenance Event Time and Landing Information

Date	Mx Event	Total Landings	Flight Hours
03/23/2018	Aileron and aileron trim system check	2438	2946.8
05/27/2018	Installation of ATLAS system	2508	3049.5
07/13/2018	TCU ATLAS SBATLAS-57-03	2556	3113.8
11/20/2018	LH/RH winglet tip cap repair (last MX record)	2689	3296.7
11/29/2018	Last reported aircraft hours/cycles	2696	3306.5

4.3 Accident Site Information

The systems group chairman did not travel to the accident scene. The group chairman was briefed by the on-scene investigative team that the aircraft impacted trees consistent with a high-speed impact. The aircraft was destroyed with only small sections of structure and system components identifiable.

4.4 Systems Descriptions, Inspections and Testing

The following sections contain descriptions and operation information for the respective systems. The information is based on aircraft flight manual documentation and manufacturer documentation.

4.4.1 Flight Controls System:

The primary flight controls (ailerons, elevator and rudder) are mechanically actuated by cables and bellcranks directly connected to the pilot/copilot control columns and rudder pedals.

The aircraft was equipped with an autopilot system. Individual servos are installed in the aircraft and connected to the primary flight control cables via control cables. The servos consist of a motor, electromechanical clutch assembly, synchronizer and power gear train, ref Figure 1. The servo receives electrical signals from the autopilot computer. The servo utilizes a clutch which, when disengaged, allows the servo output shaft to rotate freely. The servo also contains torque and current limiting, which if the servo torque or current exceeds predetermined limits, will cause the autopilot system to disengage.

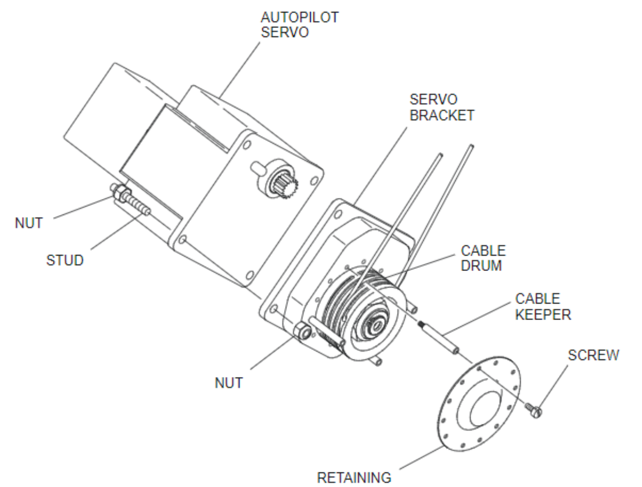


Figure 1 - Typical autopilot servo assembly (individual flight control installations may differ) (source Textron Aviation Cessna 525A Mx Manual)

Per the aircraft operating manual, "Normal autopilot disengagement (by pilot action) results in a single tone or verbal alert." The pilot can disengage the autopilot by:

- Lowering the autopilot lever
- Selecting the red AP disconnect button on either control yoke
- Activating the electric elevator trim
- Selecting the go-around button on the left throttle
- Lowering the yaw damper lever

The autopilot can also disengage during abnormal situations, which may result in repeated alerts which can be cancelled using the red AP disconnect button on either control yoke. Abnormal disconnects can be done by:

- Stick shaker
- Yaw damper or internal autopilot failure
- Attitude Heading Reference System (AHRS) failure or miscompare
- Loss of power to the normal (main) DC bus
- Excessive attitudes
    - Pitch: 25° nose-up, 15° nose-down
    - Roll: 45° left or right wing down

Secondary flight controls consist of the flaps, speed brakes, trim systems and rudder bias system. The flaps and speed brakes are electrically controlled and hydraulically actuated. The ailerons, elevator and rudder have trimmed control surfaces and cockpit trim position indicators, which are also mechanically controlled. The elevator trim system also has an electrically controlled component.

Flaps can be operated to 15° at 200 KIAS or below and 35° at 161 KIAS or below. On the ground, the flaps can be extended to 60° to add additional aerodynamic drag during landing rollout. Mechanical interconnections between the left- and right-wing flap segments prevent asymmetric flap operation. If flaps are extended beyond 35° in flight and the throttles are below approximately 85% N_2 the MASTER CAUTION will light after an 8-second delay, if the throttles are above 85% N_2 the MASTER CAUTION will light immediately.

Speed brake panels are hydraulically actuated and electrically controlled and can be extended at any airspeed but must be retracted prior to 50 feet AGL before landing.

4.4.1.1 Recovered Components

Due to the impact damage sustained by the aircraft, most of the components related to the aileron portion of the flight control system, were difficult to identify during the wreckage examination at the storage facility. Control cables showed signs consistent with overload failure. Some of the autopilot system components could be identified, however, a definitive determination of the location on the aircraft, or the flight controls (roll, pitch, yaw) system they were a part of could not be made.

4.4.1.2 Additional Testing

Due to the damage to the identified and recovered components, no further testing or inspections were conducted.

4.4.2 Tamarack Aerospace Group Active Technology Load Alleviation System (ATLAS):

The aircraft was equipped with the Tamarack Aerospace Group[1] Active Technology Load Alleviation System (ATLAS). The system modified the original aircraft design by removing the wing tip assembly and adding winglets and wing extensions which contained active aerodynamic surfaces, ref Figure 2. The system was designed to provide increased aerodynamic efficiency without adverse structural effects due to the winglet installation. The system operated independently of other aircraft systems.

[1] Tamarack Aerospace Group (TAG) will also be referred to in the report as Tamarack or TAG

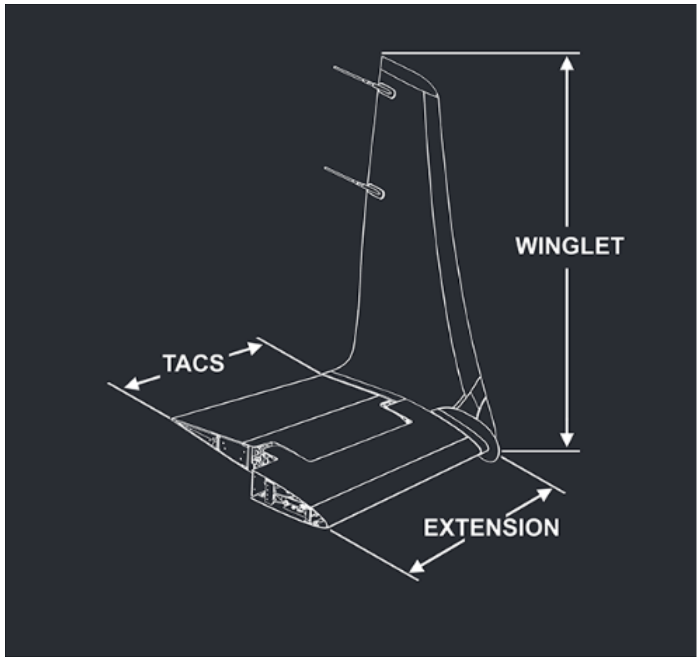


Figure 2 - Drawing of winglet and wing extension of ATLAS (courtesy TAG)

The main components of the ATLAS system consisted of two wing extensions and two winglets with an Active Control Unit (ACU), an Annunciator line replaceable unit (LRU), an ATLAS INOP button, two TACS Control Units (TCU) and two Tamarack Active Camber Surfaces (TACS).

The Annunciator LRU contained relays which will trigger the annunciation 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 typically installed below the floor in the main cabin near the wing fuselage interface.

The ATLAS INOP button was installed on the main instrument panel, ref Figure 3 and Figure 4. The illumination of the ATLAS INOP button does not result in an aural annunciation. The ATLAS INOP button was a LED-backlit momentary button mounted on the main instrument panel. The button would illuminate in the event of a fault condition and provide the flight crew with a primary means of resetting the system during a faulted condition. Prior to flight, the crew could activate a built-in test feature by selecting the button three times in rapid succession. The built-in test exercised select portions of the system in order to identify any latent failures in the system prior to flight and the LEDs in the INOP button.

Figure 3 - Installation of the ATLAS INOP button in an exemplar aircraft (courtesy TAG)

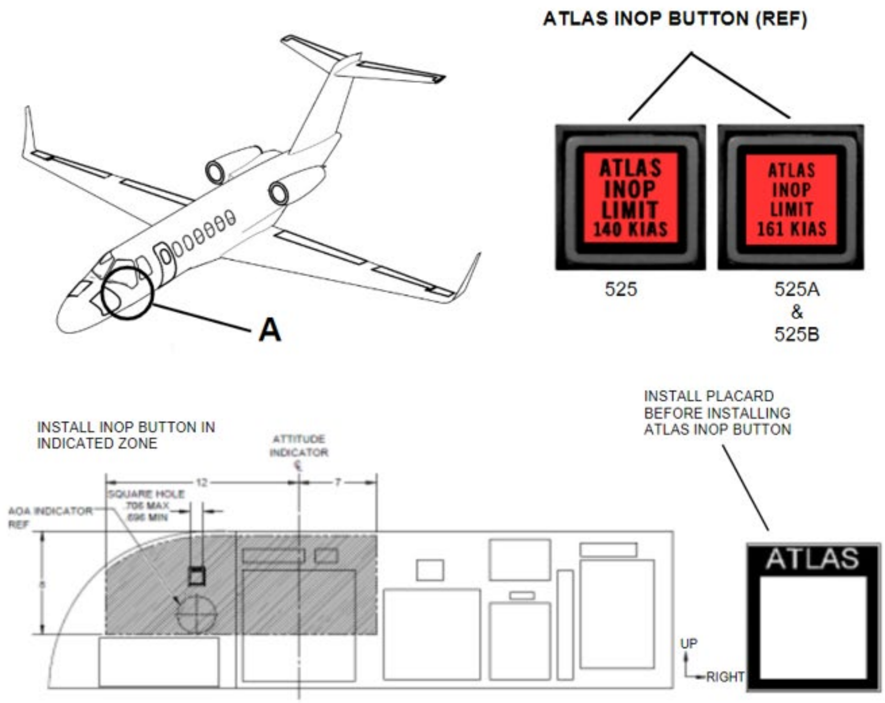


Figure 4 - Excerpt from ATLAS installation manual showing acceptable button installation zone and illuminated state (courtesy TAG)

The ACU was mounted to the forward spar stiffeners close to the centerline of the aircraft and the aircraft's center of gravity. The ACU contained 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 monitored for power faults, accelerometer differences, TCU reported faults and the TCU positions in the event of difference between commanded and actual position, or in the event of an asymmetry between the left and right TCUs. In the event of a fault being detected the ACU would signal the TCU to depower the motor. The ACU was an analog device and did not contain any software or non-volatile memory.

Each wingtip has a TCU installed in existing aircraft structure, ref Figure 5. The TCU contained a linear actuator, a motor controller, two linear variable differential transducers (LVDTs) and is operated based on commands received from the ACU. The TCU communicated with the ACU for fault monitoring and system operation. The TCU contained individual internal monitors for power faults, temperature faults and position monitoring which included, for example, differences between the two LVDT positions. In the event of a fault being detected the TCU would register the fault and communicate the fault to the ACU. In addition, it received commands from the ACU for positioning of the TACS and provides position feedback to the ACU. The TCU is designed with a nominal stroke length of 1.58 inches and can travel between neutral and extend or retract positions in approximately 100 ms. The TCU contained electronic limits to actuator travel, commonly referred to as "soft-stops" and hardware limits, or "hard-stops"[2]. When power was not applied to the TCU, the units are free to move with an applied force of 10 lbs or less.

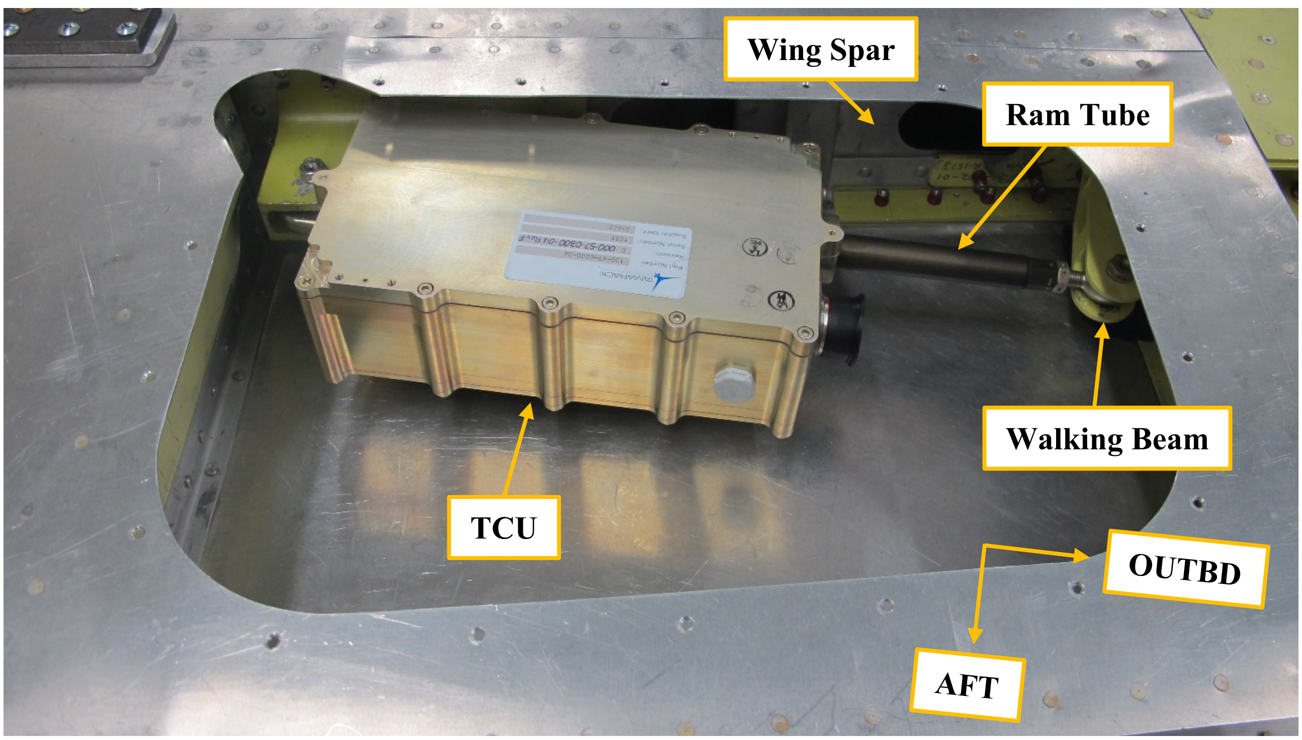


Figure 5 - TCU exemplar installation in lab test fixture (view looking at underside of wing section, with no electrical connections)

[2] The "hard-stops" described here are internal to the TCU. Additional "hard-stops" are located within the bell-crank mechanism.

Each wingtip contained a TACS, which is integral to the winglet/wing tip extension. The TACS was attached to the wing tip extension through two hinges and is mass balanced. The TACS was connected to the TCU via pushrods, a bellcrank and a walking beam, ref Figure 6. The TACS installation allows travel 21° ±1° trailing edge up and 10° ±1° trailing edge down to mechanical stops located in the bellcrank assmbly. The nominal operational travel was 20° trailing edge up and 9° trailing edge down utilizing electronic stops within the TCU. During normal operations due to electronic limits, the bellcrank should not contact the hardstops. The bellcrank contained a TCU return spring and two hard stops, one in the trailing edge up (TEU) direction and one in the trailing edge down (TED) direction, ref Figure 7.

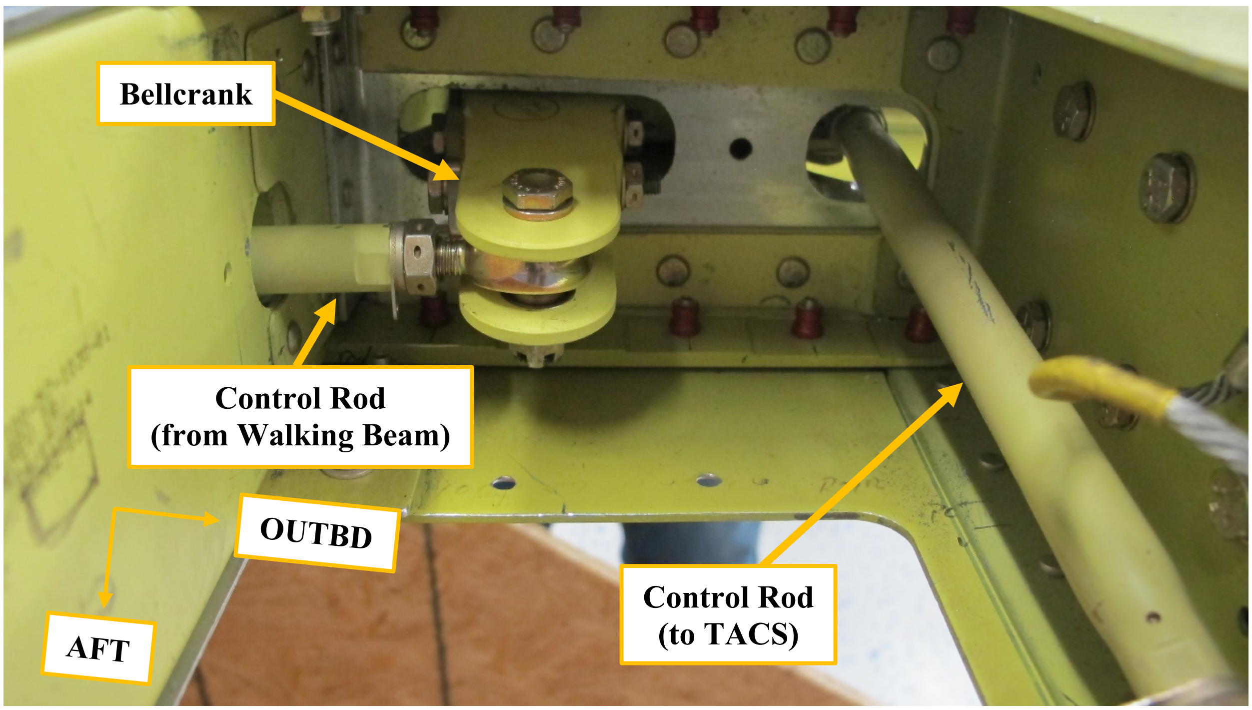


Figure 6 – TCU/TACS exemplar installation in lab test fixture

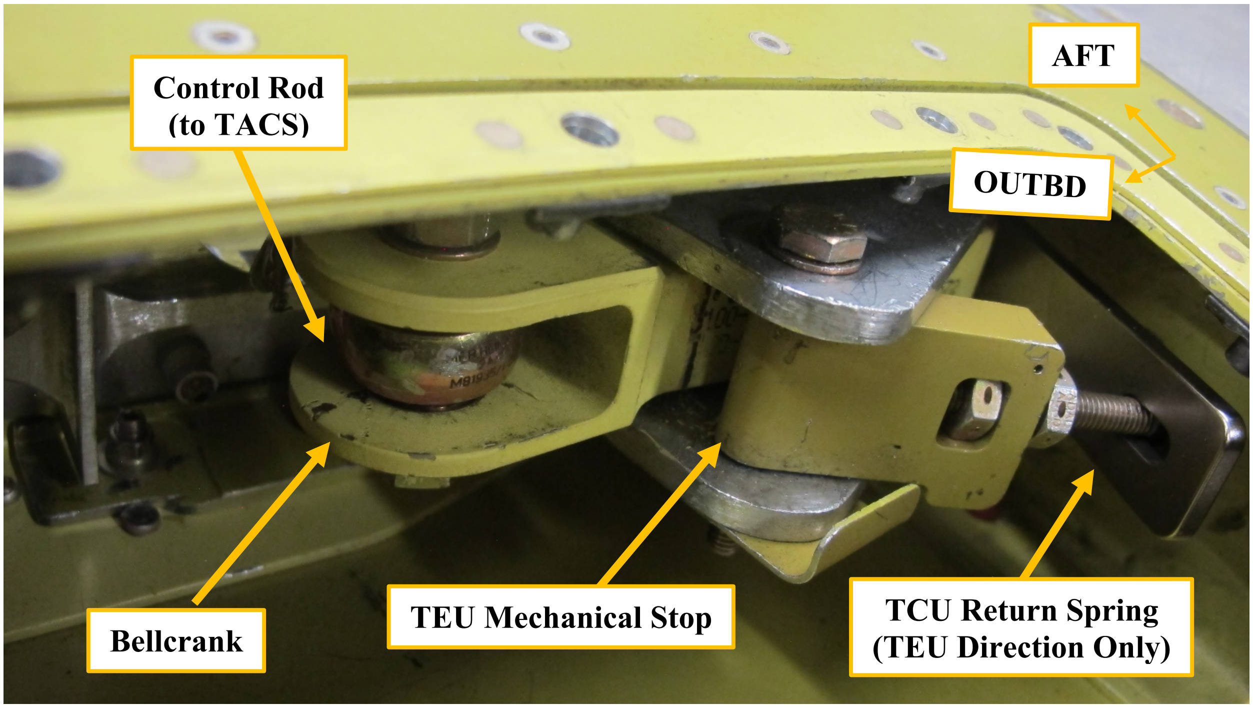


Figure 7 - TCU/TACS exemplar installation in lab test fixture (safety wire not installed)

4.4.2.1 Recovered Components

The group reexamined the recovered wreckage at the storage facility to locate components of the ATLAS system. The ATLAS INOP button and Annunciator LRU were not located in the wreckage.[3] The following subsections document the recovered ATLAS components and inspection and testing results.

4.4.2.1.1 ATLAS Control Unit (ACU)

The ACU was located in the recovered wreckage and was found detached from its mounting location in the wing root fairing.

4.4.2.1.1.1 Data Plate and Service History

Based on the unit's data plate:

Part Number:	101-57-1000
Revision:	F
Serial Number:	1043

[3] The group located the instrument panel where the INOP button was mounted, but the button was not found attached to the panel.

The unit was manufactured on September 22, 2017. According to manufacturer records, the unit passed its final acceptance test on September 22, 2017. The unit had not been returned to the manufacturer for any maintenance since its time of manufacture. The manufacturer reported that only two of 94 in-service ACUs have been returned due to removals from aircraft[4]. In both cases, no faults were found with the units during testing and they were returned to service[5].

4.4.2.1.1.2 Visual Inspection

The unit case showed signs of crushing damage to its exterior consistent with impact, ref Figure 8. On the side of the unit the 9 pin D-sub[6] connector was attached; however, the associated wiring was not present. The 37 pin D-sub connector was partially detached, and wiring was present with the connector. The mating pins were extensively damaged and bent.

Figure 8 - ATLAS ACU as recovered at storage facility

The ACU cover screws were not present and light prying pressure was applied to remove the cover. Multiple electrical components were loose in the unit and missing from the main circuit card, ref Figure 9. Two daughter cards, which normally attach to the main circuit card, ref Figure 10, were found loose in the unit, with one embedded in the top cover.

[4] The manufacturer is the only place approved to perform testing and repair of in-service ACUs.
[5] On both units a jack screw located on the harness assemble was repaired. The jack screw is used to secure the aircraft harness to the unit and does not impact ACU operations.
[6] D-sub connector, also referred to as D-subminiature due to their D-shaped metal shield.

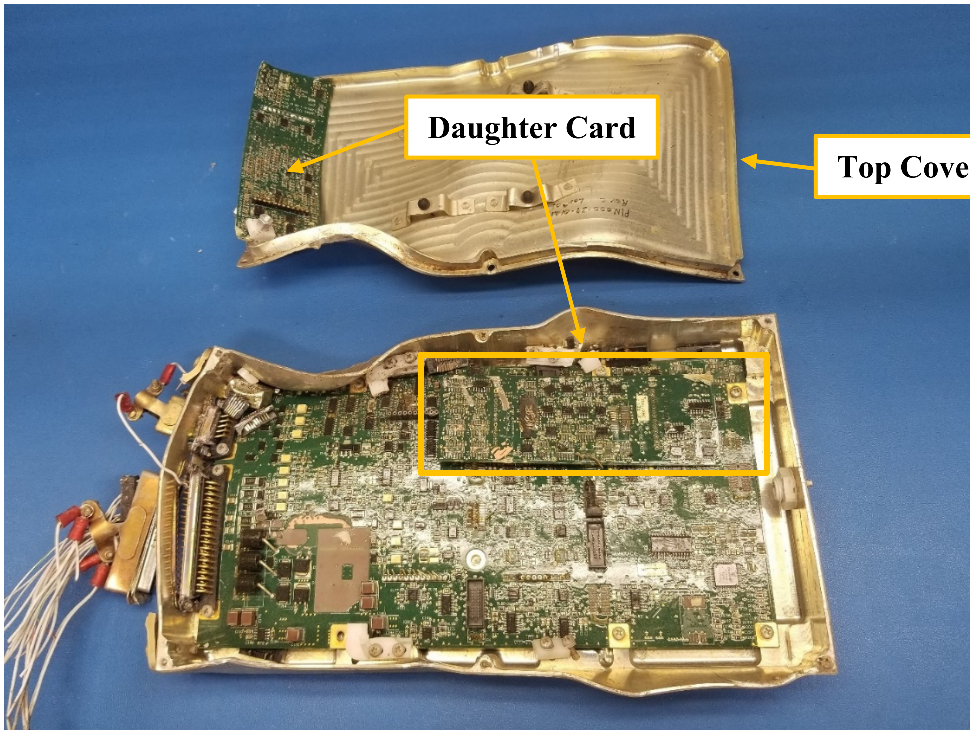


Figure 9 - Acc cover removed

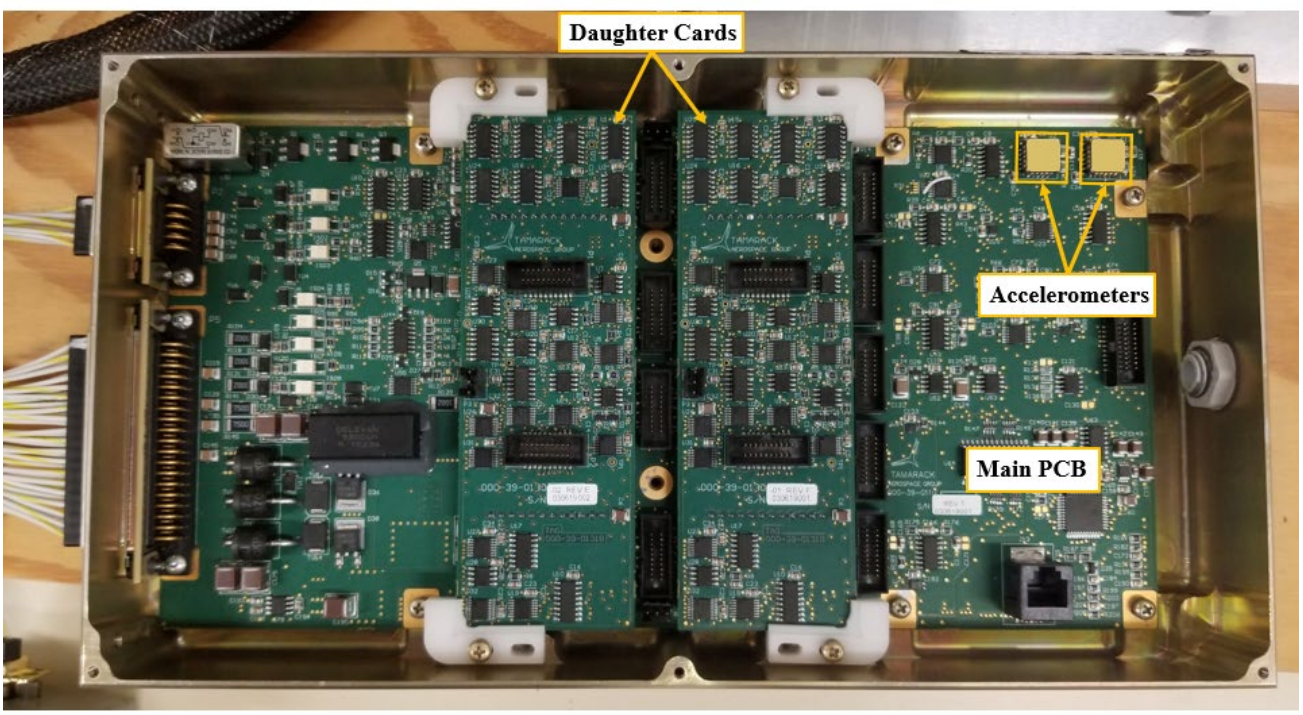


Figure 10 - Exemplar ACU showing layout of daughter cards (redacted)

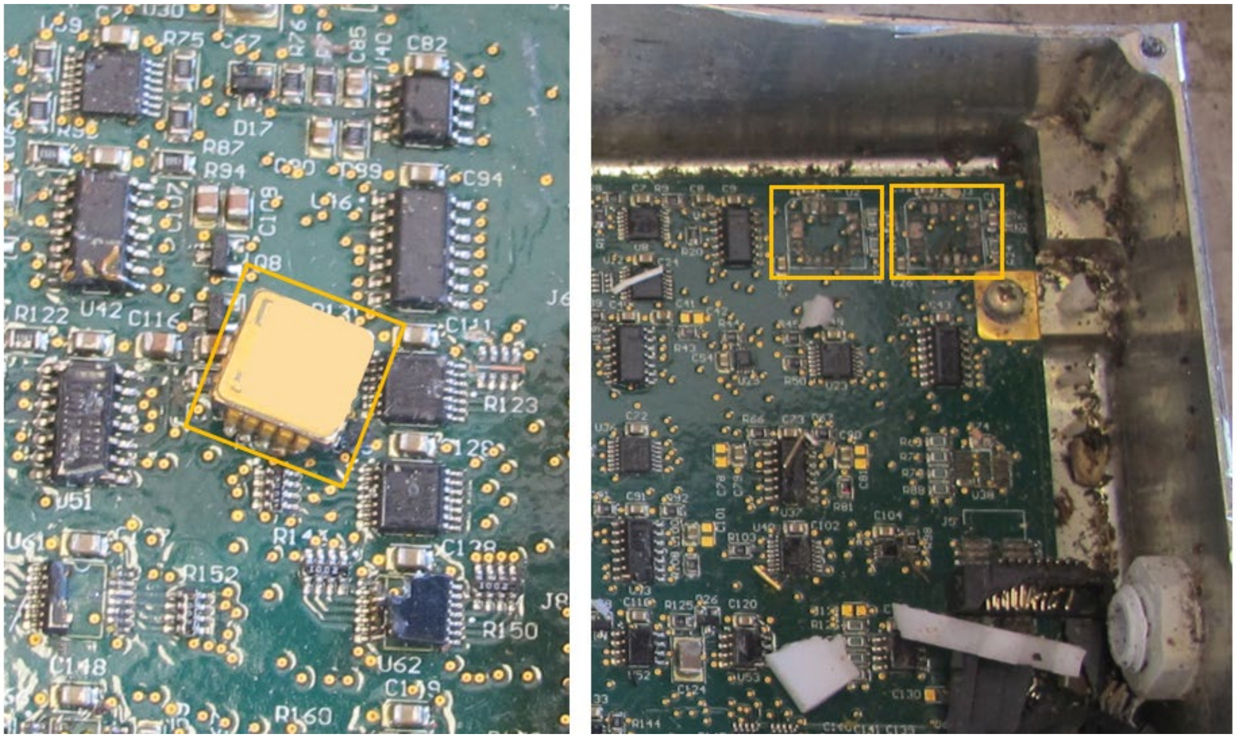


Figure 11 - Accelerometer and accelerometer mounting positions highlighted as found in accident unit (images cropped and redacted).

The mounting location for the two accelerometers on the main PCB did not contain either accelerometer, ref Figure 11. One of the accelerometers was identified and found loose in the unit at the initial wreckage recovery. The second accelerometer was located beneath the main PCB during the visual inspection of the unit at the manufacturer.

4.4.2.1.1.3 Additional Testing

Due to the damage to the ACU and its internal PCBs no further testing or inspections were conducted.

4.4.2.1.2 Right TACS Control Unit (TCU)

The TCU was located in the recovered wreckage and was found detached from its mounting location in the wing tip structure. The TCU was found in the wreckage path but not attached to the wing structure where it is normally mounted.

4.4.2.1.2.1 Data Plate and Service History

Based on the unit's data plate:

Part Number:	100-57-0300-04
Revision:	D 000-57-0300-04 REV F

Serial Number: 1090

The unit was manufactured on November 14, 2017. According to manufacturer records, the unit passed its final acceptance test during initial manufacturing on November 14, 2017. The unit had been returned to the manufacturer for rework per service bulletin CAS/SB1467 (ref section 4.6.2). The unit was reworked, tested, and returned to service on July 6, 2018.

As of October 30, 2019, the manufacturer reported the following statistics for TCU's returned due to removals from aircraft.[7]

- 221 returned for compliance with CAS/SB1467
- 17 returned, tested no fault found and returned to service.[8]
- 18 returned with confirmed failures of various nature. Units repaired, tested and returned to service.

4.4.2.1.2.2 Visual Inspection

The TCU case was deformed and twisted with the upper cover partially separated from the unit consistent with impact damage. The ram tube was fractured at the barrel seal face.[9] The circular electrical connector and grounding wires from the aircraft wiring harness were not present with the unit when it was found.

Figure 12 - RH TCU as recovered prior to visual inspection at the manufacturer

[7] The manufacturer is the only place approved to perform testing and repair of in-service TCU units.
[8] Count includes units if they were returned multiple times or contained multiple failures
[9] The ram tube is the actuator arm that extends and retracts based on the linear actuator movement.

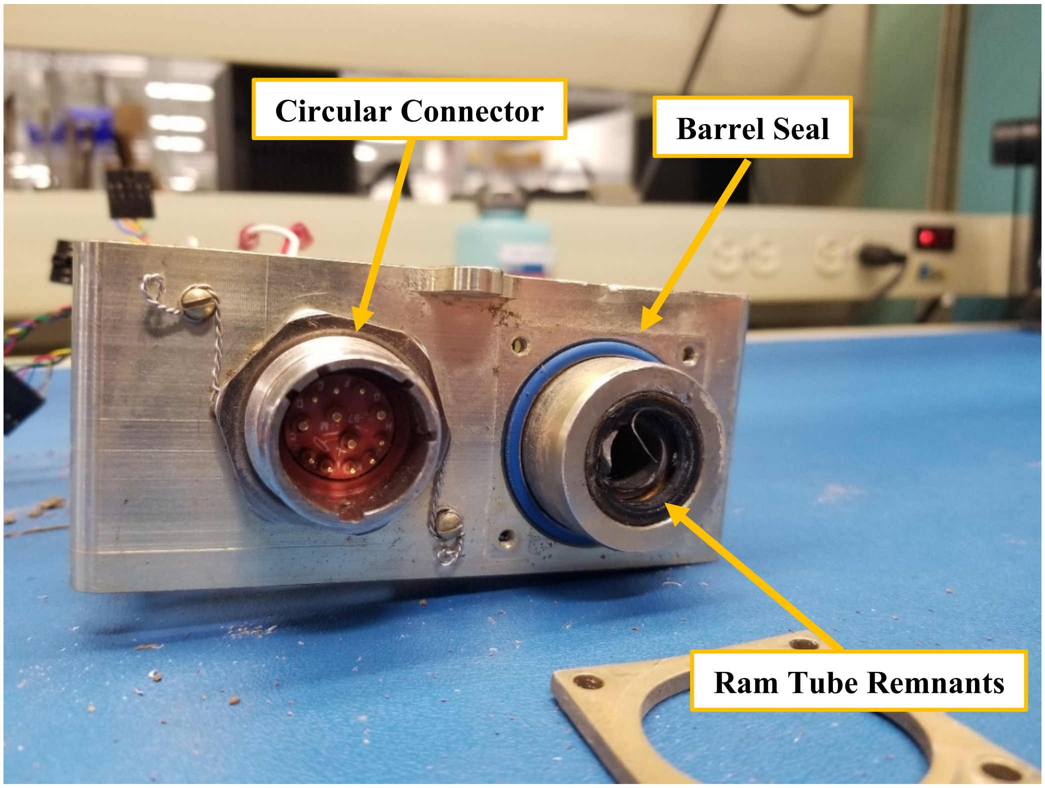


Figure 13 - View of circular connector and barrel seal with mounting plate removed

The top cover of the unit was held on by three of the twelve fasteners. The top cover was removed, and unit contained dirt and leaves inside, ref Figure 14. Damage was noted to multiple fasteners for the linear actuator cover and housing. All of the electrical harness connections from the linear actuator to the main PCB were found disconnected.

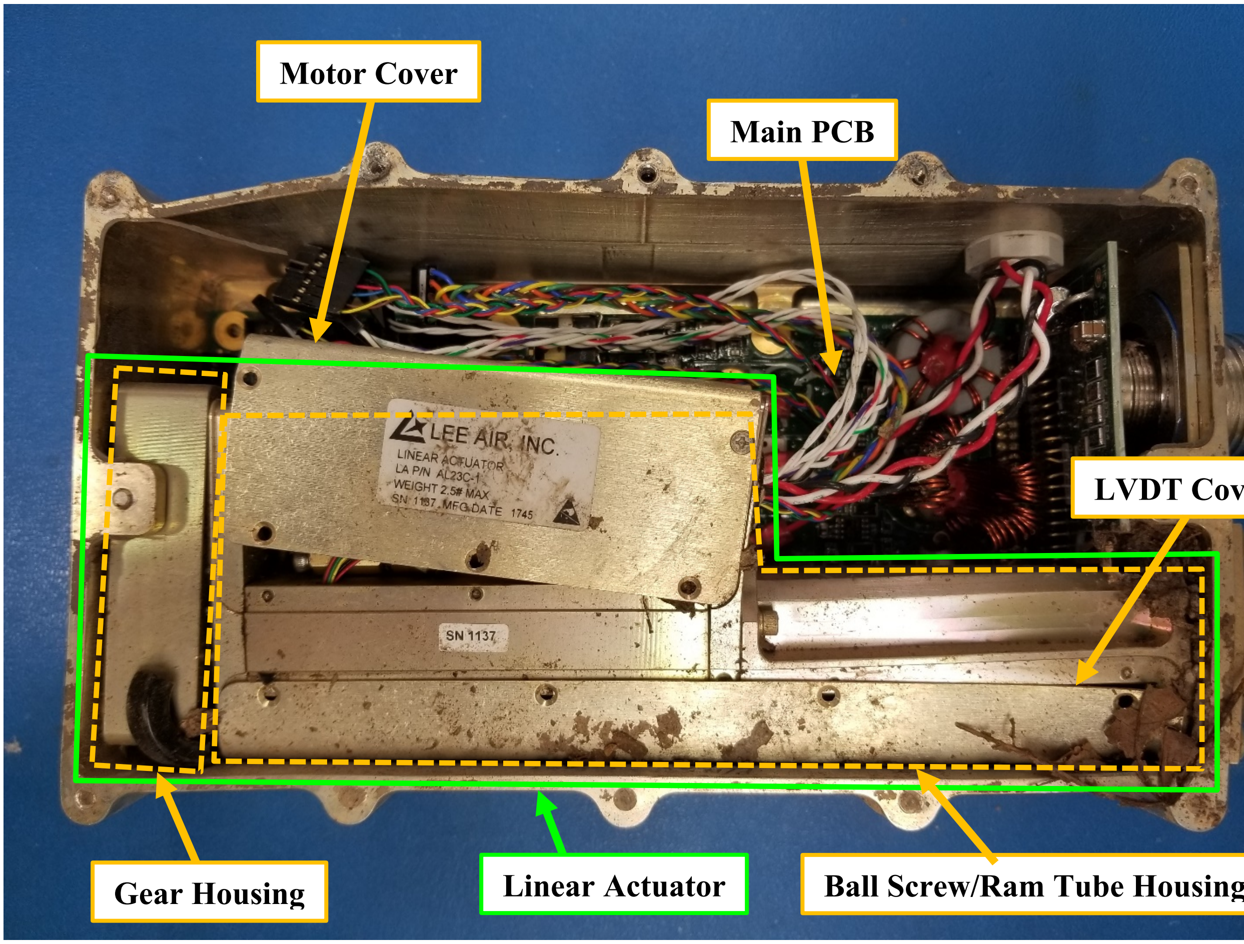


Figure 14 - View of inside of RH TCU

The ground screw, subject of service bulletin CAS/SB1467, was present and secure along with the spring/flat washer combination, ref Figure 15. One of the toroid inductors mounted on the main circuit board was fractured and multiple pieces of the toroid core were recovered within the unit. The linear actuator was removed to allow examination of the main PCB and the actuator. The circular connector PCB was removed and damage/witness marks were noted around the interface of the frame to the standoff and circular connector, ref Figure 16.

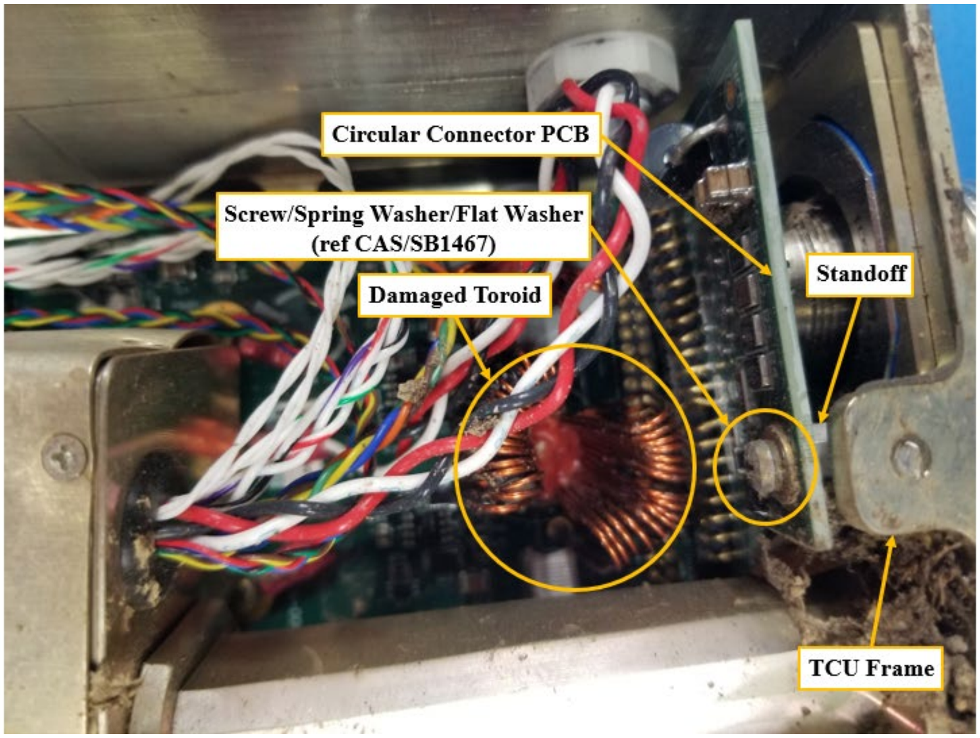


Figure 15 - Close-up view of damaged toroid and PCB screw

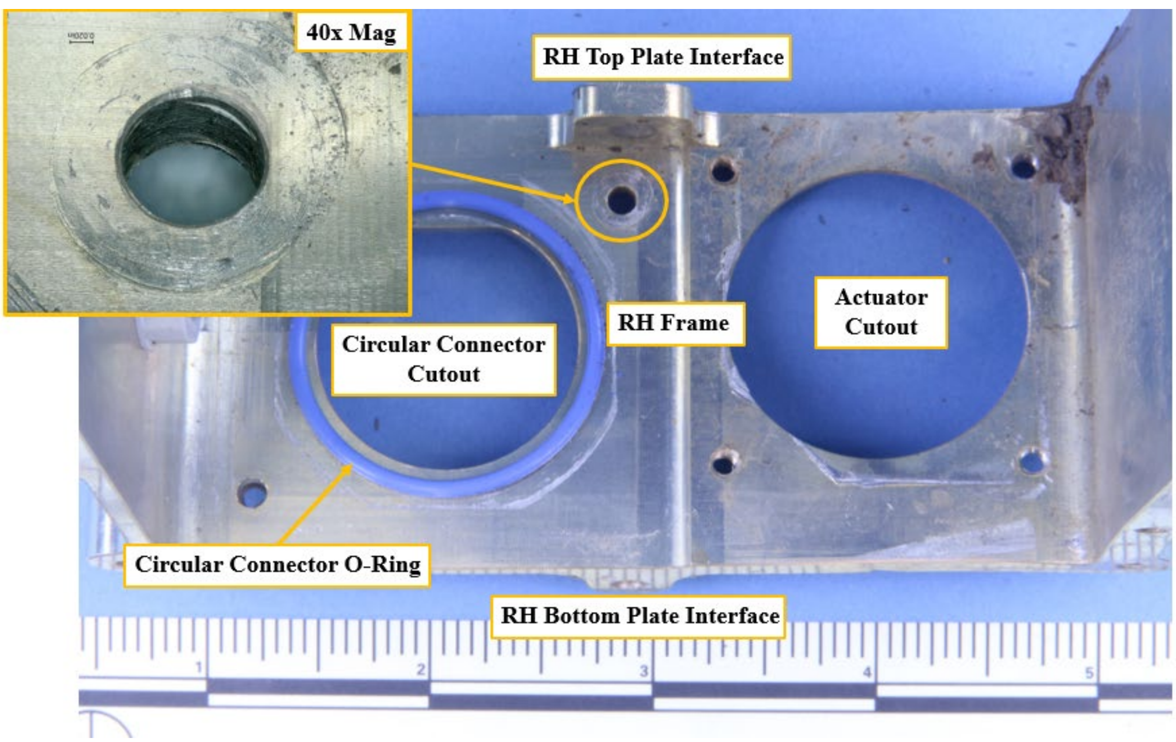


Figure 16 - View of RH frame and close-up of damage around standoff, circular connector and frame interface

The main control board, which is typically fastened to the bottom cover, was displaced in the unit and all the mounting bolts exhibited tension failures with the bolt heads not present. The main control board was distorted, and some components were damaged on both sides of the board.

Multiple surface mounted components were not attached to the PCB and were not located. Damage to multiple pins on the 40-pin connector was also noted, ref Figure 17.

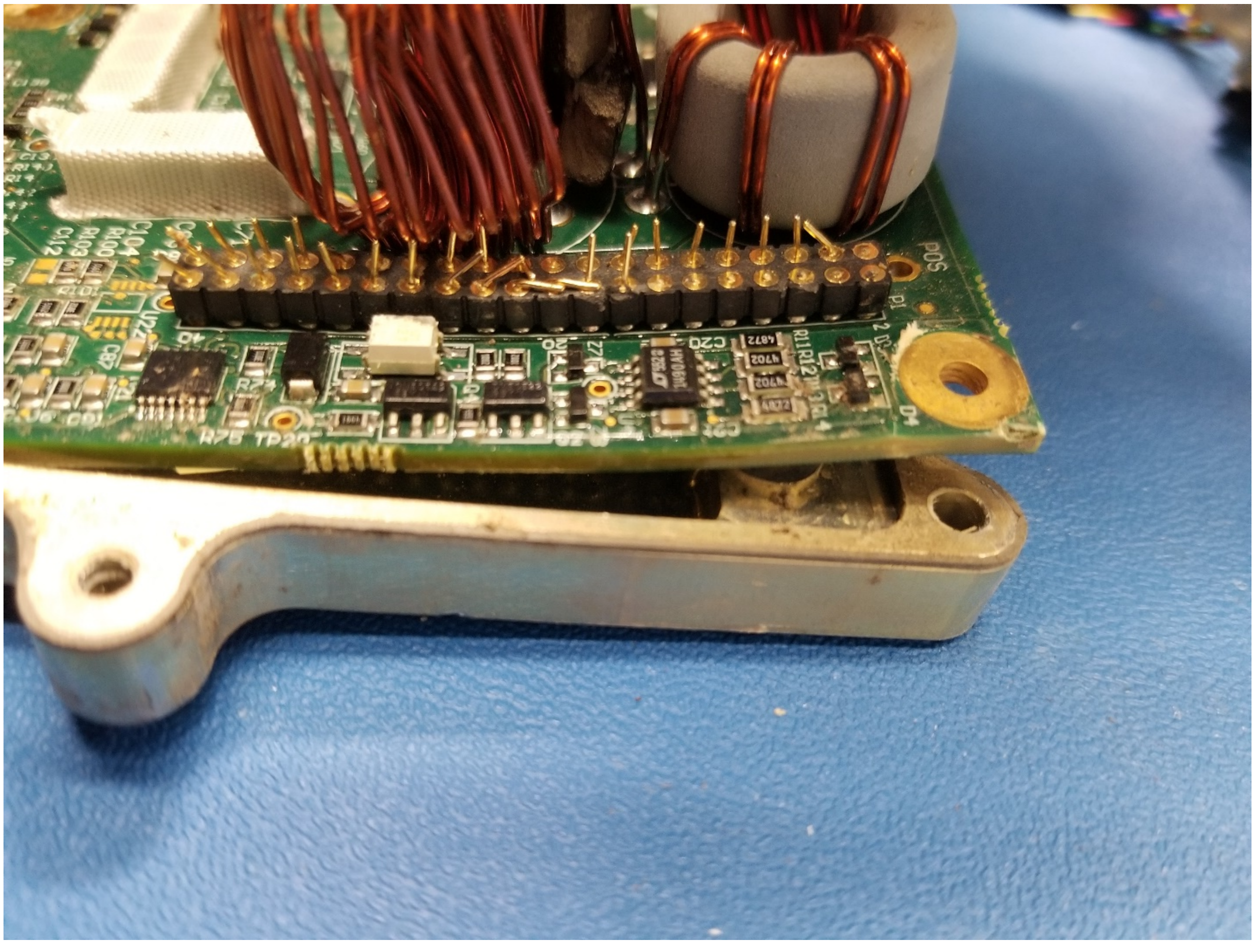


Figure 17 - View of main PCB and 40-pin connector

Additional images of the backside of the main PCB and the bottom plate show the extent of damage to the components. Figure 18 highlights damage to the J-frames of three stacked capacitors, exhibiting signs of crushing. Figure 19 contains the bottom plate of the RH TCU and approximations of the locations of the 40-pin connector and stacked capacitors.

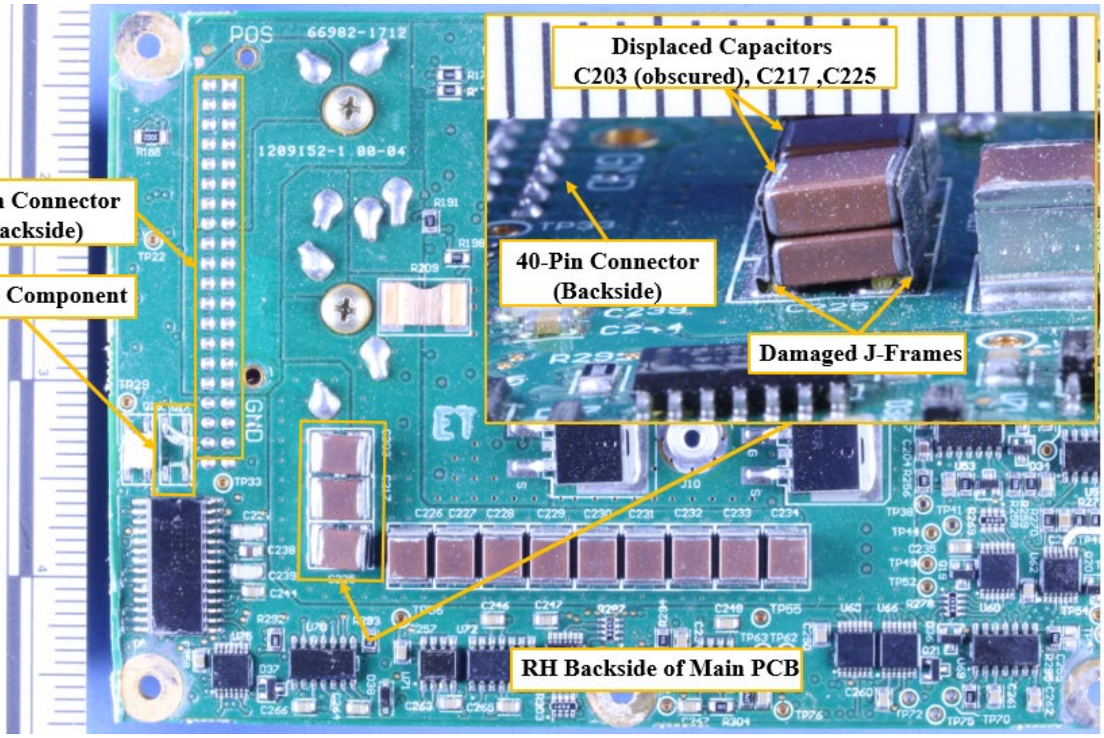


Figure 18 - Damage to the backside of the main PCB components in area around the 40-pin connector

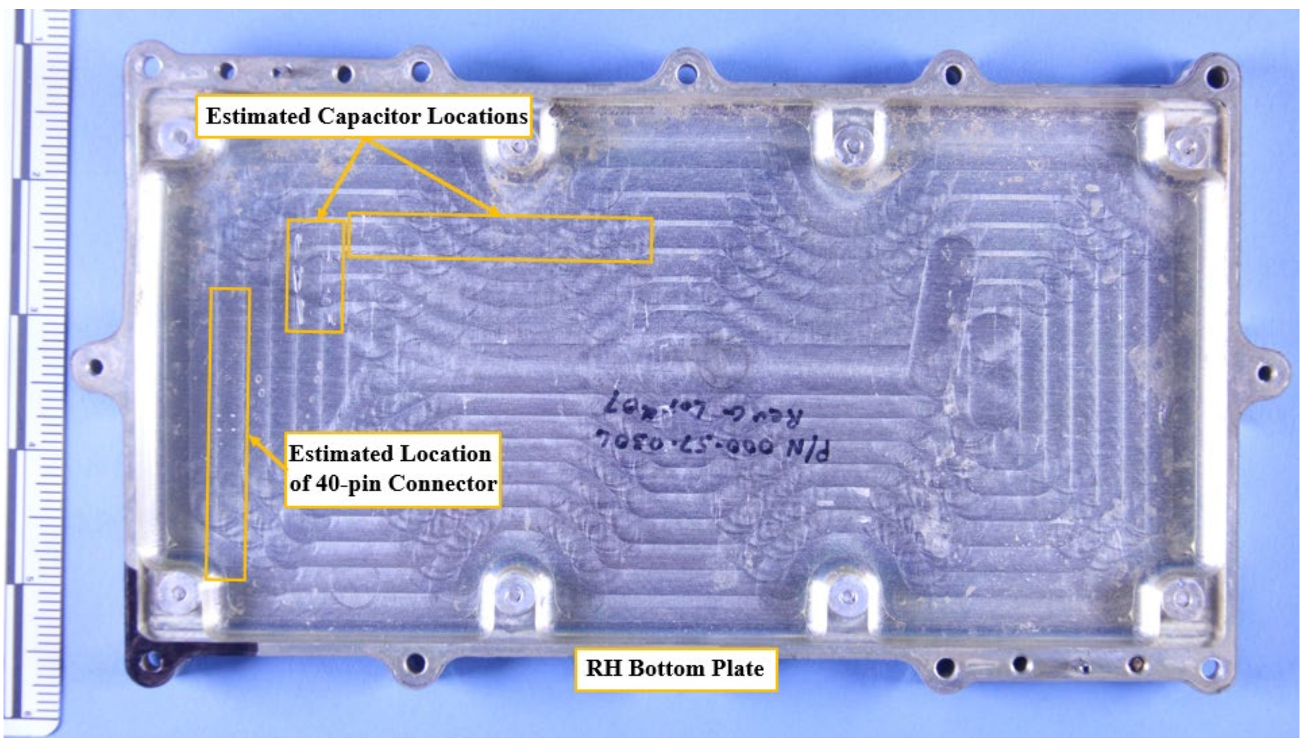


Figure 19 - The RH TCU bottom plate with approximate locations of 40-pin connector and stacked capacitors

Located on the linear actuator, the linear variable differential transformer (LVDT) cover screws and some motor cover screws on the actuator were sheared off at their respective locations. The screws are typically #2-56 flat head machine screw. The gear housing was separated from the motor and ram tube assembly. The gears did not show signs of missing teeth or damage. The screws attaching the gear train to the motor and ram tube exhibited signs of tensile failure consistent with impact damage. All three motor screws were fractured, one mounting screw was not present.

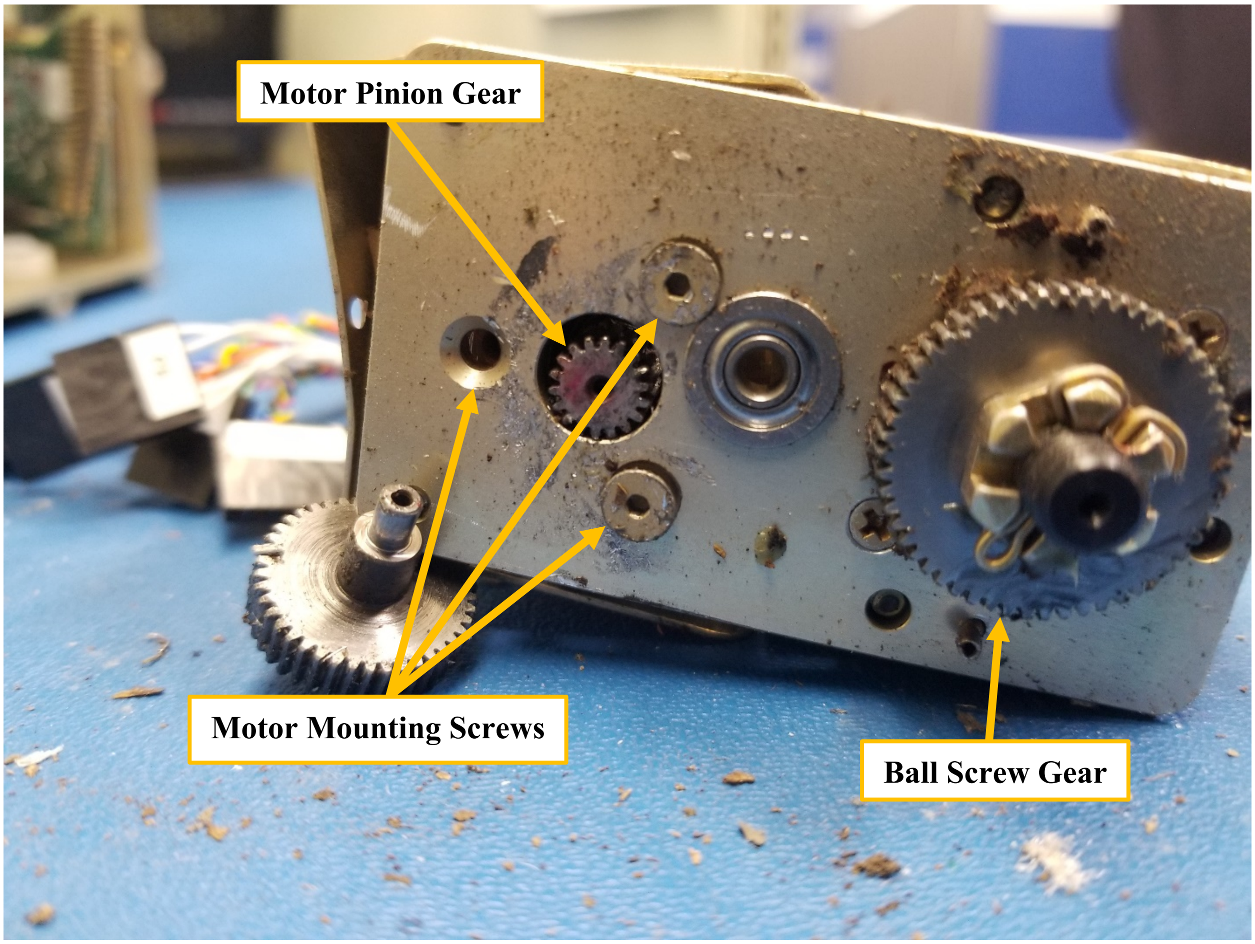


Figure 20 - View of the motor mounting screws, pinion gear and ball screw gear.

The ball screw was lubricated and free to move by hand with no signs of binding. The ram tube assembly was fractured at the ball screw and the remaining portion of the ram tube, internal to the actuator assembly, was bent.[10] There were no discernable marks on the retract hard stop indicative of a high force impact. There was a slight mark which was consistent with marks occurring during acceptance testing procedure (ATP) testing of the actuator during the back-drive force test, ref Figure 21. There were no discernable marks on the extend hard stop, ref Figure 22.

Witness marks were observed on the ram guide housing, ref Figure 23. An additional mark was seen on the bottom ram guide housing which would not normally be in contact with the ball nut, ref Figure 24. The location of the witness marks corresponded to a position of approximately mid-travel of the actuator.

[10] The remaining portion of the ram tube assembly was located within the aircraft structure.

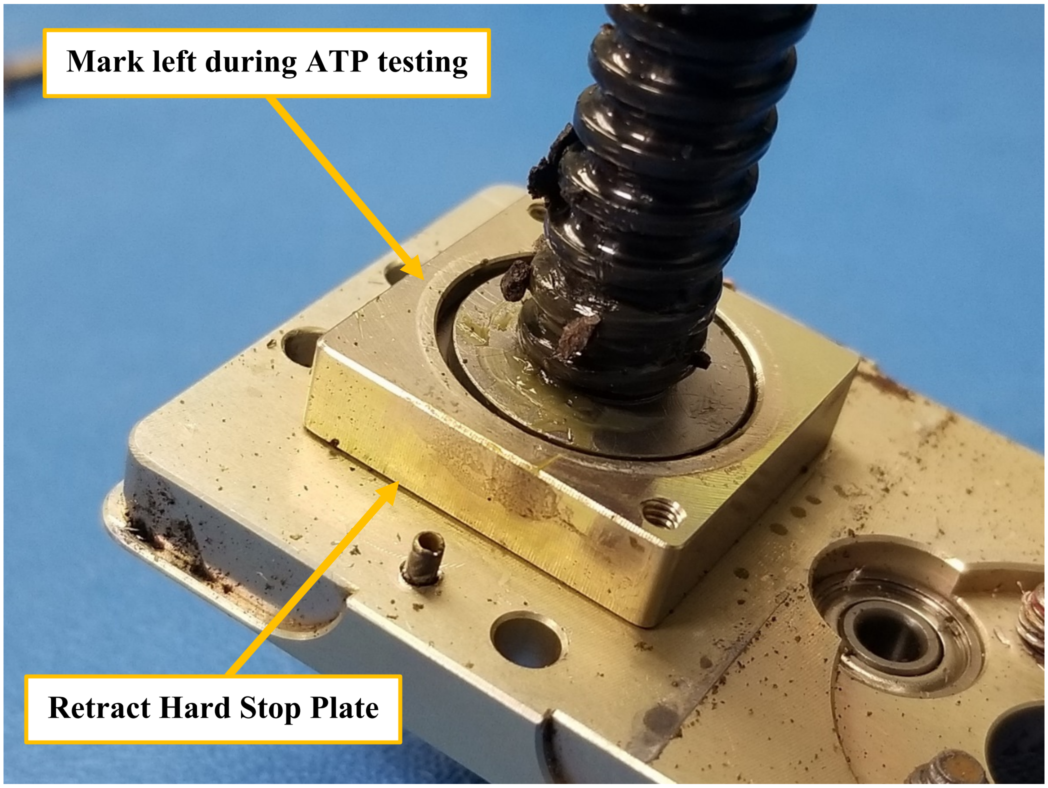


Figure 21 - Retract hard stop plate

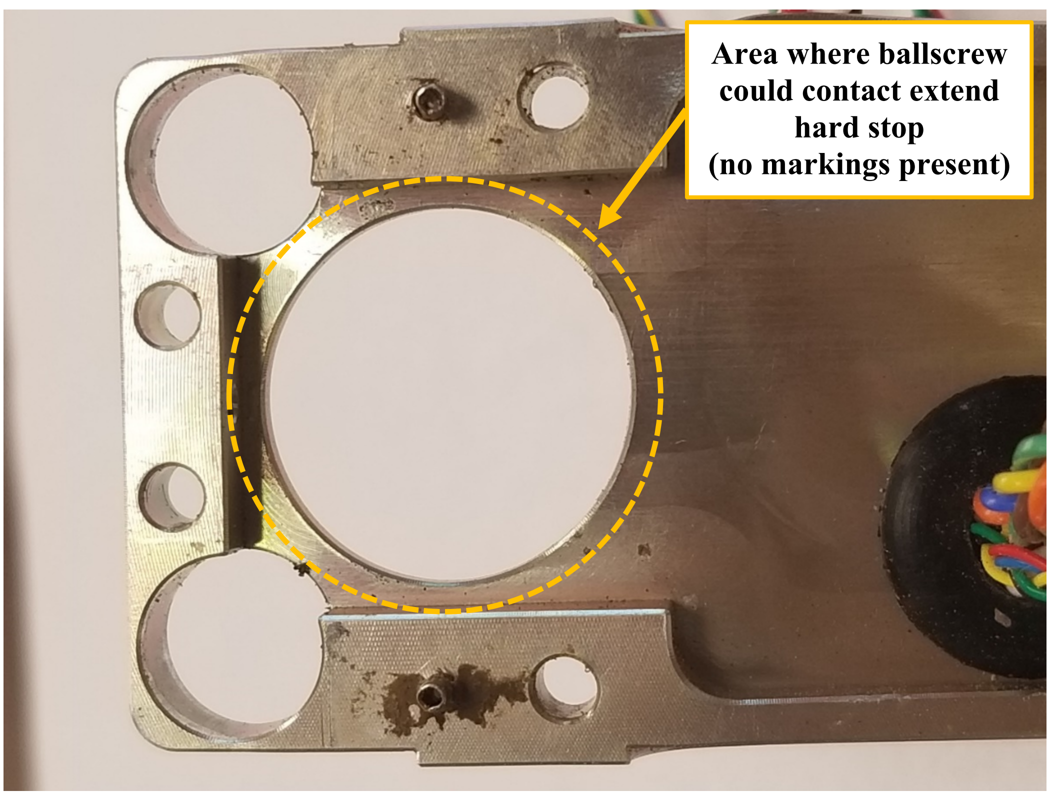


Figure 22 - Extend hard stop highlighting area where marks could be present

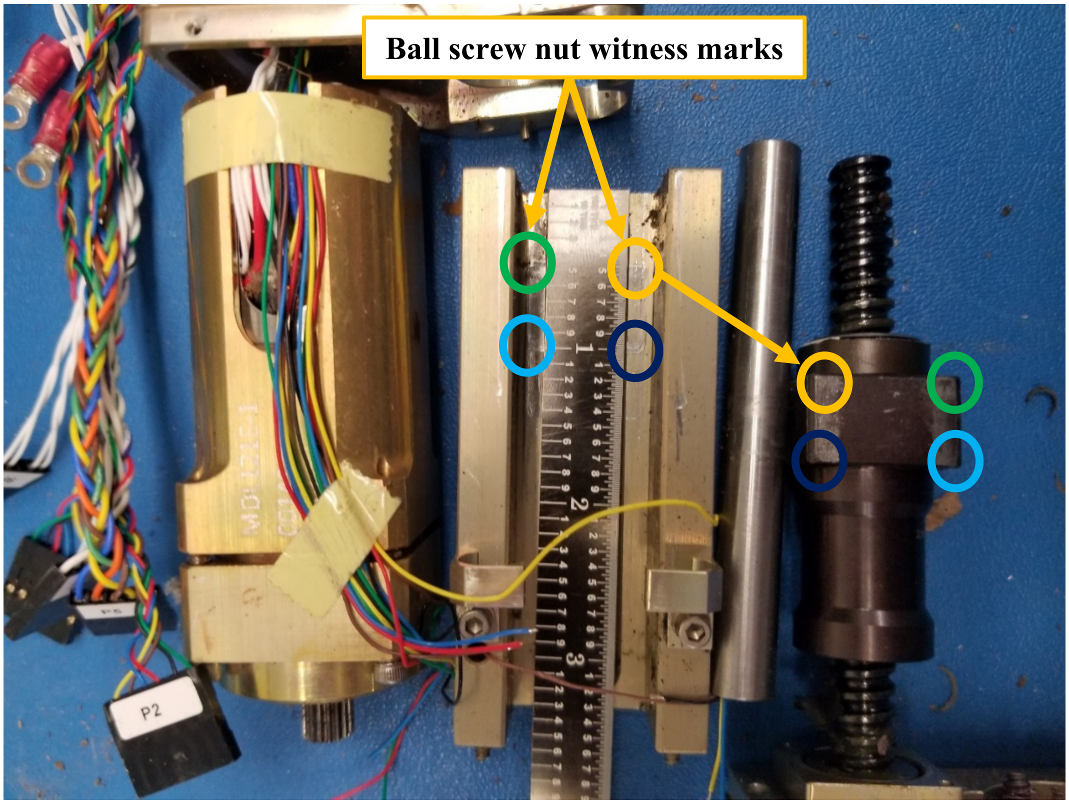


Figure 23 - Ball screw nut witness marks on ram guide housing

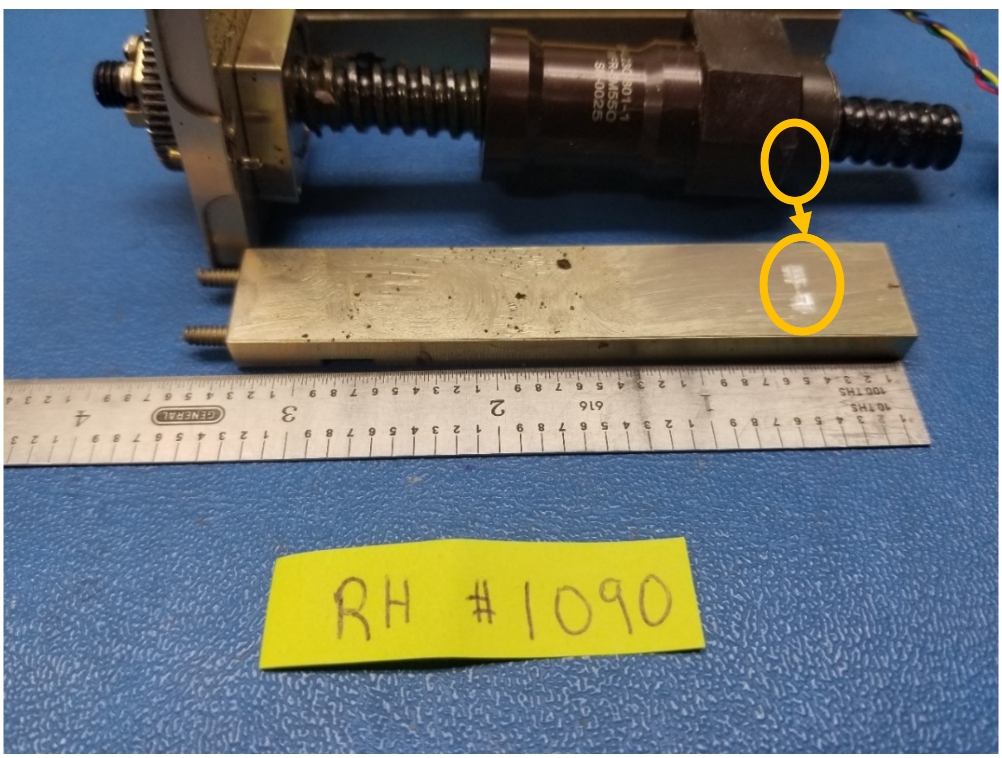


Figure 24 – Bottom ram guide housing with witness mark highlighted

The linear actuator contains two independent linear variable differential transformers (LVDTs). Both LVDTs were displaced from their mounting positions. Scratch marks were observed starting where the LVDTs were originally secured and continuing lengthwise along the LVDT towards the final, as found position. Wiring to both LVDTs was broken.

During the production of the units, Tamarack requested that additional staking compound be added to the signal wires, as a general product improvement, to improve stability where they exit the LVDT, ref Figure 25[11]. The additional staking was implemented by the manufacturer in the beginning of 2019 for new production units and previously produced units would have the additional staking applied per SB CAS/SB1480. The LVDTs for the accident unit did not have additional staking where the signal wires exit the unit, ref Figure 26.

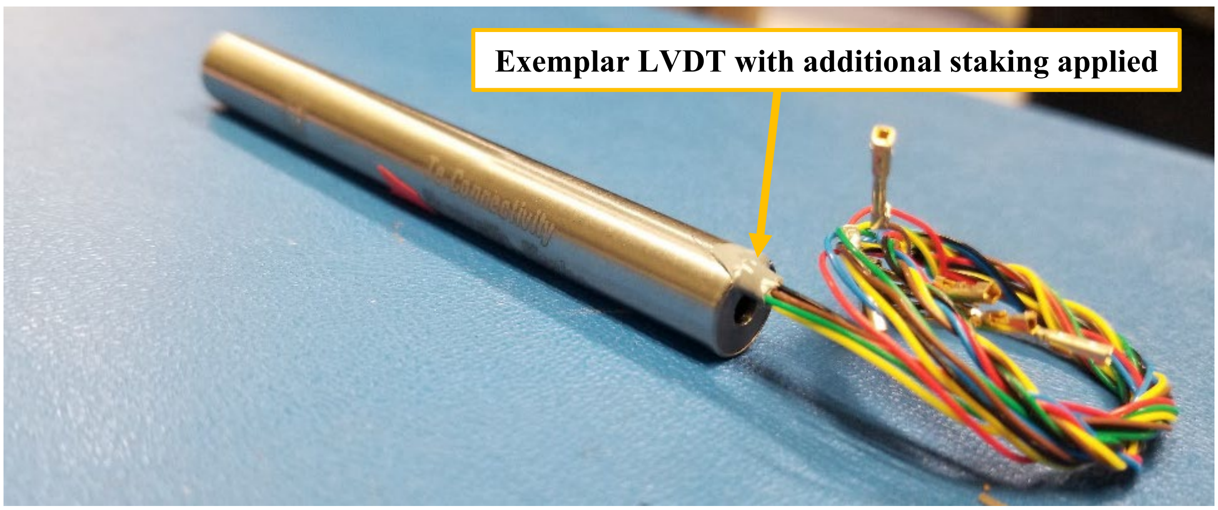


Figure 25 - Exemplar LVDT with staking applied to signal wires

[11] Staking is a process where an adhesive or epoxy is applied to a component to relieve strain on components or wiring in areas that see high vibration or shock.

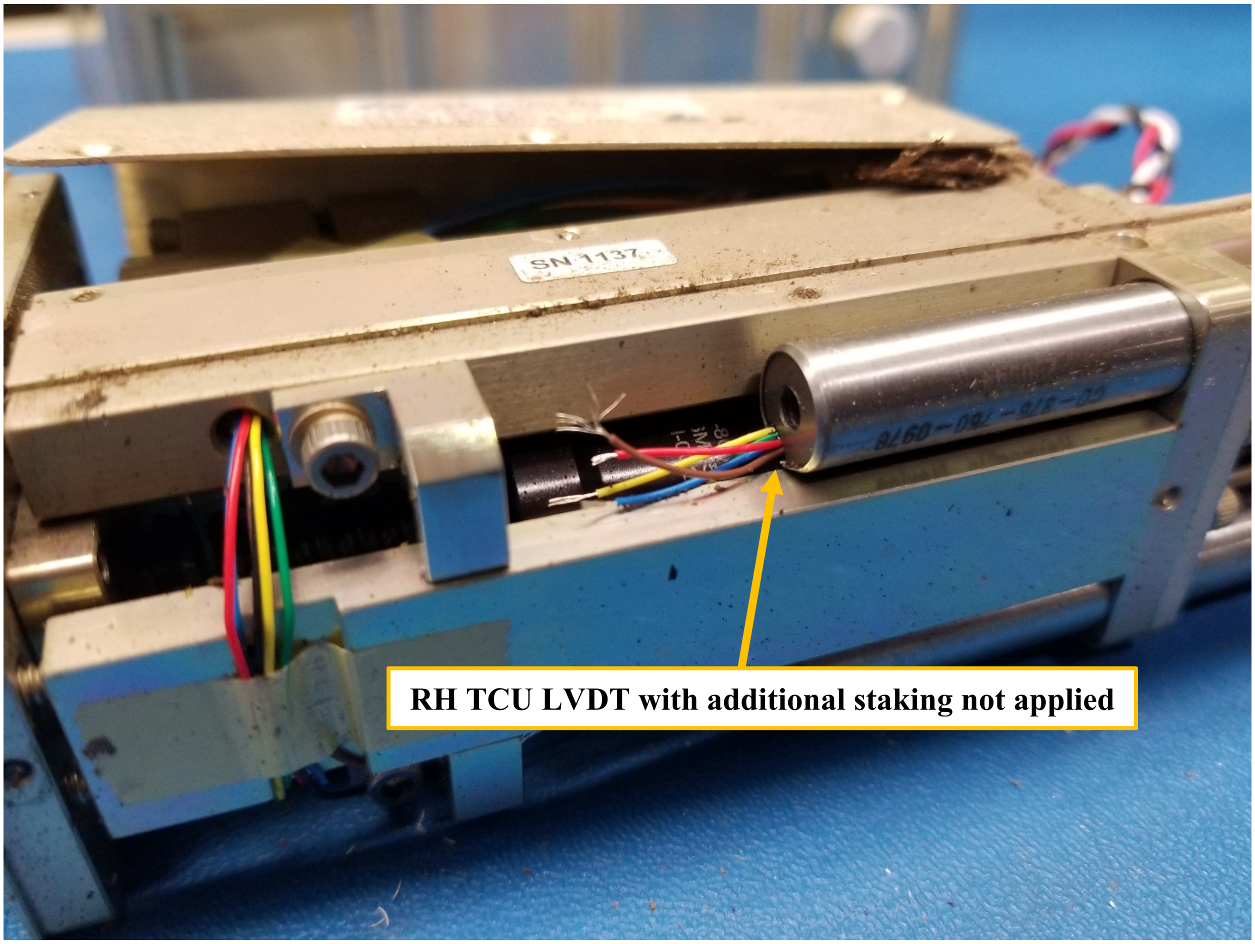


Figure 26 - RH TCU LVDT (one side shown) noting the absence of additional staking

4.4.2.1.2.3 Additional Testing

Due to the damage to the TCU, the ATP testing could not be performed. Testing of individual components could not be performed, except for the LVDTs. Electrical checks of the LVDTs for shorts/continuity were performed for each unit. One unit was consistent with an exemplar unit. The other unit was missing two wires due to the impact damage and could not be fully tested.

4.4.2.1.3 Left TACS Control Unit (TCU)

The TCU was located in the recovered wreckage and was found in a section of wing tip structure where it is mounted, ref Figure 27. The section of wing tip structure where the TCU was mounted still had the access panel attached. Due to impact forces, an outline consistent with the TCU, was impressed into the access panel, ref Figure 28. The TCU was removed from the wing structure.

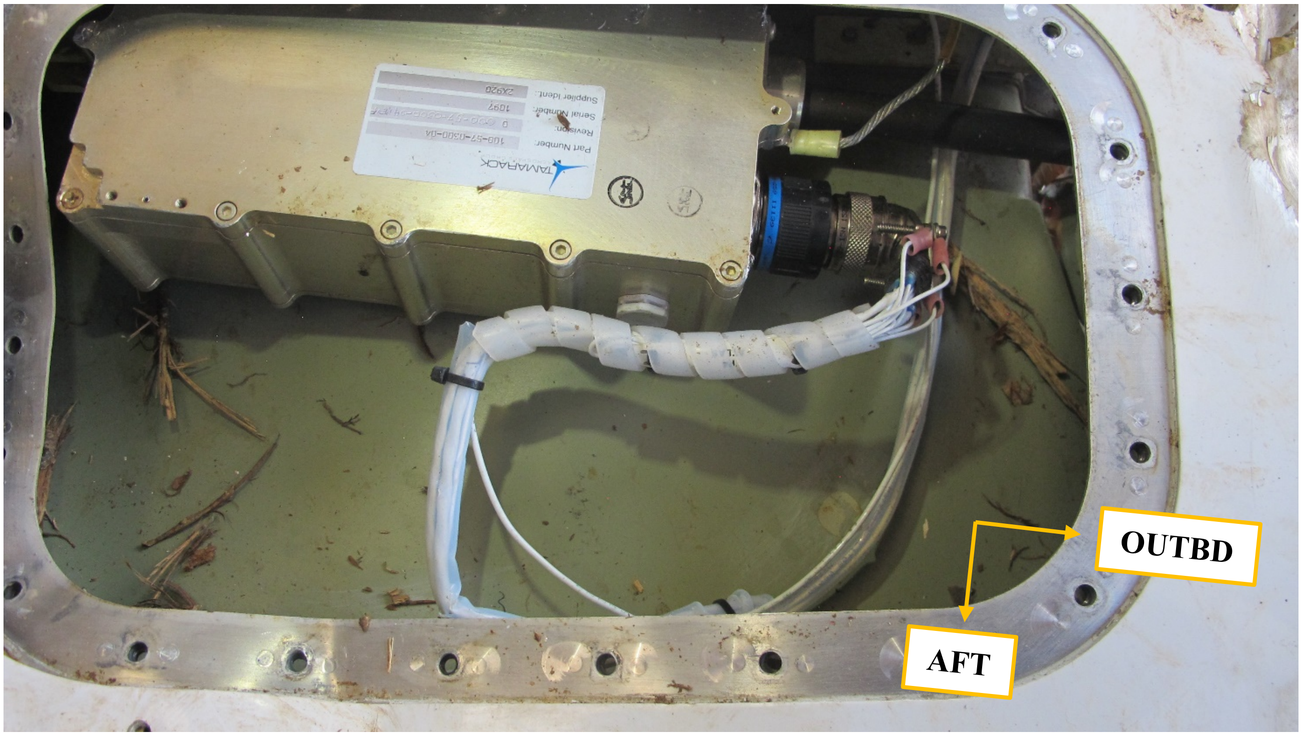


Figure 27 - LH TCU as found in wing tip structure with access panel removed, view looking at underside of wing

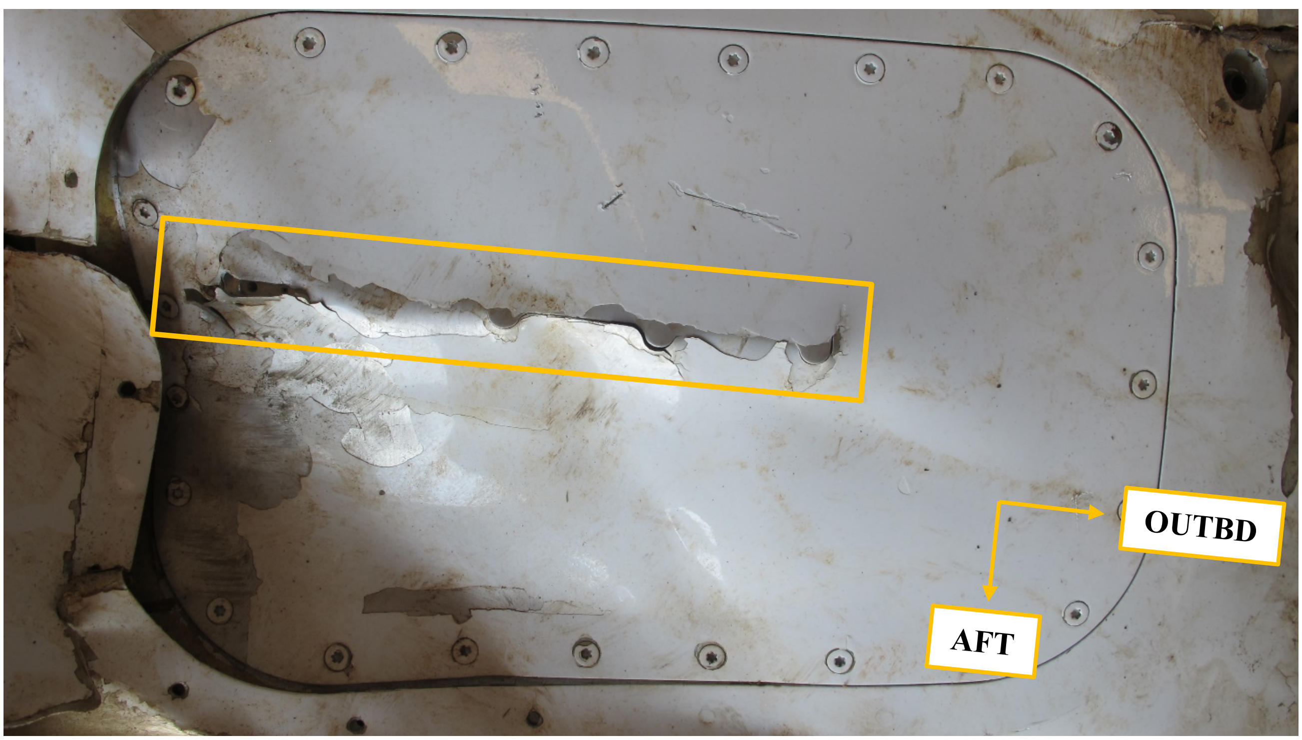


Figure 28 - Wing tip structure with access panel in place, outline of TCU highlighted, view looking at underside of wing

4.4.2.1.3.1 Data Plate and Service History

Based on the unit's data plate:

Part Number:	100-57-0300-04
Revision:	D 000-57-0300-04 REV F
Serial Number:	1097

The unit was manufactured on December 18, 2017. According to manufacturer records, the unit passed its final acceptance test during initial manufacturing on December 18, 2017. The unit had been returned to the manufacturer for rework per service bulletin CAS/SB1467 (ref section 4.6.2). The unit was reworked, tested, and returned to service on July 6, 2018.

4.4.2.1.3.2 Visual Inspection

The TCU case did not exhibit any signs of deformation to the unit's case and the top and bottom cover were secured to the unit. The ram tube was bent and the rod end attaching the remaining section of the walking beam to the ram tube was rotated approximately 90° from nominal, ref Figure 29.

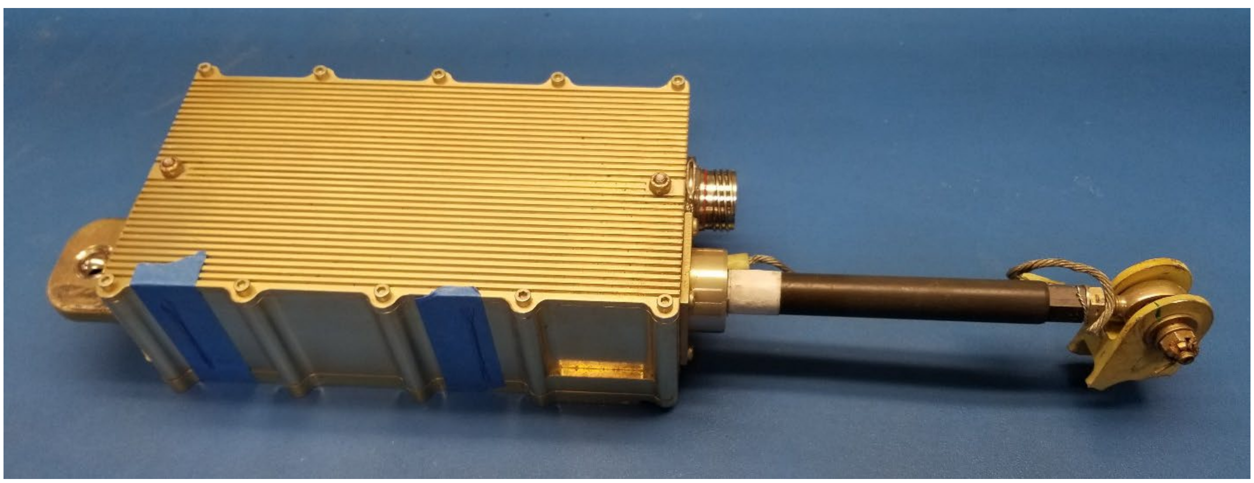


Figure 29 - LH TCU as recovered prior to visual inspection at the manufacturer

During the CT scan review, it was noted that five screw heads were loose within the unit. After removal of the top cover, a visual inspection was conducted, and the five screw heads were identified as part of the LVDT and motor cover assemblies. The screws are #2-56 flat head machine screws and the screw head damage was consistent with shearing due to deformation to the actuator housing. The five screw heads were removed from the TCU prior to starting the electrical testing.

The ground screw, subject of service bulletin CAS/SB1467, was present and secure along with the spring/flat washer combination, ref Figure 30. An additional image showing the SB installation can be seen in Figure 59.

The circular connector PCB was removed and damage/witness marks were noted around the interface of the frame to the standoff and circular connector, ref Figure 31.

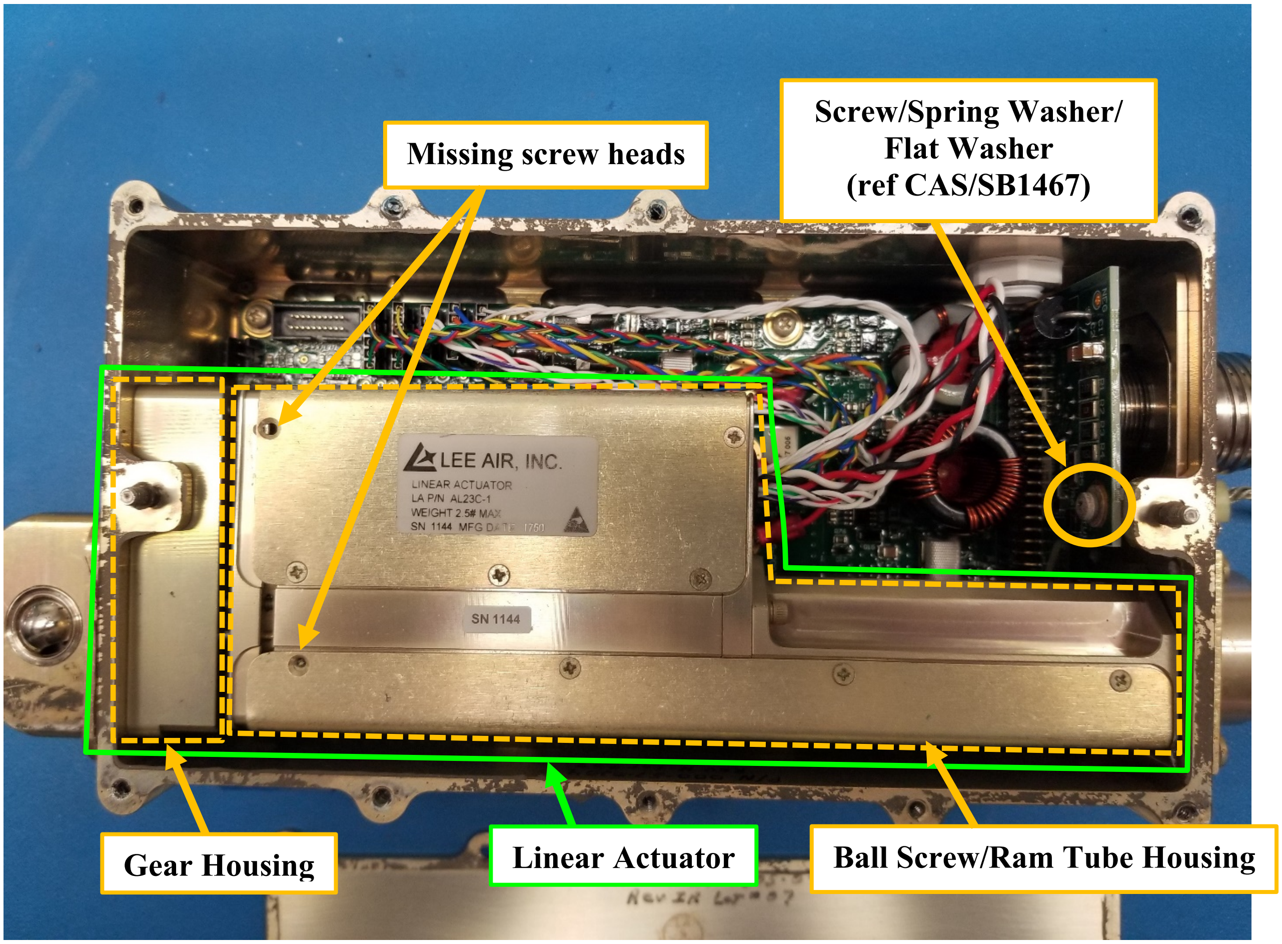


Figure 30 - LH TCU with top cover removed with two of the missing screws noted (three on aft side of linear actuator)

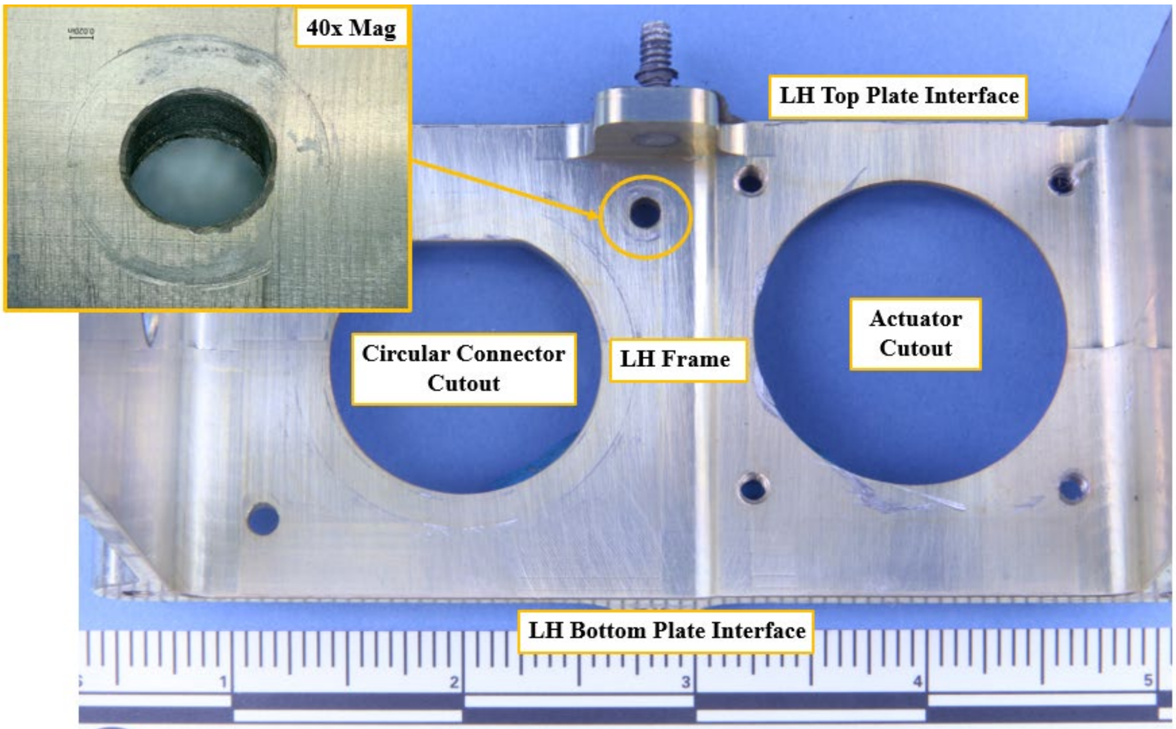


Figure 31 - View of LH frame and close-up of damage around standoff, circular connector and frame interface

During the CT scan review, it was noted that six pins appeared bent near one end of the 40-pin connector in the unit. A visual inspection was performed to check the condition of the 40-pin connector, prior to the electrical testing. See section 4.4.2.1.3.3 for electrical testing discussion and results. The bent pins were not easily visible with only the top cover removed; however, a larger than normal gap between the two halves of the connector was visible, with the gap at a maximum in the location of the bent pins. After completion of the electrical testing the unit was further disassembled, and the 40-pin connector was separated. Figure 32 shows the 40-pin connector after the center case was removed and prior to the main PCB/circular connector PCB separation. Figure 33 shows the damaged pins and highlights the signals that are carried along the pin. Figure 34 shows the socket interface where the damage from the bent pins is visible.

The manufacturer noted that during the build process for the TCU, the pin/socket connection is mated and de-mated 3 or more times during the build process. The pin/socket connection is visually verified by the technician assembling the unit and subsequently visually inspected during the build process. During the discussions with the manufacturer, they stated that the build process did not match the manufacturing aid document and the document also contained an incorrect statement with regards to the connector PCB attachment to the controller PCB. Additionally, during the rework process for service bulletin CAS/SB1467, a visual inspection of the unit and PCBs is performed. During service bulletin CAS/SB1467, the pin/socket connection is not mated or de-mated per the manufacturer's instructions. As of June 15, 2020, the manufacturer inspected 40 units, representing 18% of the in-service TCU's, and did not find any damage consistent with the bent pins seen on the accident unit.

Figure 32 - View of the 40-pin connector showing damaged pins after center case removed

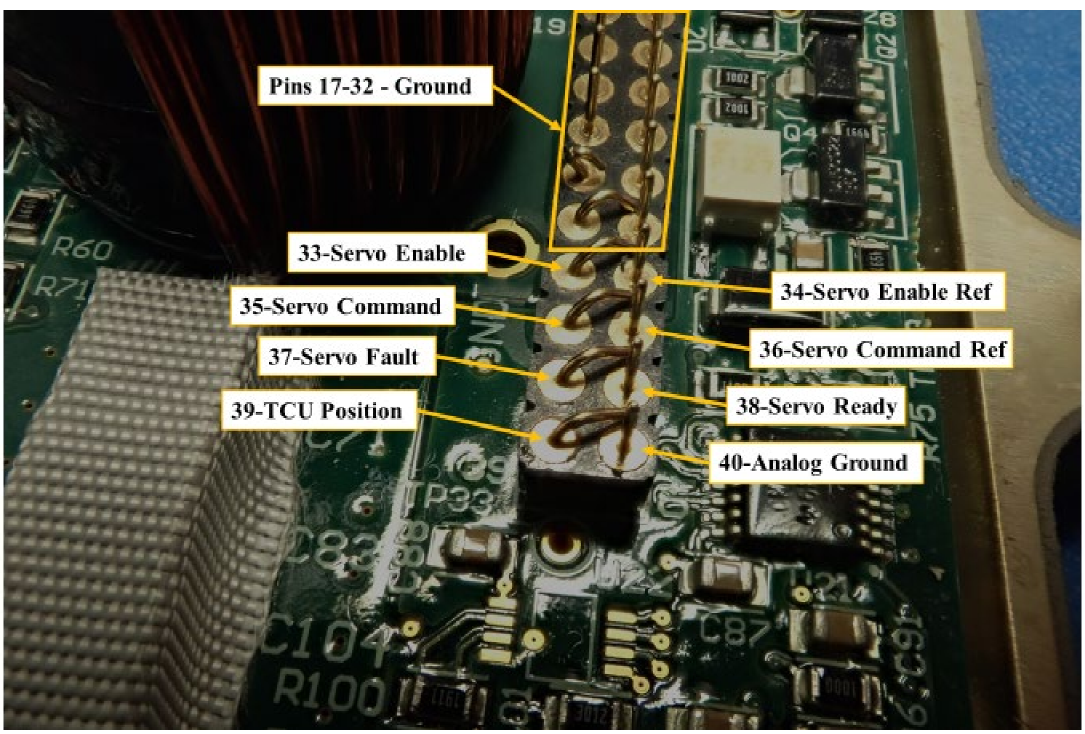


Figure 33 - View of 40-pin connector after separation

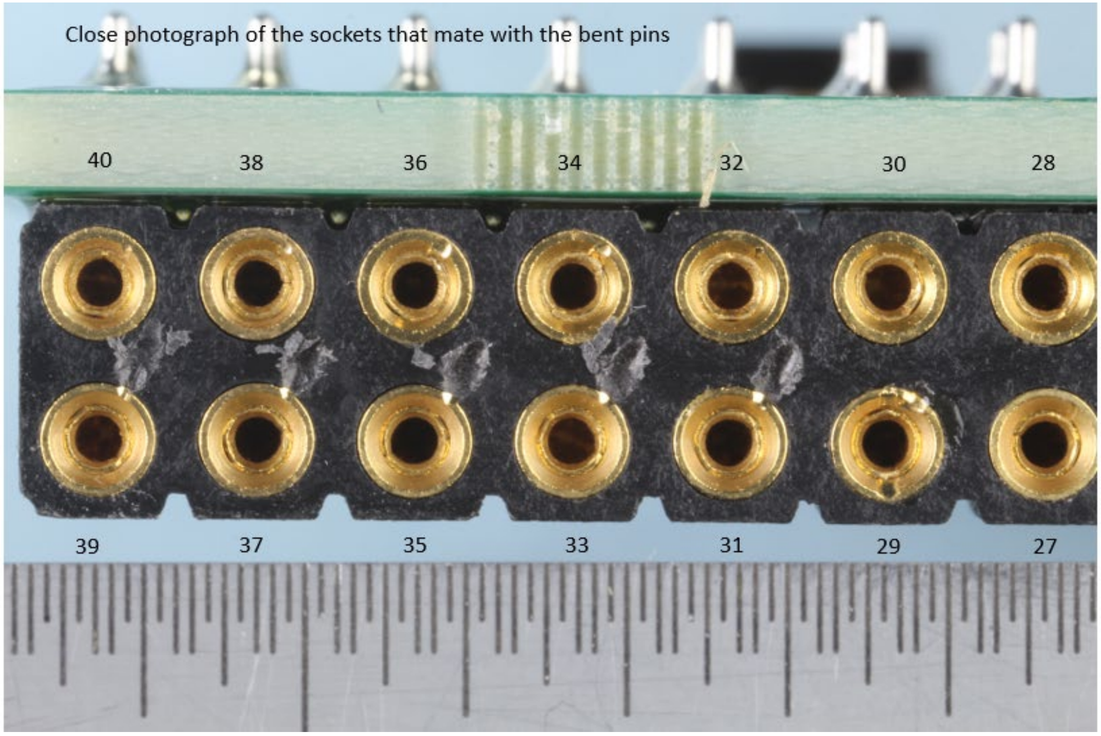


Figure 34 - Sockets in the area around the bent pin locations, damage to connector material is visible

The pins and the sockets of the 40-pin connector were inspected using the NTSB Materials Laboratory high power microscopes and their Scanning Electron Microscope (SEM). The socket and pin layout contains two rows of twenty pins each. Images of the socket contact points were taken for the sockets of multiple socket sets on each row. In Figure 35 and Figure 36, sockets related to pins 07, 08 and 36 which were unbent and socket related to pin 35 which was bent. Additional SEM imagery can be found in Appendix A.

Additionally, even numbered pins 24 through 40 and pin 27 exhibited nick artifacts in approximately a 5 o'clock position. Socket 24, even numbered sockets 28-40 and socket 27 exhibited a nick or a material deposit at the 1 o'clock position.

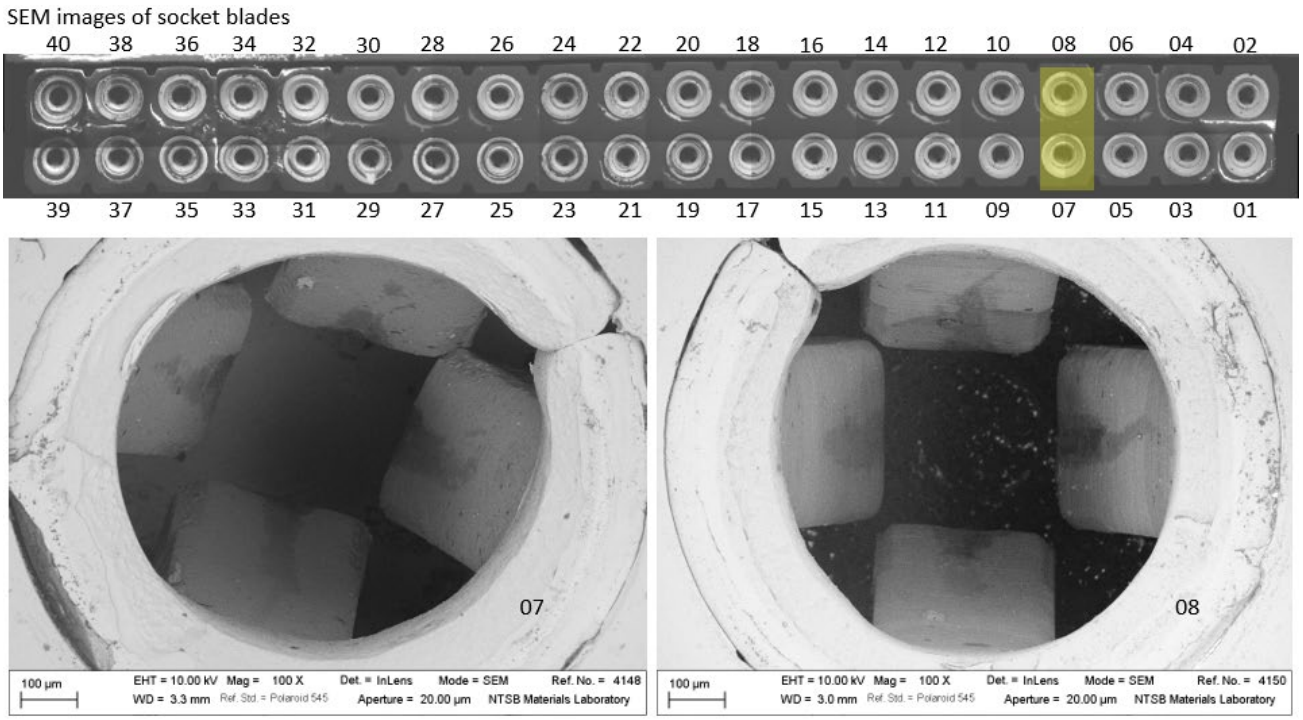


Figure 35 - SEM imagery comparison of sockets 07 and 08

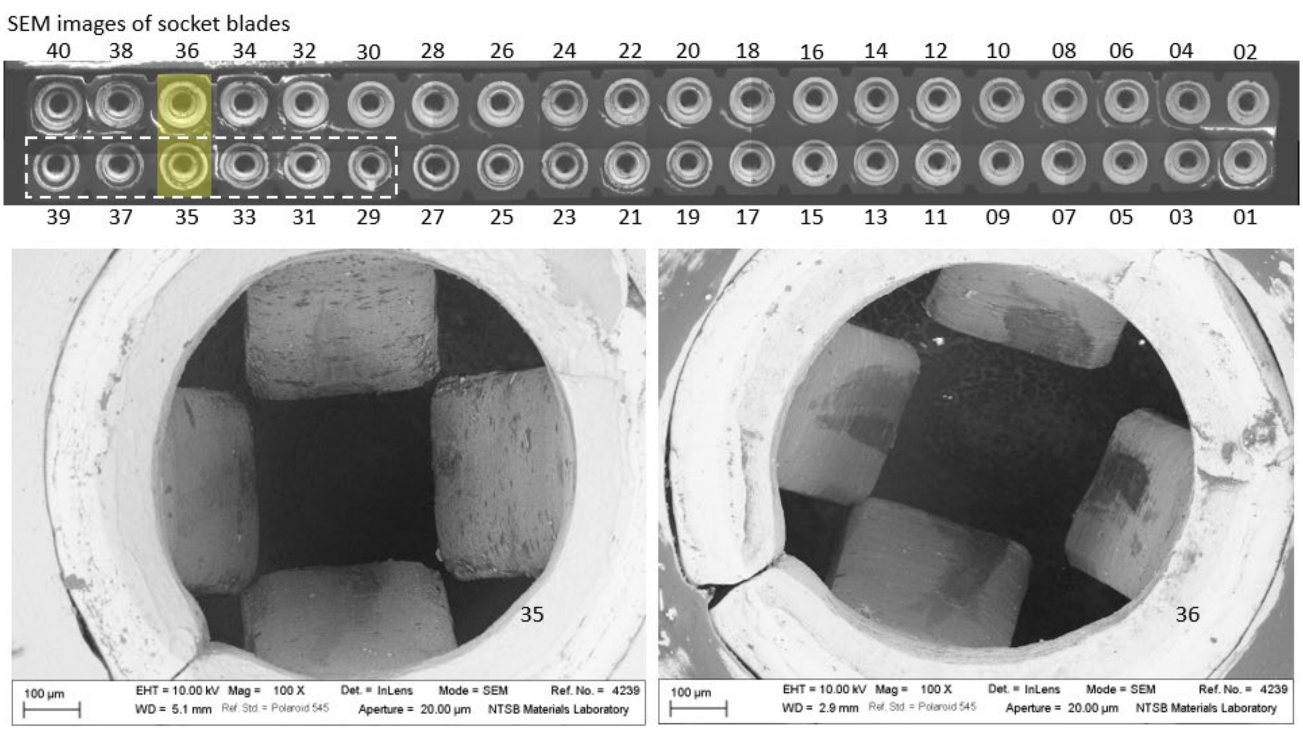


Figure 36 - SEM imagery comparison of sockets 35 and 36

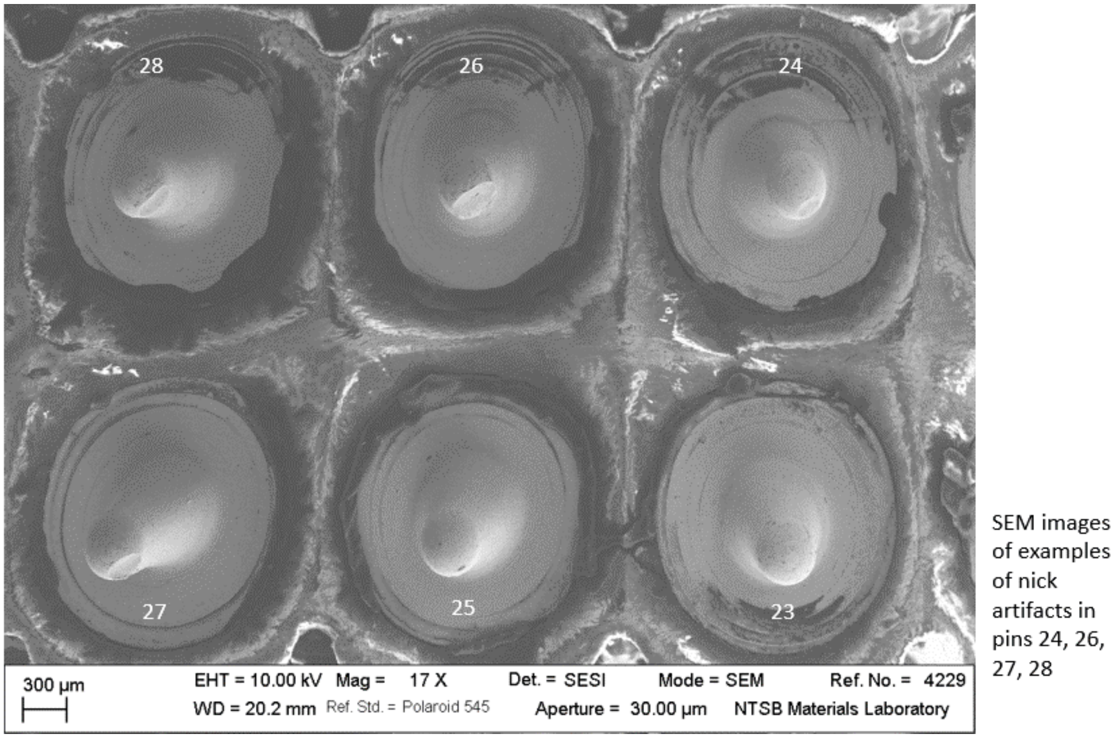


Figure 37 - SEM imagery nick artifacts on pins at approximately 5 o'clock position

SEM Images of sockets with a nick or deposit at the ~1:00 position

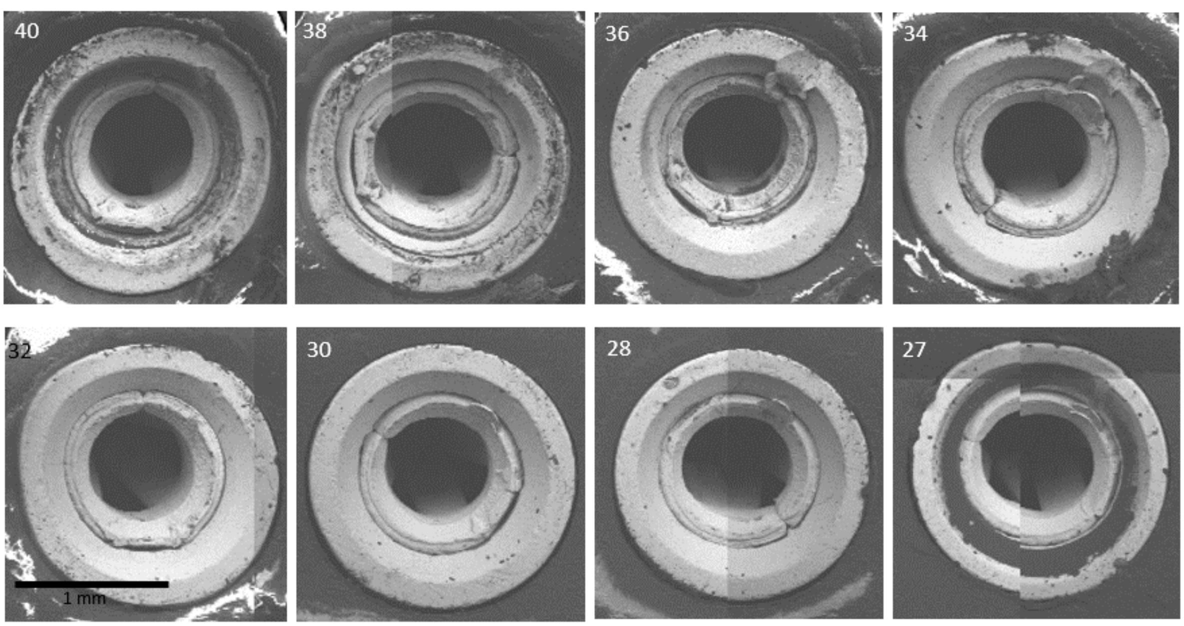


Figure 38 - SEM imagery nick artifacts on sockets at approximately 1 o'clock position

The main PCB was removed from the bottom case to check for any marks or damage. No components appeared to be missing from the backside of the main PCB. There were no marks or patterns consistent with bending or flexure on the PCB. One capacitor, C226, was misaligned with respect to the adjacent capacitors, ref Figure 39. One J-Frame, attached to C226, was fractured across a majority of the width near the base of the J-Frame, but appeared to remain in electrical contact with the capacitors and PCB. An area on the top of capacitors C226 and C227 had noticeable damaged to the conformal coating and the corner of the J-Frame, ref Figure 40. Additionally, the J-Frame exhibited signs of buckling near the PCB attach point.

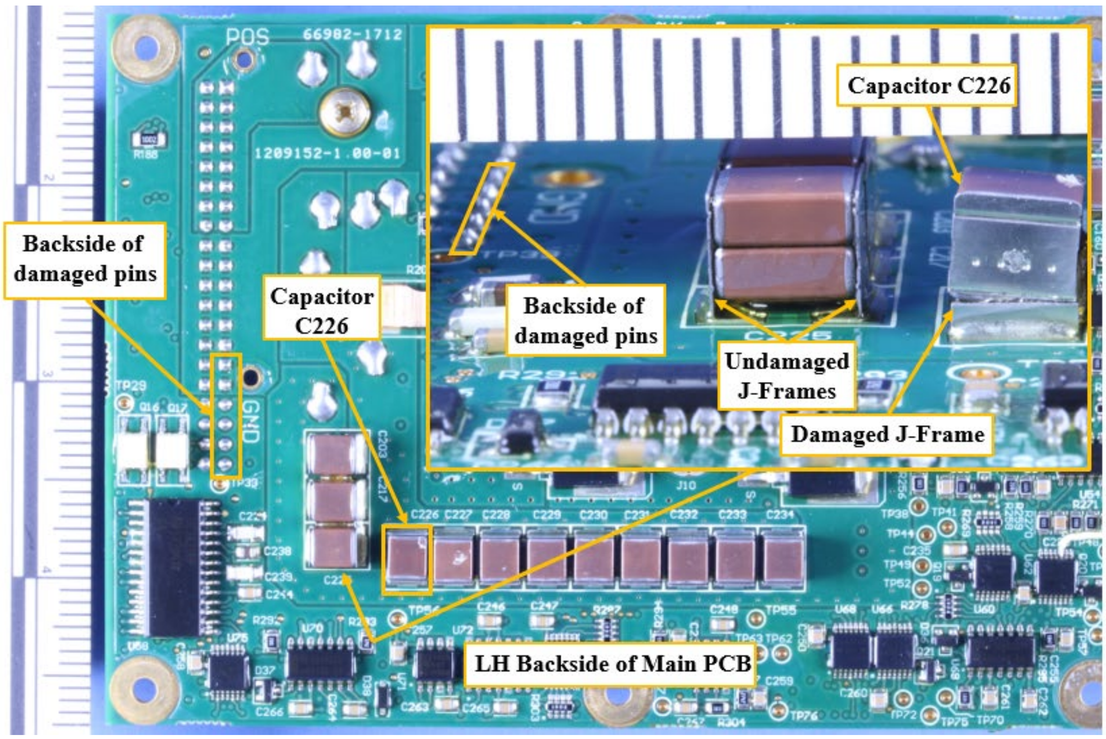


Figure 39 - View of back side of main PCB of the LH TCU in area of 40-pin connector

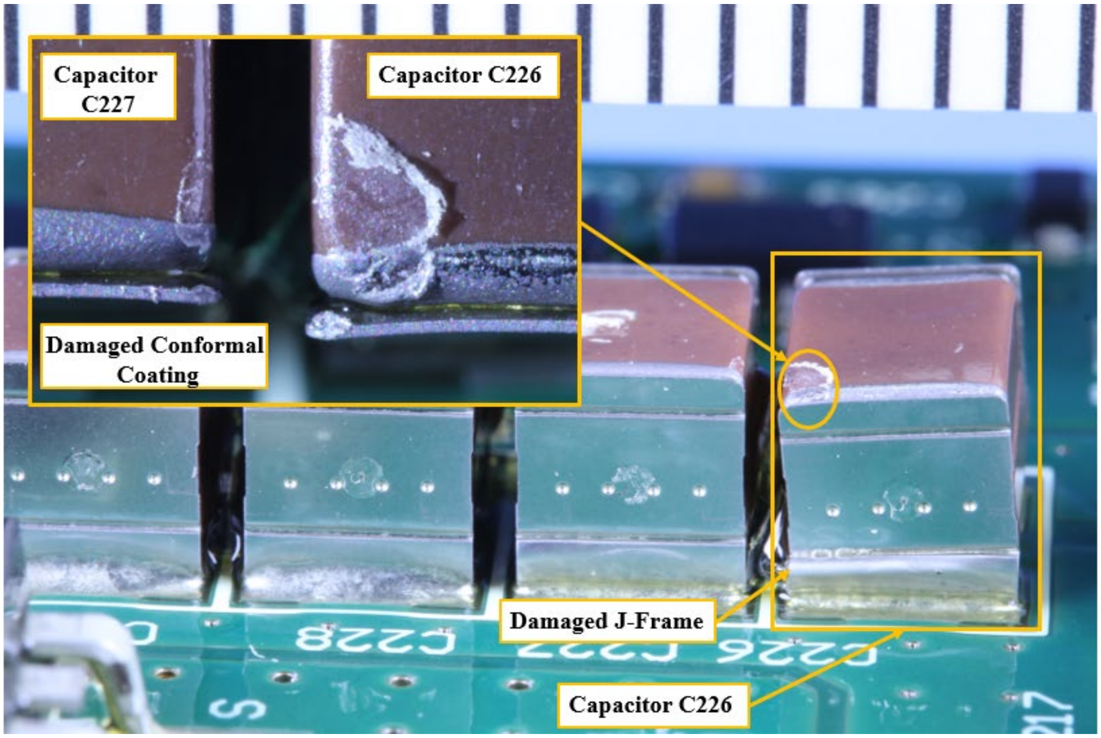


Figure 40 - View of the C226 capacitor showing the damage to the conformal coating and J-Frame

A pair of circular marks/deposits located approximately under C226 and C227 and a pair of witness marks in the area approximately under capacitor C203 were identified on the TCU bottom plate. Figure 41 contains the bottom plate of the LH TCU and approximations of the locations of the 40-pin connector and stacked capacitors. Figure 42 contains an additional view of the circular marks and a microscopic image of the marks/deposits.

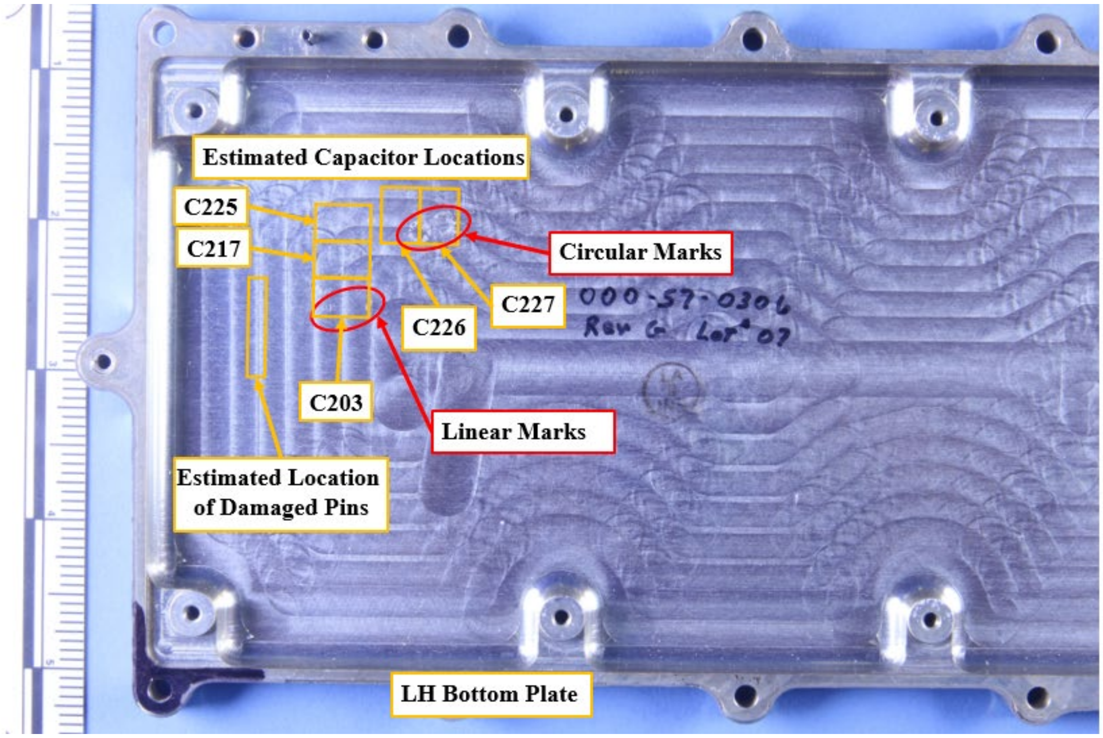


Figure 41 - The RH TCU bottom plate with approximate locations of 40-pin connector and stacked capacitors

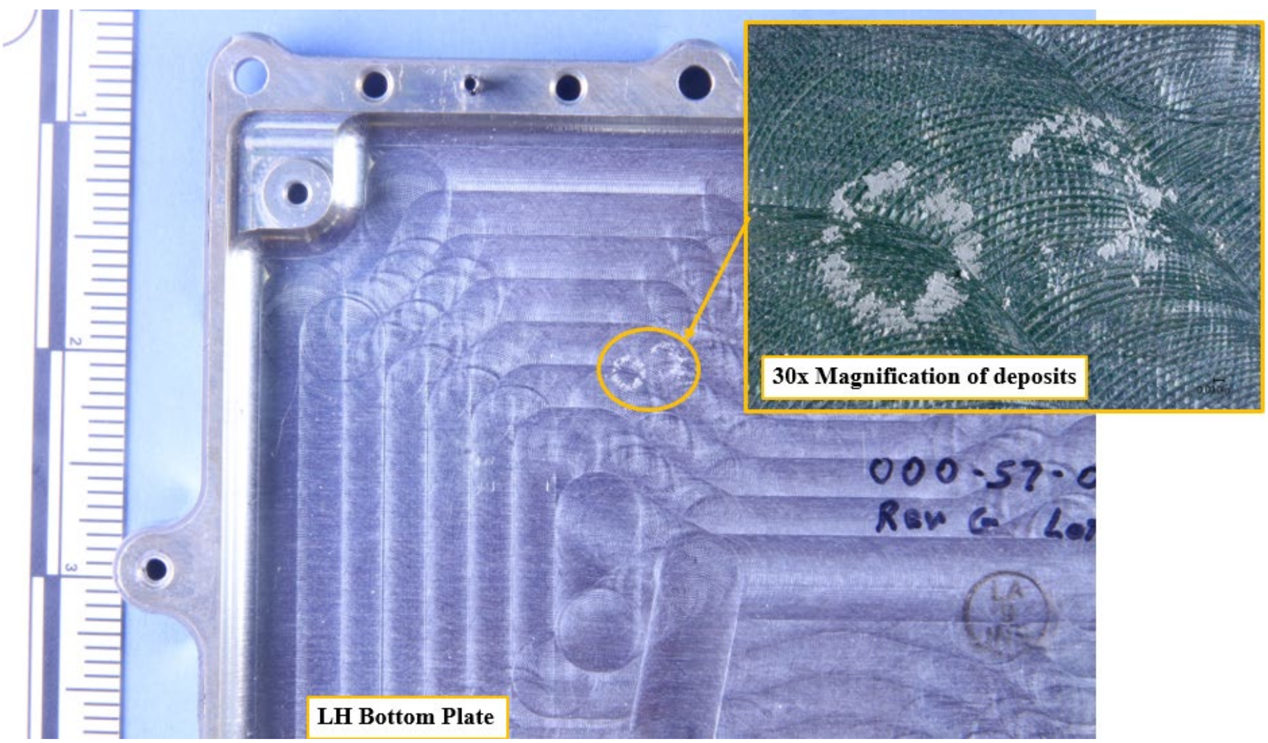


Figure 42 – Circular marks and microscopic image of the marks

The NTSB performed a visual inspection of both the left and right TCU bottom plates using a UV-A light, commonly referred to as a blacklight. The conformal coating on the PCB contains additives that will glow blue, or fluoresce, when placed under a blacklight[12]. The bottom plates were inspected for evidence of conformal coating transfer from the PCB to the backplate. Figure 43 contains a side by side image of the LH and RH TCU bottom plates taken under UV light. The RH bottom plate had multiple areas of conformal coating transfer that could be seen. The LH TCU bottom plate did not have any evidence of fluorescent indications around the area of the circular marks.

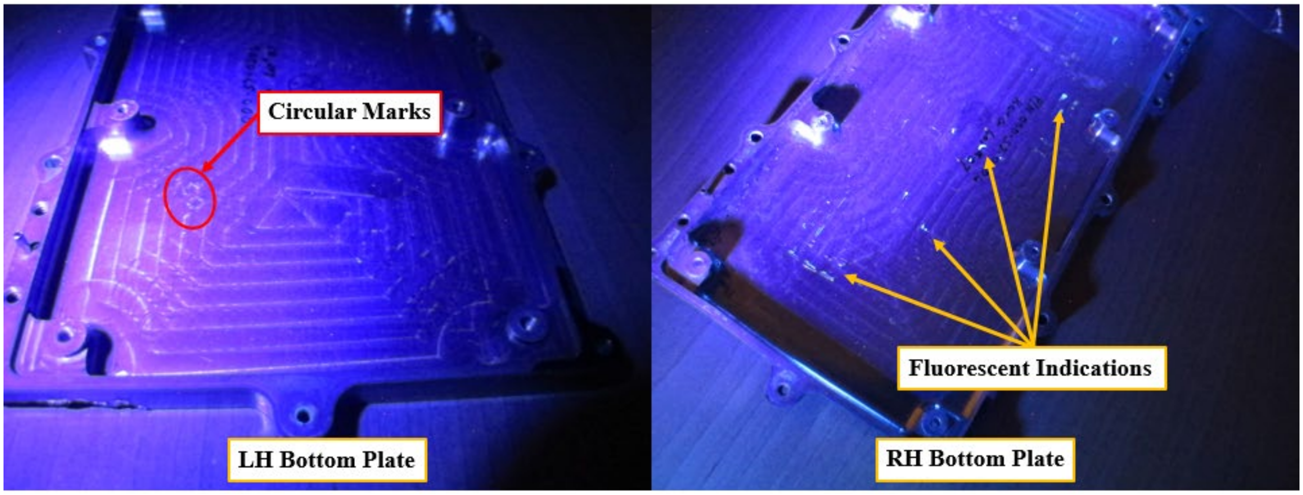


Figure 43 - Images of LH and RH TCU bottom plate UV inspection

The linear actuator was removed, and the gear housing of the unit was partially separated from the motor and ram tube assembly, ref Figure 44. The gears did not show signs of missing teeth or damage. The screws that hold the gear housing exhibited signs consistent with tensile failure.

[12] Conformal coating is typically applied after assembly to PCBs for environmental protection and corrosion resistance to the PCB and components.

Figure 44 - LH linear actuator and gear housing

The ram tube was bent and could not be removed using normal disassembly procedures without applying excessive force. There were no visible marks on the retract hard stop to indicate a high-force impact. Minor marks, similar to the RH TCU, consistent with backdrive force tests during ATP were visible, ref Figure 45. There were witness marks on the extend hard stop consistent with a high energy impact, ref Figure 46.

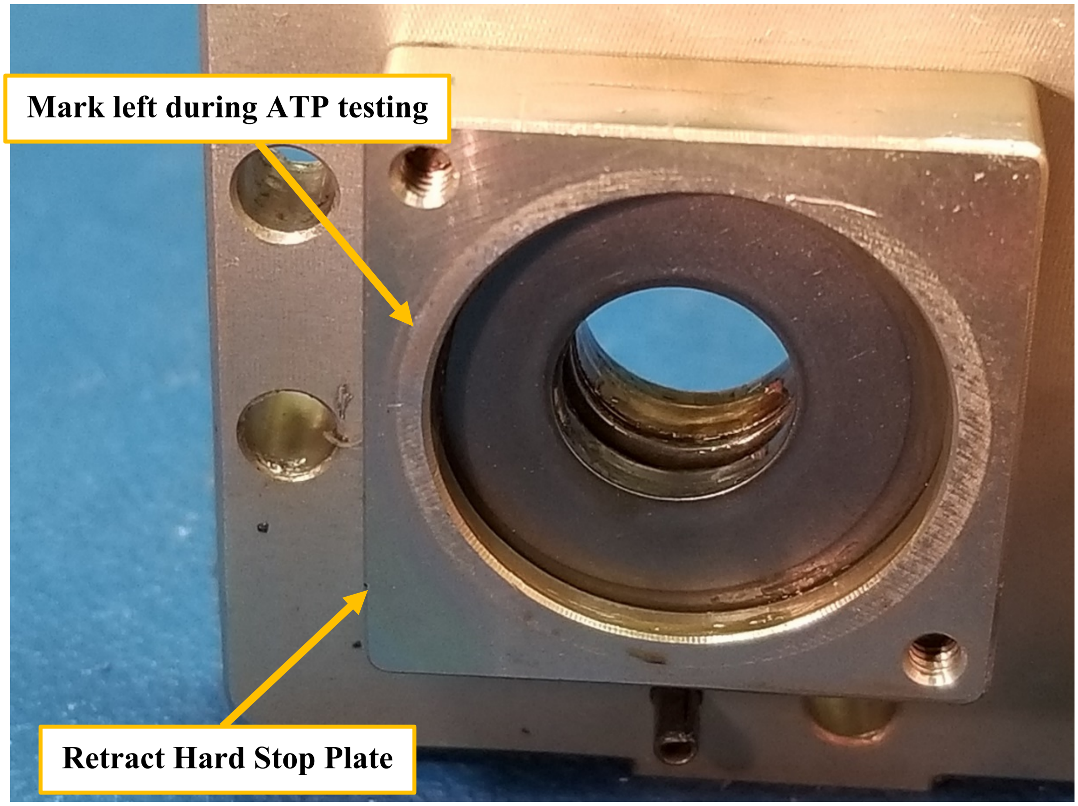


Figure 45 - LH TCU retract back plate

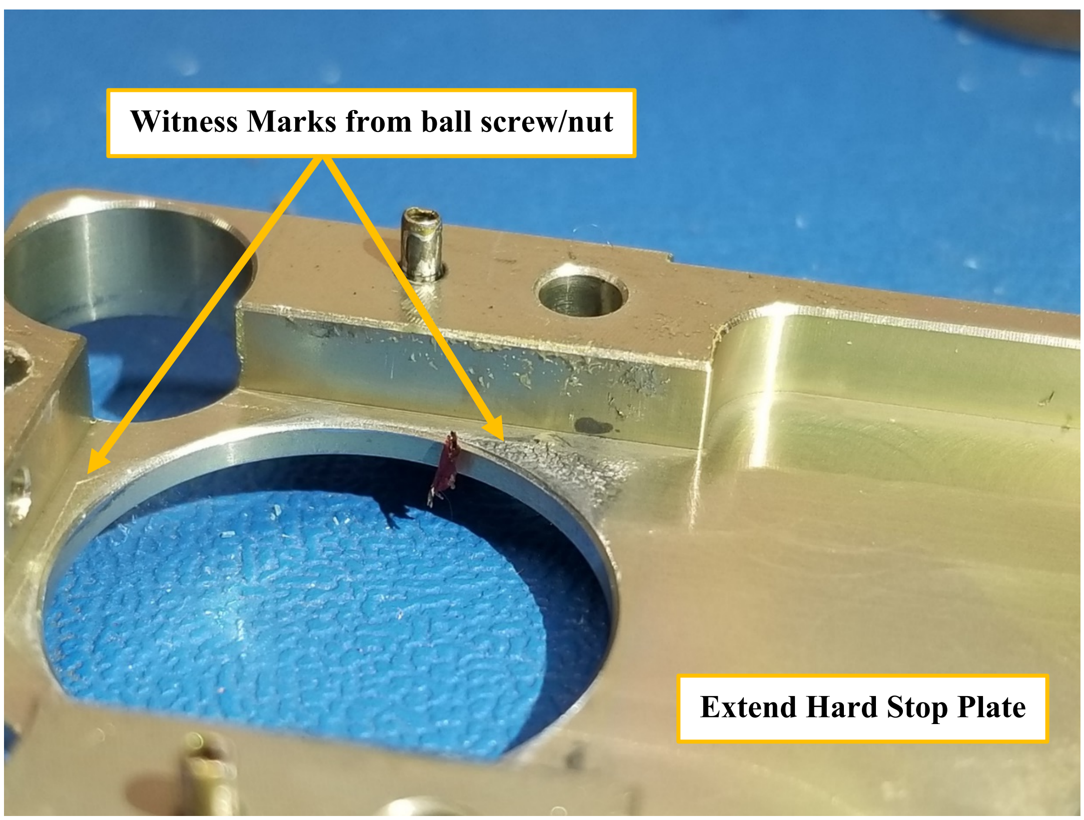


Figure 46 - LH TCU extend hard stop

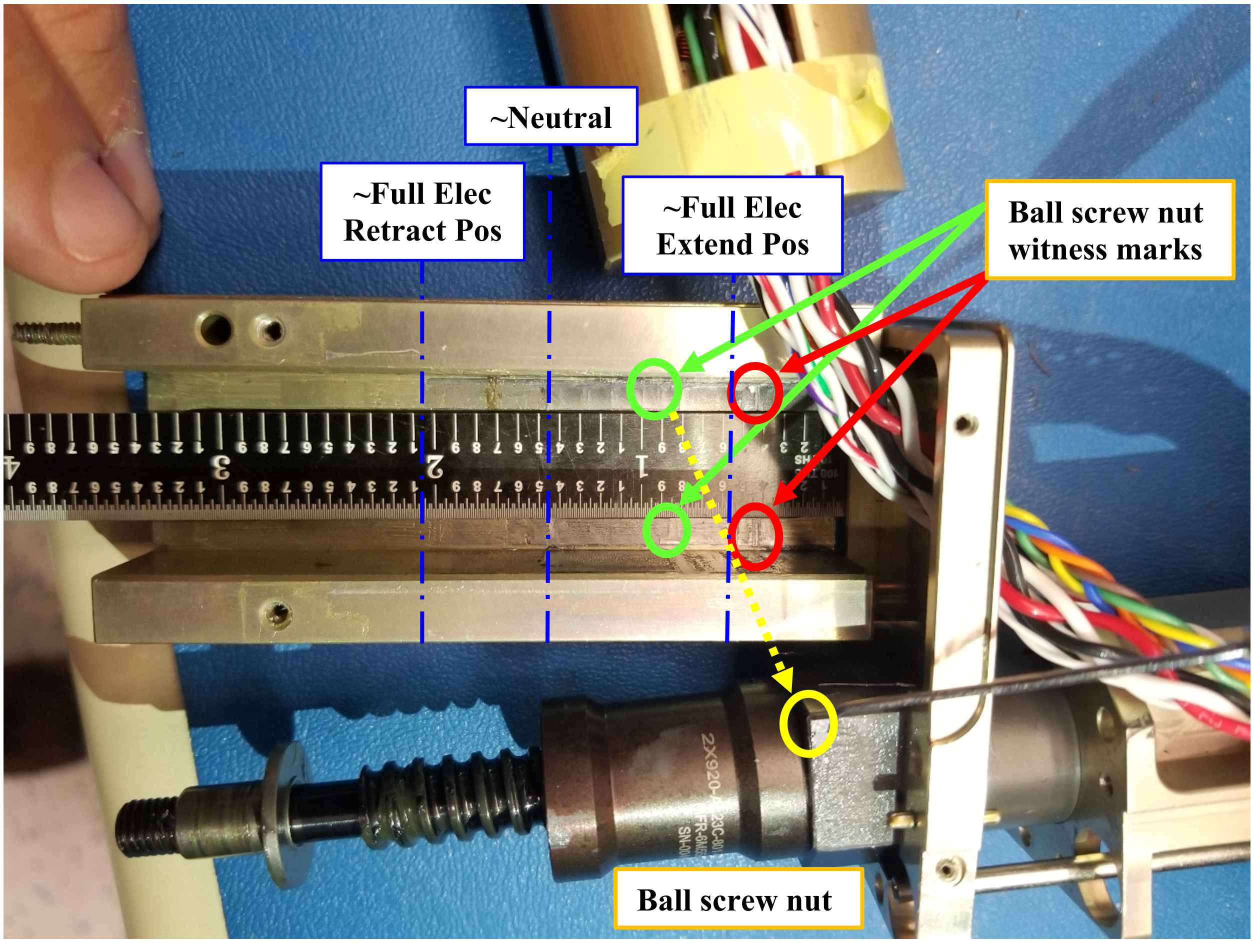


Figure 47 - Upper ram guide housing with witness marks highlighted and estimated travel positions

The ball screw nut was lubricated and free to move by hand with no signs of binding. Two sets witness marks were observed on the ram guide housing, ref Figure 47. One set of witness marks (green in picture) correspond to a position of intermediate extension. The location of the other set of witness marks (red in picture) corresponds to a position of full extension of the actuator. Two additional sets of marks were seen on the bottom ram guide housing, which would not normally be in contact with the ball nut, ref Figure 48.

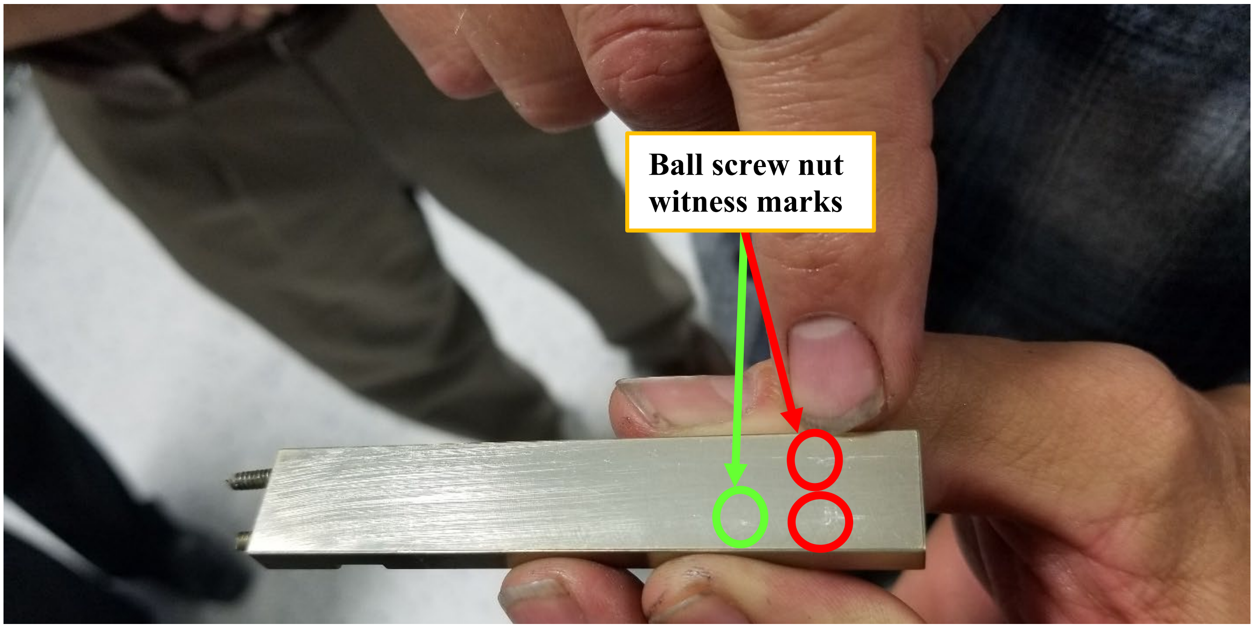


Figure 48 - Bottom ram guide housing with witness marks highlighted

Both LVDTs were in their original mounting positions. The LVDTs did not have additional staking (potting) where the signal wires exit the unit[13]. Wiring from each LVDT to the main PCB was intact and secure.

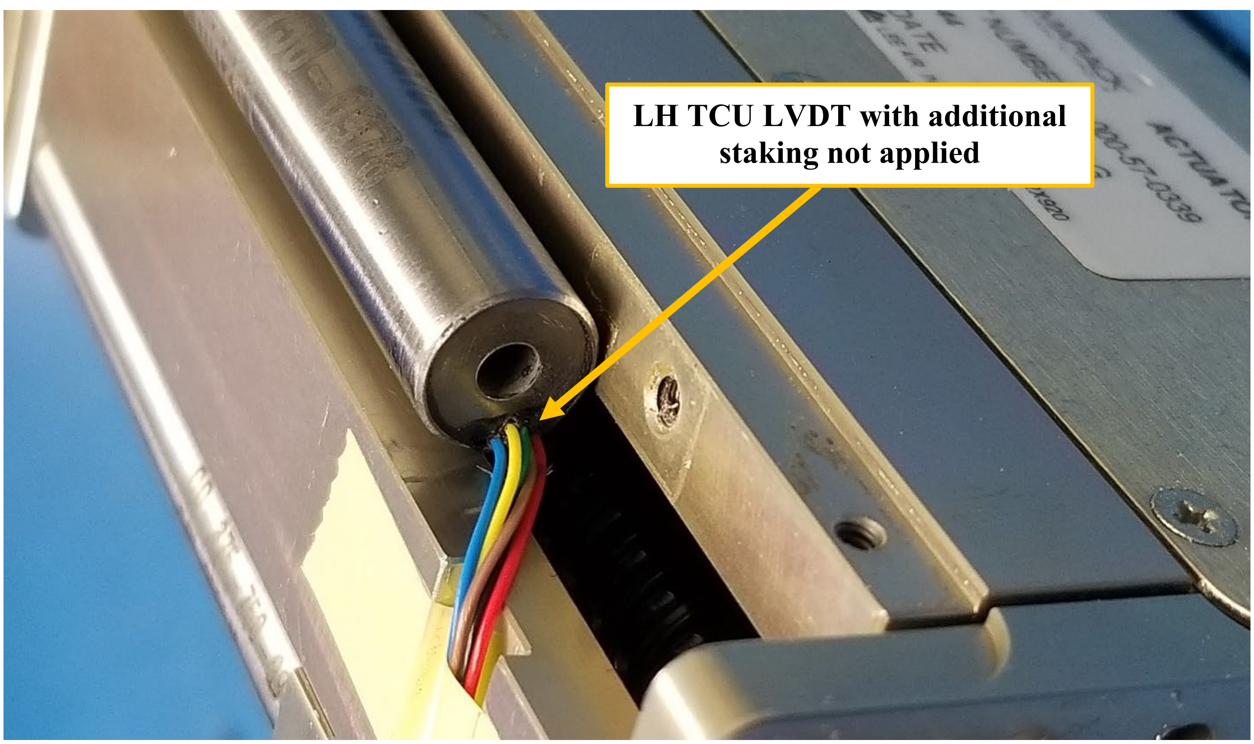


Figure 49 - One LVDT on LH TCU linear actuator

[13] Refer to section 4.4.2.1.2.2 for additional information regarding the LVDT staking.

4.4.2.1.3.3 Additional Testing

Due to the damage to the TCU PCB pins, the ATP testing could not be performed.

Continuity checks between the circular connector PCB and the main PCB were performed.

Based on CT scanning information and electrical schematics, the bent pins on the 40-pin connector were identified as follows:

- 29 – GND
- 31 – GND
- 33 – Servo Enable
- 35 – Servo Command
- 37 – Servo Fault
- 39 – Position Output

The electrical continuity testing was conducted from pins on the external circular connector to various positions on the TCU control board.[14] Test results showed an open connection between the main PCB and the circular connector PCB for:

- Servo Enable - Circular Connector Pin A and Pin 33
- Servo Command - Circular Connector Pin D and Pin 35

Electrical checks of the LVDTs for shorts/continuity were performed for each unit. Both LVDTs' test results were consistent when compared to an exemplar unit.

No additional testing of the remaining components was performed.

4.4.2.1.4 RH Tamarack Active Camber Surfaces (TACS)

Portions of the RH Tamarack Active Camber Surface (TACS) were located in the recovered wreckage.

4.4.2.1.4.1 Data Plate and Service History

Based on the TACS data plate:

Part Number:	10*57-1400-02[15]
Revision:	K
Serial Number:	18

[14] Continuity was checked between pins on the circular connector and various pin, test point and the first component pins per the production schematic. The signal line was considered "open" if continuity could not be established along the circuit.
[15] Due to damage to the data plate part of the number was illegible and is identified by "*".

4.4.2.1.4.2 Visual Inspection

Components from the RH TACS and RH aileron were laid out at the accident site, ref Figure 50. Components, except for the aileron, were covered in residue consistent with soot from the post-crash fire.

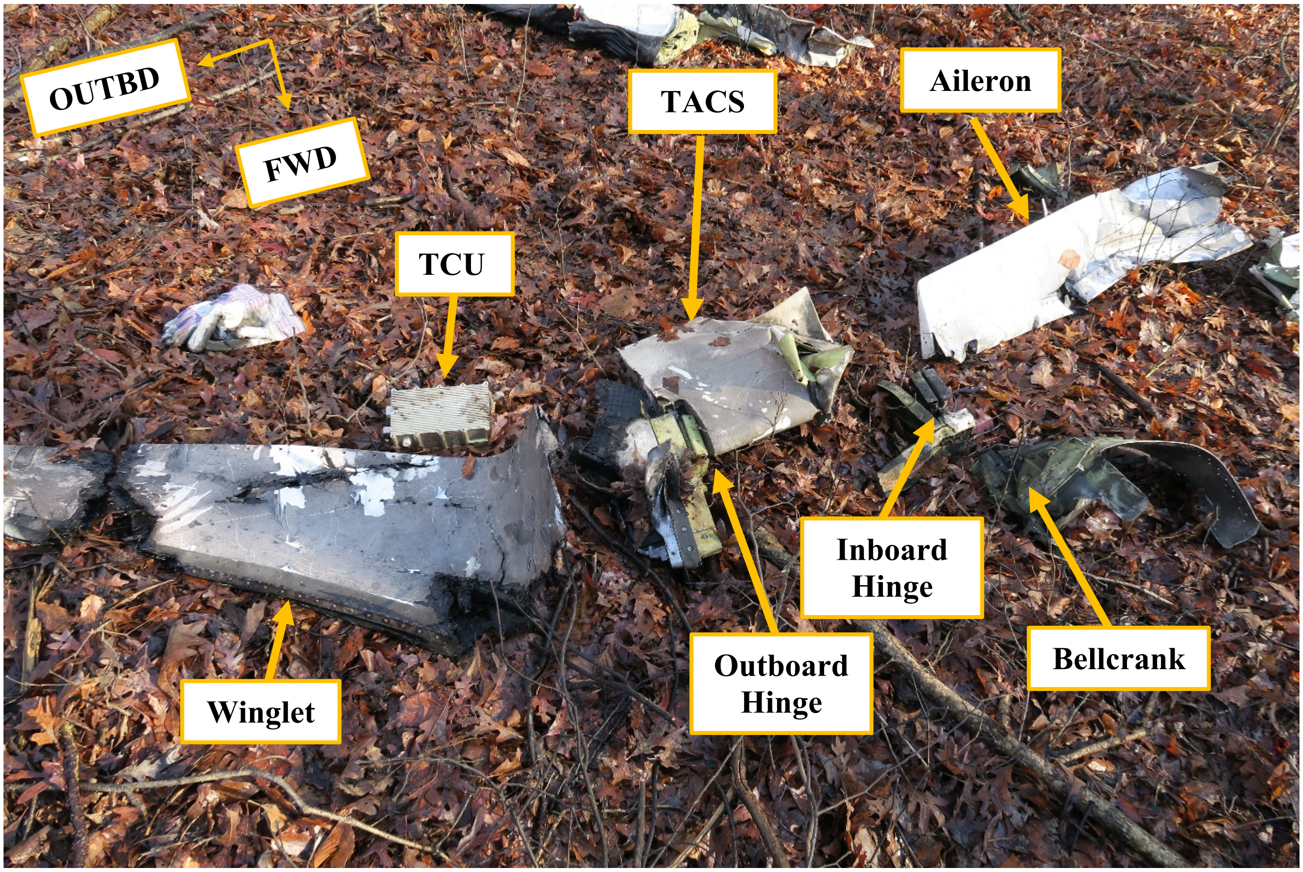


Figure 50 - RH TACS and aileron components found and laid out at accident scene by on-scene investigators (photo courtesy of Textron Aviation)

The recovered control linkages exhibited failures consistent with overload. All attachment and securing hardware were present on recovered rod ends. A visual inspection of the trailing edge down mechanical stop revealed that the bolt/stop was deformed and the nut and cotter pin were not present and could not be located, ref Figure 51. The damage to the bolt was consistent with shear loading at the lower attachment fitting. Additional damage consistent with over deflection was noted to the inboard hinge fitting, ref Figure 52.

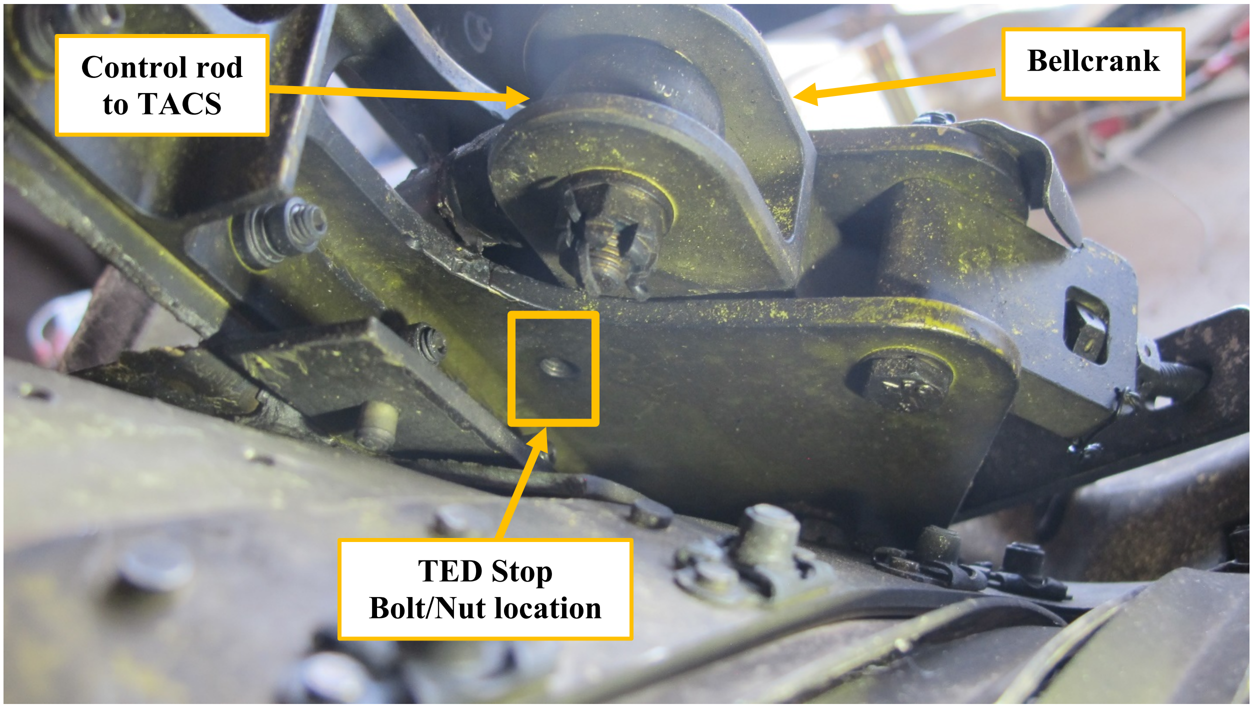


Figure 51 - RH ATLAS bellcrank and TED stop damage

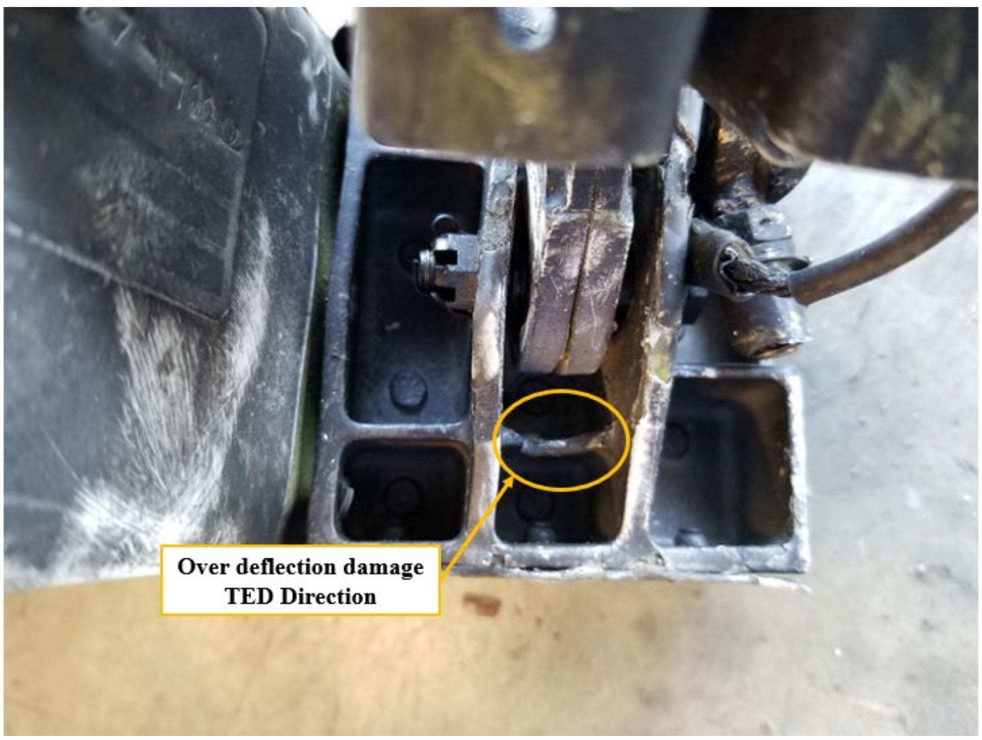


Figure 52 - RH TACS Inboard hinge with signs of over deflection damage highlighted

4.4.2.1.5 LH Tamarack Active Camber Surface (TACS)

Portions of the LH Tamarack Active Camber Surface (TACS) were located in the recovered wreckage.

4.4.2.1.5.1 Data Plate and Service History

Based on the TACS data plate:

Part Number:	103-57-1400-01
Revision:	K
Serial Number:	18

4.4.2.1.5.2 Visual Inspection

Components from the LH TACS, wing structure and LH aileron were laid out at the accident site, ref Figure 53.

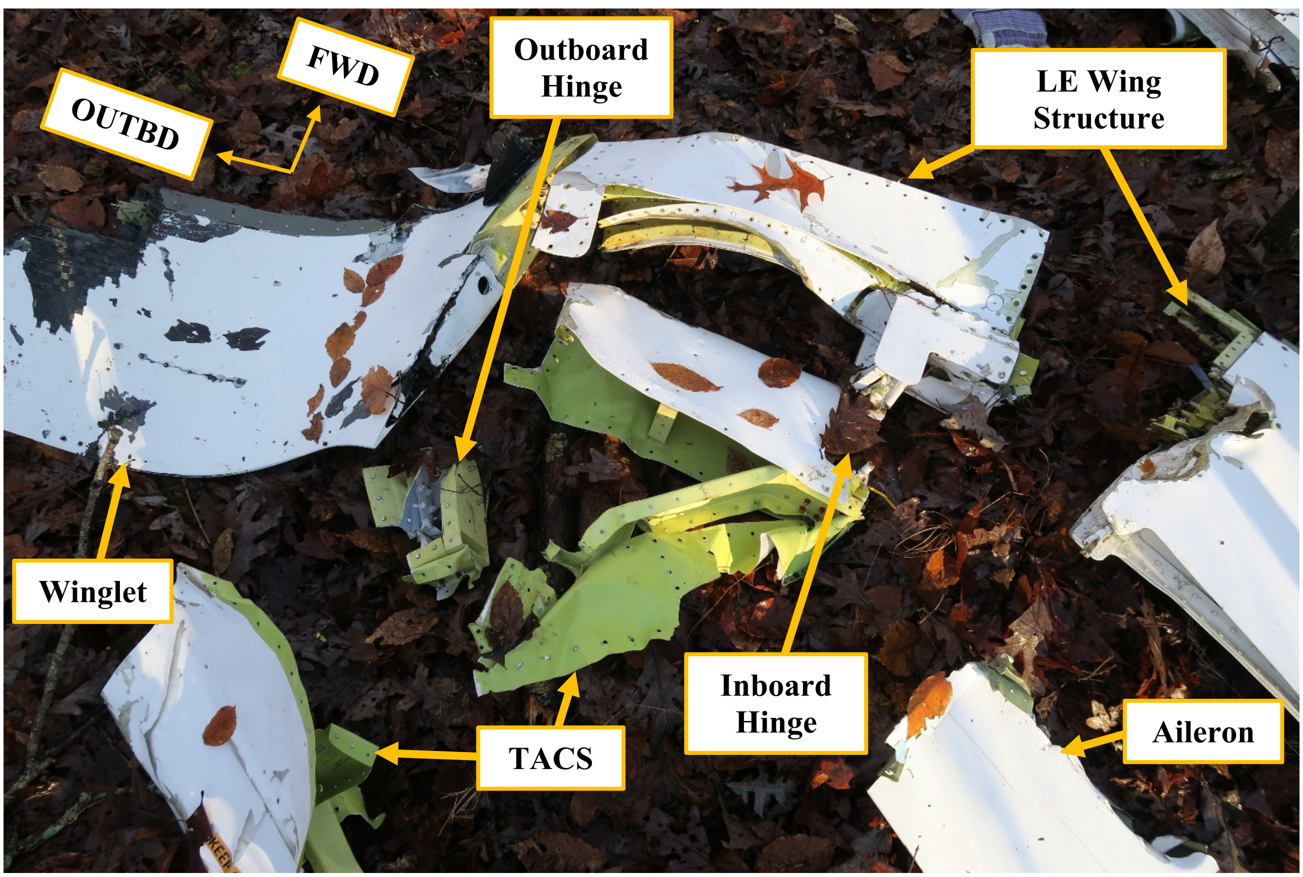


Figure 53 - LH TACS, wing structure and aileron components found and laid out at accident scene by on-scene investigators (photo courtesy of Textron Aviation)

The recovered control linkages exhibited failures consistent with overload. All attachment and securing hardware was present on recovered rod ends. A visual inspection showed a witness mark on the bellcrank, which was consistent with contact with the trailing edge up mechanical stop, ref Figure 54. Additional damage consistent with over deflection was noted to the inboard hinge fitting, ref Figure 55.

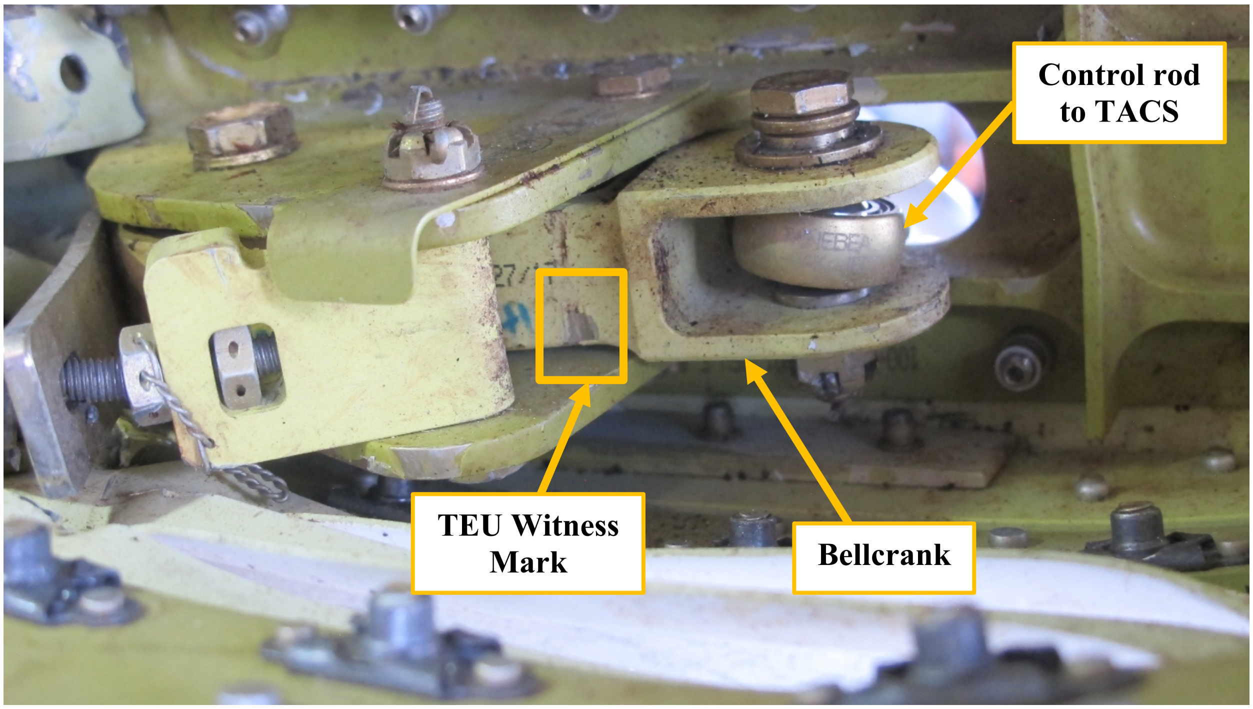
.

Figure 54 - LH ATLAS bellcrank and TEU stop witness mark

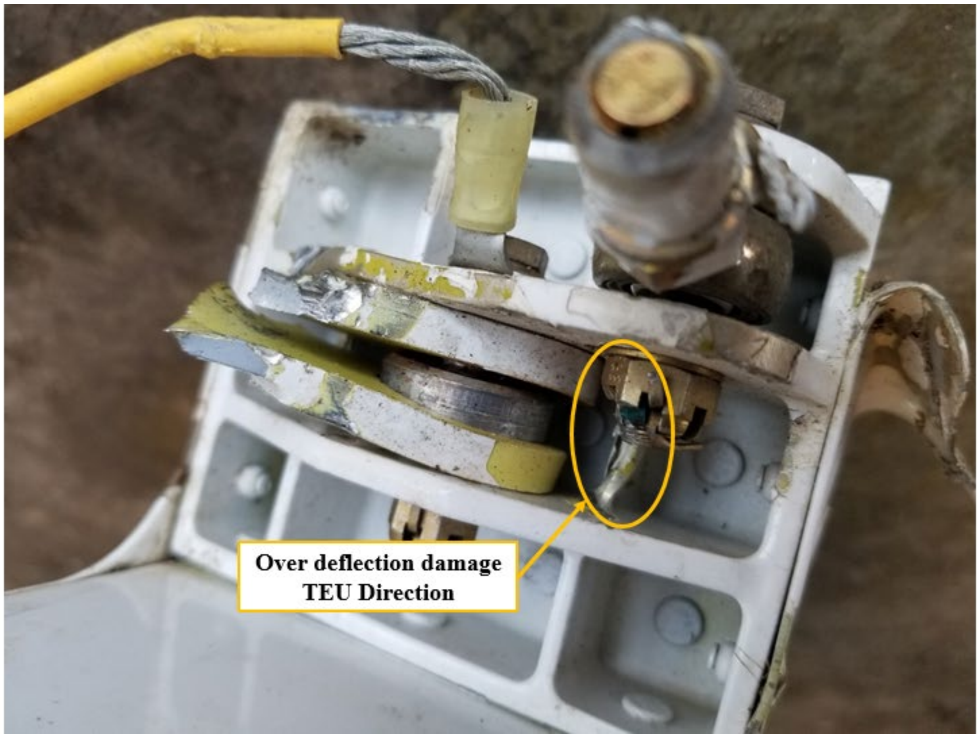


Figure 55 - LH TACS Inboard hinge fitting with signs of over deflection damage highlighted

4.4.3 Enhanced Ground Proximity Warning System (EGPWS):

The aircraft was equipped with a Honeywell Mark VIII Enhanced Ground Proximity Warning System (EGPWS). The unit interfaces with various aircraft systems (radar altimeter, ground position system (GPS), etc.) and provides 6 modes of alerts for the flight crew.

Mode 6 provides advisory callouts through the aircraft's cockpit audio system. The callout for "Bank Angle" alerts the pilot to excessive bank angles. The bank angle which triggers the alert varies linearly from 10° at 30 ft AGL, to 40° at 150 ft AGL, 55° at 2,450 ft AGL and above.

The EGPWS also contains NVM memory mounted to a circuit card inside the unit. In the event of an alert being triggered, the unit will record a snapshot of data both before and after the alert is triggered.

4.4.3.1 Recovered Components

On scene the team was able to locate a portion of the outer case of the EGPWS, ref Figure 56. On scene, the team was unable to locate any of the internal circuit cards associated with the EGPWS.

Figure 56 - Portion of outer cover of EGPWS unit (photo courtesy of Textron Aviation)

The group attempted to inspect the recovered wreckage to locate components of the EGPWS system at the wreckage storage facility. Efforts to retrieve additional components and circuit cards containing the NVM memory were unsuccessful.

4.4.3.2 Additional Testing

Due to the impact damage to the aircraft and system components and the absence of locating the NVM memory components, no further testing or data retrieval efforts were conducted.

4.4.4 Cessna Aircraft Recording System (AReS):

The aircraft was equipped with an Aircraft Recording System (AReS), which records aircraft system maintenance data in order to help with maintenance troubleshooting procedures. Data received from the aircraft and avionics system is stored on a compact flash (CF) card is installed in the AReS Recording unit. The unit can store a minimum of 25 hours of flight data. The unit is not required, nor is certified to regulatory standards for a flight data recorder for crash worthiness data storage and required parameters.

4.4.4.1 Recovered Components

On scene the team was able to locate the AReS unit, ref Figure 57. The exterior of the units showed signs of damage consistent with an impact. The outer case of the unit was compromised, exposing the internal circuit cards and compact flash (CF) card. The outer case of the CF card, was breeched, exposing the internal circuit cards. The memory chip was not attached to the CF card circuit board and could not be located.

Figure 57 - AReS unit as recovered on-scene (photo courtesy of Textron Aviation)

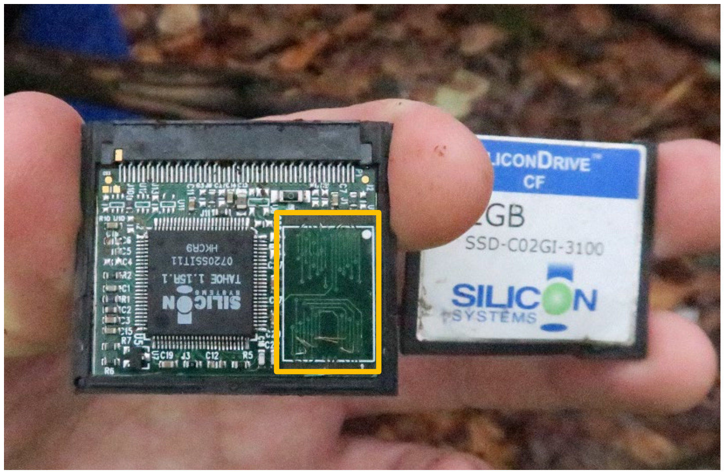


Figure 58 - AReS CF card with missing memory chip highlighted (photo courtesy of Textron Aviation)

The group attempted to inspect the recovered wreckage to locate components of the AReS CF card at the wreckage storage facility. Efforts to retrieve additional components of the CF card containing the NVM memory were unsuccessful.

4.4.4.2 Additional Testing

Due to the impact damage to the aircraft and system components and the absence of locating the NVM memory components, no further testing or data retrieval efforts were conducted.

4.5 Additional Fleet Events

Utilizing manufacturer and FAA records, a review was conducted to note any uncommanded roll events for the fleet of Cessna CitationJet 525 aircraft without the ATLAS system installed. For the history of the aircraft, there have not been any reported events of uncommanded rolls.

Five incidents have been reported to either EASA or the FAA through the service difficulty reporting system, related to the operation of the ATLAS system. Table 2 summarizes the reported events. None of the listed events reported injuries or airframe damage.

Table 2 - Incidents involving ATLAS reported to FAA or EASA by Tamarack

Date	Reported Event
February 2018	Aircraft banked to the right in cruise achieving approximately 30 degrees of bank as the pilot recovered. ATLAS would not reset in the air.
August 2018	Left Seat was being trained by Right Seat. "Right Seat" told "Left Seat" to recover and "Left Seat" did without "Right Seat" touching controls. "Left Seat" reported full aileron input for recovery. "Right Seat" reports that he "was never out of training mode".
February 2019	Pilot reported a "violent roll" input. Passenger didn't notice the event until notified on landing.
March 2019	Pilot reported a roll input he assumed was autopilot hardover. Less than 45 deg bank during recovery, using ¼ to 1/3 roll input.
April 2019	Pilot reported a large roll input with 90 deg bank during recovery, and large yoke forces.

Subsequent examination of LRUs found that a TCU connector chassis screw was loose in the box in three of these five events. See the description of service bulletin CAS/SB1467 in Section 4.6.2 for further information.

The event from April 2019 happened in the United Kingdom and was the subject of an investigation by the Air Accidents Investigation Branch (AAIB)[16]. Shortly after the event EASA issued Emergency Airworthiness Directive (AD) 2019-0086-E. Further information on the AD and other regulatory information can be found in section 4.6.

4.6 ATLAS Certification and Regulatory Information:

The following section contains certification and regulatory information related to the Tamarack ATLAS system that pertains to the Cessna CitationJet installation.

4.6.1 Supplemental Type Certificate

The ATLAS system was designed and manufactured by Tamarack. Cranfield Aerospace Solutions Ltd (CAeS) was used by Tamarack to provide support for a European Aviation Safety Administration (EASA) Supplemental Type Certification (STC)[17]. On December 22, 2015 EASA approved STC 10056170[18]. The holder of the STC was Cranfield Aerospace Solutions Ltd.

[16] The incident occurred on April 13, 2019 involved a Cessna CitationJet CJ1, registration number N680KH.
[17] A supplemental type certificate (STC) is a type certificate (TC) issued when an applicant has received EASA/FAA approval to modify an aeronautical product from its original design. The STC, which incorporates by reference the related TC, approves not only the modification but also how that modification affects the original design.
[18] At the time of initial release, the EASA STC covered the CitationJet and variants to include the CJ, CJ1, and CJ1+. The STC would be subsequently revised to add additional models and variants. The accident aircraft was added at revision 5, dated March 22, 2018.

On December 27, 2016, the FAA issued STC SA03842NY after validation of the released EASA STC. The FAA has a bilateral agreement with EASA and the United Kingdom, which allowed for issuance of an FAA STC[19].

On November 19, 2018 CAeS applied with EASA for a transfer of the STC to Tamarack. On October 9, 2019 the transfer was completed the FAA. The FAA became the State of Design and Tamarack has the responsibilities that are required of the STC holder. The FAA STC, SA03842NY, was reissued on this date.

4.6.2 Service Bulletins

CAeS/Tamarack issued six service bulletins (SB) related to the ATLAS system[20]. Only pertinent SB are discussed in this factual report.

On April 25, 2018 CAeS/Tamarack originally issued CAS/SB1467 and revised on August 1, 2018. The SB was applicable to TCUs with a serial number prior to 1101. The SB was due to previous occurrences in service of the screw/lockwasher securing the connector PCB to the spacer and center case was loosening and, in some occurrences, detaching. Operator compliance with the service bulletin was "*Category 2: Do as soon as possible without effect on service or by 150 flight hours or 1 year from the date of receipt of this service bulletin, whichever occurs first.*" The SB required the removal of the TCUs and returning them to an approved facility for rework. Upon completion of the rework, the TCUs would be reinstalled in the aircraft. The rework required the TCU to be opened and existing screw and split lockwasher to be removed and discarded. A new screw, split lockwasher and flat washer was installed to improve securing of the PCB to the spacer, ref Figure 59. Both TCUs installed on the accident aircraft complied with this SB on July 13, 2018. The SB rework was accomplished by Lee Air Inc. on July 6, 2018 and both units passed ATP tests and were returned to service.

[19] The FAA STC was revised on March 26, 2018 to include the accident aircraft model.
[20] At the time of the SB issuance, CAeS was the STC holder and would release the SBs as required.

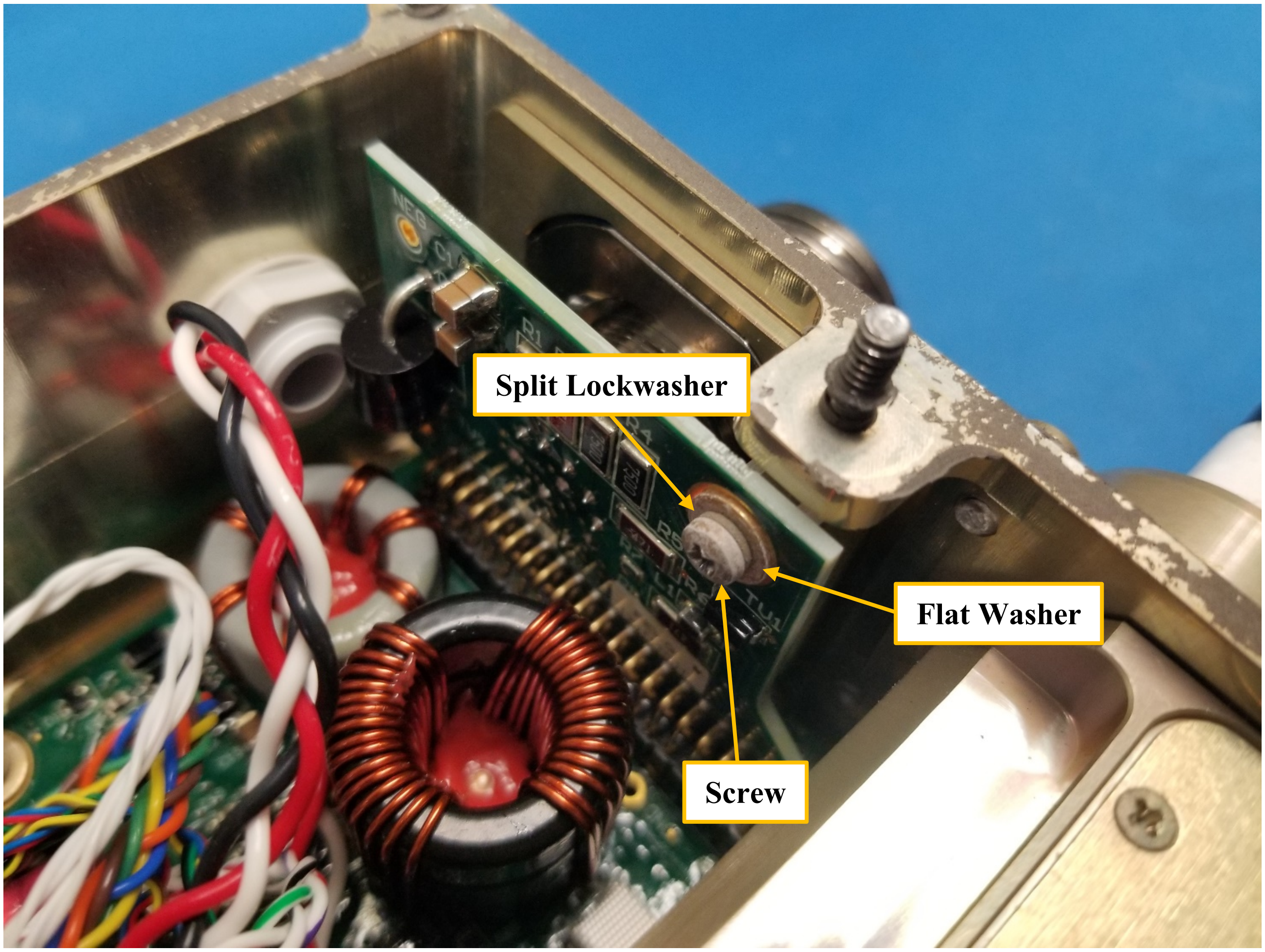


Figure 59 - LH TCU showing SB installation.

On March 1, 2019 CAeS/Tamarack issued CAS/SB1475. The SB was in response to "*three uncommanded roll events related to Tamarack ATLAS failures*". The SB stated that the aerodynamic overbalance of the TACS allowed for the TACS to remain deployed when power was removed from the TCU while the TACS are deployed or if unique aerodynamic conditions were encountered causing the TACS to deploy with the TCUs in an unpowered state. The SB was applicable to all TACS units. Operator compliance with the service bulletin was "*Category 7: Do at customer convenience*". The SB accomplished the installation of centering strips on the trailing edge of each TACS, ref Figure 60. The SB was released after the accident. The accident aircraft did not have centering strip installed on either TACS.

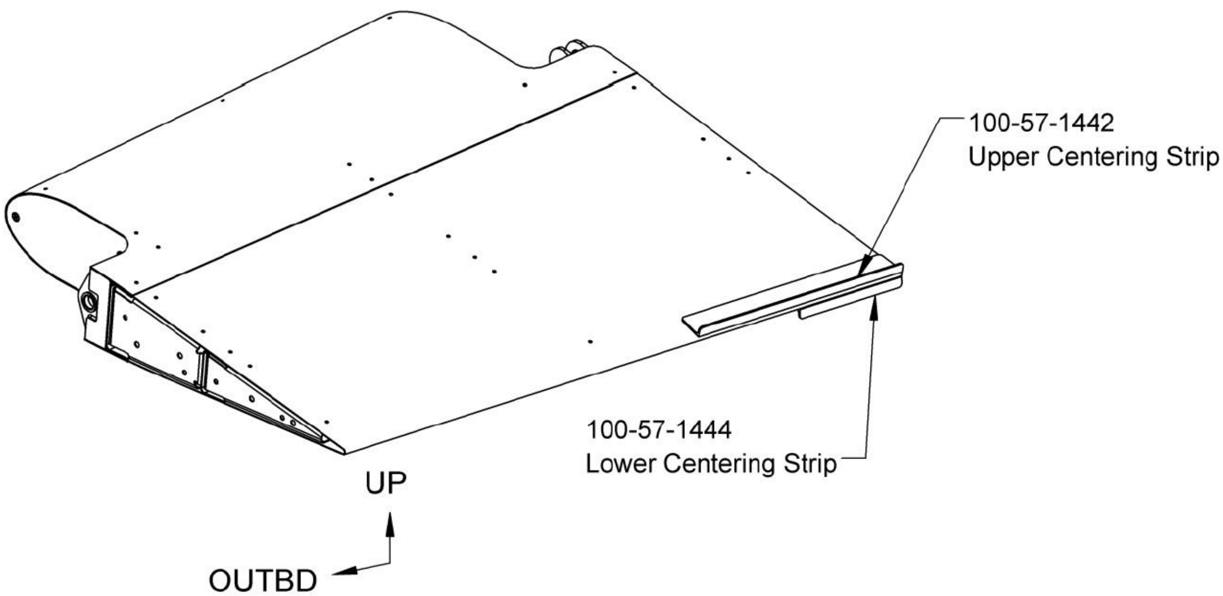


Figure 60 - SB drawing showing the installation of the centering strips (courtesy Tamarack)

On April 18, 2019 CAeS/Tamarack issued CAS/M0132. The SB gave specific guidance to European operators to allow for limited operations with ATLAS disabled as subject to the EASA Emergency Airworthiness Director released on April 19th, 2019 (ref 4.6.3). The SB required operators to disable the ATLAS system by pulling and collaring the circuit breaker, rendering the TACS immovable, application of speed tape around the edge of each TACS and amending the Aircraft Flight Manual Supplement (AFMS)[21]. The AFMS amendments provided additional preflight inspection procedures and flight envelope limitations.

On July 4, 2019 CAeS/Tamarack issued CAS/SB1480. The SB provided operators with instructions to remove the requirement to deactivate the system (CAS/M0132) in EASA Emergency Airworthiness Directive released on April 19th, 2019 (ref 4.6.3). The SB required operators to verify/modify the aircraft to be in accordance with CAS/SB1467 and CAS/SB1475. Additionally, the SB included a list of TCU serial numbers to ensure they are in accordance with the latest build standard. The TCUs installed on the accident aircraft (1090 and 1097) were not on the included list and the SB would have required the units to be replaced. Operator compliance with the service bulletin was "*Category 1: Mandatory – Before flight with the Tamarack ATLAS winglets installed*".

4.6.3 Airworthiness Directives and Alternate Means of Compliance

On April 19, 2019, EASA issued Emergency Airworthiness Directive (EAD) 2019-0086-E. The EAD was issued due to reported occurrences where the ATLAS system experienced malfunctions resulting in upset events and in some cases the pilots had difficulty in recovering the aircraft. The EAD included additional preflight inspection procedures and flight envelope limitation. The EAD referenced the information provided in SB CAS/M0132 (ref 4.6.2). The EAD compliance was prior to the next flight after the effective date of the EAD.

[21] The addition of speed tape was to ensure the TACS remains in a faired position with power off.

On May 24, 2019, the FAA issued an Airworthiness Directive (AD) 2019-08-13. The AD was applicable to all Cessna aircraft with the ATLAS system installed. The AD resulted from mandatory continuing airworthiness information issued by the aviation authority of another country to identify and correct an unsafe condition on an aviation product. The AD was in response to the EASA EAD 2019-0086-E and prohibited operations of the aircraft with the ATLAS system installed, effective on May 24, 2019. The FAA AD prohibited further flight with the ATLAS system installed until "a modification has been incorporated in accordance with an FAA-approved method."

The EASA EAD allowed for operation of the aircraft with the ATLAS system disabled for 100 hours in accordance with the EASA approved master minimum equipment list (MMEL)[22]. At the time of the EASA EAD, the FAA did not have an approved MMEL for ATLAS operations, therefore the FAA AD did not allow operations with the ATLAS system disabled[23].

On July 10, 2019, the FAA issued an alternate means of compliance (AMOC) which, if complied with removes the flight restrictions put in place by the FAA AD. The AMOC requires operators to follow the instructions set forth in EASA SB CAS/SB1480.

On August 23, 2019, EASA issued a revision to EAD 2019-0086-E, effective August 9, 2019. The revision removes the restrictions put in place by the EASA EAD, if the operators complies comply with the instructions set forth in SB CAS/SB1480. The original STC was also revised to include the appropriate modifications outlined in SB CAS/SB1480.

Michael Bauer
Aerospace Engineer

[22] Prior to the EAD the EASA MMEL allowed for 10 flight hours of operation with the ATLAS system disabled.
[23] In early 2020, the FAA issued MMEL relief for ATLAS STC SA03842NY for all affected aircraft models.