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

1 ACCIDENT:

Location: Willow Run Airport, Ypsilanti, Michigan
Date: March 8, 2017
Time: about 1452 EST
Aircraft: Boeing MD-83
Serial Number: 53123
Registration: N786TW

2 SYSTEM'S GROUP:

Chairman: Michael Bauer
National Transportation Safety Board
Washington, D.C.

Member: Pamela Tressler
Federal Aviation Administration
Ypsilanti, Michigan

Member: Michael Lasley
The Boeing Company
Seal Beach, California

Member: Richard Cole
Ameristar Air Cargo
Addison, Texas

3 SUMMARY

3.1 Event Summary

On March 8, 2017, about 1452 EST, Ameristar Air Cargo, Inc. dba Ameristar Charters flight 9363, a Boeing MD-83, N786TW, ran off the end of runway 23L after executing a rejected takeoff at Willow Run Airport (YIP), Ypsilanti, Michigan. (The MD-83 was manufactured by McDonnell Douglas, which merged with Boeing in August 1997.) All 110 passengers and 6 crewmembers evacuated the airplane. One passenger was reported to have received a minor injury. The airplane sustained substantial damage (no post-crash fire occurred). The airplane was operating under the provisions of 14 Code of Federal Regulations (CFR) Part 121 as an on-demand charter flight and was destined for Washington Dulles International Airport (IAD), Dulles, Virginia. Daytime visual meteorological conditions prevailed at the time of the accident.

3.2 Systems Group Summary

The Systems group was formed on March 9th, 2017 during the on-scene phase of the investigation. The group documented the cockpit, flight controls and associated systems from March 9th to 12th, 2017. Due to prevailing weather conditions, the group postponed the removal of the elevators from the aircraft.

The Systems group reconvened on March 22nd through 23rd, 2017 at Willow Run Airport, Ypsilanti, Michigan, to remove the left and right elevators and package them for shipping to the Boeing laboratory for further inspections and testing.

The Systems group reconvened on May 15th through May 18th, 2017 at a Boeing Company laboratory in Huntington Beach, California to examine and perform testing on the elevators removed from the accident aircraft.

Based on information from the testing in Huntington Beach, the Systems group reconvened on July 18th through July 19th, 2017 at Ameristar headquarters in Addison, Texas to conduct testing on an exemplar aircraft.

During the week of September 5th, 2017 members of the Systems group met to perform testing on structural and system components at locations in Southern California.

The Systems group reconvened on September 19th through September 21st, 2017 at a Boeing Company laboratory in Huntington Beach, California to perform additional testing on an elevator removed from the accident aircraft.

3.3 Acronyms

A	amps	IAS	Indicated Airspeed
AFM	Aircraft Flight Manual	in	inch
AMM	Aircraft Maintenance Manual	INBD	Inboard
AND	Aircraft Nose Down	inHg	inches of Mercury
ANU	Aircraft Nose Up	kt,kts	knot(s)
BFU	German Federal Bureau of Aircraft Accident Investigation	lb	pound
C	Celsius	LCL	Local
C/B	Circuit Breaker	LED	Leading Edge Down
CFR	Code of Federal Regulation	LEU	Leading Edge Up
CG	Center of Gravity	LH	Left hand
EDDM	Munich Airport, Munich Germany	MPH	Miles Per Hour
EGPWS	Enhanced Ground Proximity Warning System	N/A	Not Applicable
EPAS	Elevator Power Assist System	NVM	Non-volatile memory
EPC	Electrical Power Center	OUTBD	Outboard
EST	Eastern Standard Time	OVHD	Overhead
F	Fahrenheit	PSI	Pounds per square inch
FOB	Flight Operations Bulletin	RH	Right hand
FWD	Forward	RPM	Revolutions Per Minute
GMT	Greenwich Mean Time	SC	Special Conditions
GSB	Ground Service Bus	TC	Type Certificate Data Sheet
HRB	Rockwell Hardness "B" Scale	TCDS	Type Certificate Data Sheet
HRC	Rockwell Hardness "C" Scale	TED	Trailing Edge Down
IACS	International Annealed Copper Standard	TEU	Trailing Edge Up
IAD	Washington Dulles International Airport	YIP	Willow Run Airport, Yipsilanti, Michigan

4 DETAILS OF THE INVESTIGATION:

4.1 Aircraft Examination:

4.1.1 Cockpit

The cockpit was examined on March 9th, 2017 by members of the Systems group. The following information notes the conditions of the controls, switches and instruments as found on the day of the examination. During the cockpit examination, due to damage to the aircraft, electrical power was not applied to the aircraft, therefore any electronic instruments could not be checked by the group.



Figure 1 - Cockpit as reviewed by the Systems group

4.1.1.1 Captain's Instrument Panel



Figure 2 – Captain's Instrument Panel

The Captain's altimeter (area 2 in yellow box, Figure 2), was reading of approximately 722 feet and the Kollsman window¹ was set to 29.81 inHg.

The Captain's airspeed indicator (area 1 in green box, Figure 2), was reading 0 knots and the various white bugs were positioned on the airspeed scale at: 136, 148, 162, 198, 249 knots IAS.

¹ The Kollsman window is used by the crew to adjust the altimeter to account for the local barometric pressure. Local airport elevation on a standard day is 716 ft.

4.1.1.2 First Officer's Instrument Panel



Figure 3 – First Officer's Airspeed Indicator

The First Officer's altimeter was reading of approximately 470 feet and the Kollsman window setting was 29.81 inHg.

The First Officer's airspeed indicator (Figure 3), was reading 0 knots and the various white bugs were positioned on the airspeed scale at: 138, 152, 164, 198, 245 knots IAS.

The hydraulic pumps panel, which is located below the clock contained four switches.

Both engine driven pumps are controlled by a three-position switch, labelled "ENG1" "ENG 2", with "HI", "LOW" and "OFF" positions. Both engine driven pump switches were found in the "HI" position.

An auxiliary, electrically driven hydraulic pump is controlled by a three-position switch, labelled "AUX", with "ON", "OFF" and "OVRD" positions. The auxiliary pump switch was found in the "ON" position.

A power transfer unit mechanically connects the left and right hydraulic system and enables hydraulic pressure to be transferred from the high-pressure side to the low-pressure side. The auxiliary pump switch was found in the "ON" position.

4.1.1.3 Center Instrument Panel



Figure 4 – Center Instrument Panel and upper portion of the control pedestal

The standby altimeter/airspeed indicator (area 1 in green box, Figure 4), was reading of approximately 500 feet and the Kollsman window was set to 29.81 inHg. The airspeed indicator reading was 0 knots.

The landing gear handle (area 2 in yellow box, Figure 4), was found in the DOWN position.

4.1.1.4 Control Pedestal

The control pedestal is located between the Captain and First Officer seats. The control pedestal contains controls for the engines, fuel controls, slats, flaps, stabilizer, flight control trims, flight management system and radios.

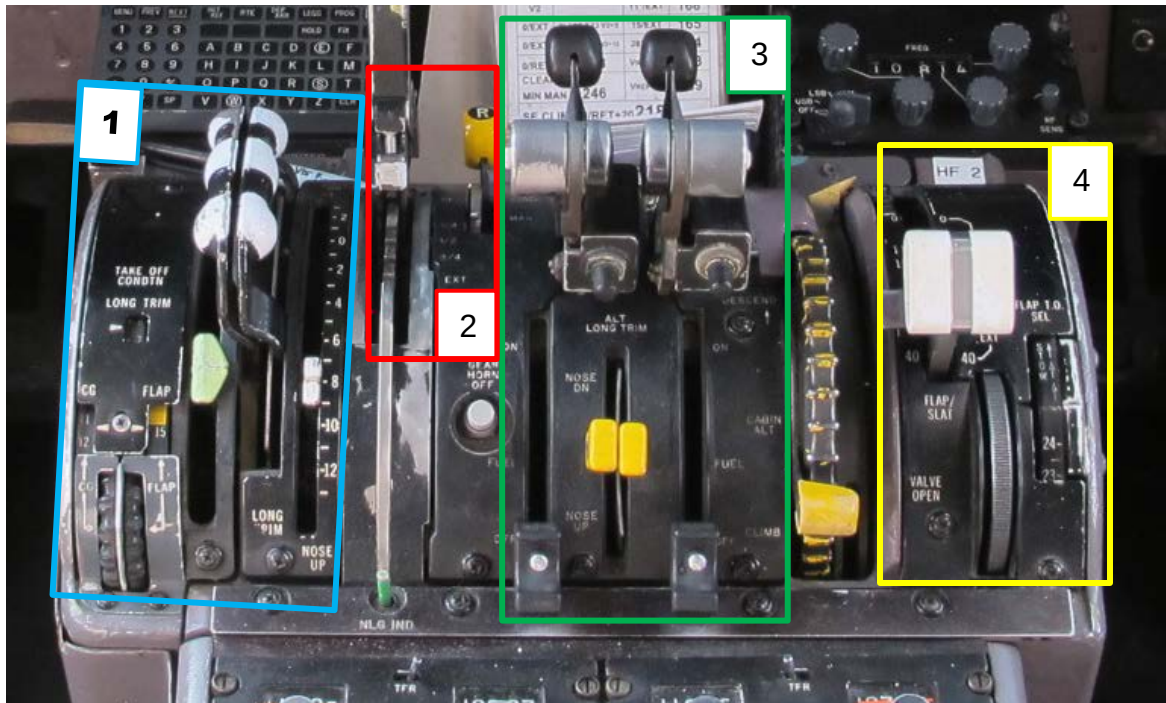


Figure 5 – Control Pedestal section with engine controls.

Refer to Figure 5, area 1 in the blue box for the takeoff condition computer and longitudinal trim handles/setting.

The takeoff condition computer, labelled “TAKE OFF CONDTN”, is located on the left-hand side of the control pedestal next to the longitudinal trim control handles. The “CG” setting was found approximately halfway between 11 and 12 and the “FLAP” setting was 15. The reading for “LONG TRIM” was approximately halfway between 7 and 8. The “Long Trim” Position setting was at 8, Aircraft Nose Up.

Refer to Figure 5, area 2 in the red box for the speedbrake/ground spoiler and rudder hydraulic shutoff valve controls.

The speedbrake/ground spoilers are controlled by the speedbrake control lever mounted on the control pedestal and labeled, “SPD BRK”. The speedbrake lever was found in the “RET” position.

The rudder hydraulic shutoff valve is controlled by a lever mounted on the control pedestal in between the speedbrake control lever and the engine controls and labeled, “RUD HYD CONT”. The lever was found in the “PWR” position.

Refer to Figure 5, area 3 in the green box for the engine, fuel and alternative longitudinal trim controls.

The engine throttles were found full aft in the idle stop position and the thrust reverser levers were found stowed. Both the left and right fuel control levers were found in the “OFF” position.

The alternate longitudinal trim (secondary) control levers labelled, “ALT LONG TRIM”, are located just below the engine throttles. Both lever positions were approximately halfway between the “NOSE DN” and “NOSE UP” position.

The slat/flap control handle is located on the right-hand side of the control pedestal next to the cabin pressure control wheel. The handle had detents at the 0, 11, 15, 28 and 40 positions. The flap/slat handle was found in the 40 detent. Refer to Figure 5, area 4 in the yellow box for the flap control handle.

At the aft end of the control pedestal are the aileron and rudder trim control knobs and position indicators. The rudder trim position was slightly nose right of the 0 unit position (estimated to be 0.2 unit). The aileron trim position was slightly right wing down of the 0 unit position (estimated to be 0.2 unit).

4.1.1.5 Circuit Breaker Panel

Multiple circuit breaker panels are located throughout the aircraft cockpit. All cockpit circuit breaker panels were inspected for any circuit breakers in a tripped/open/collared state. Circuit breakers on the electrical power center (EPC), ground service bus C/B panel (GSB) and overhead (OVHD) C/B panel in a tripped or collared position are noted in Table 1.

Table 1 - Noted Circuit Breakers

Location	Name	Panel	Condition
E11	Windshear Warning & Caution Right/Inop	EPC	Open/Trip
F6	Cockpit Voice Recorder	EPC	Open/Trip
F20	Enhanced Ground Proximity Warning Computer	EPC	Open/Trip
G7	VHF NAV-2	EPC	Open/Trip
H8	Inst Cooling Fan QA QB QC	EPC	Open/Trip
J2	Cabin Pressure Control-2	EPC	Open/Trip
J14	Cargo Compartment Heater QC	EPC	Open/Trip
K10	Strobe	EPC	Open/Trip
K14	Left Nose Gear Landing & Taxi	EPC	Open/Trip
K27	Left Fuel Flow	EPC	Open/Trip
L14	Right Nose Gear Landing & Taxi	EPC	Open/Trip
S40	App Idle Control	EPC	Open/Trip
0B	Battery Charger	GSB	Open/Trip
A11	Omega Msg Lights	OVHD	Collared

4.1.1.6 Miscellaneous Switches

The following switches were located on the overhead panel adjacent to the icing protection panel. The emergency lights switch, “EMER LTS”, was in the ARM position. The no smoking light and seat belt light switches, labelled “NO SMOK” and “SEAT BELTS”, were both found in the “ON” position. The EMER PWR switch was in the OFF position.

The left and right engine fire handles, labelled “L ENG FIRE” and “R ENG FIRE”, were located on the upper instrument panel, located above the center instrument panel and below the glareshield panel. The L and R ENG FIRE handles were both in the “OUT” (pulled) position. The handles were found in a centered position and not rotated to either the “1” or “2” extinguishing agent position.

The parking brake, which was located in the center of the steering wheel, to the left of the Captains control column. The parking brake was in the “SET” position.

4.1.2 Primary Flight Controls

All primary flight controls, elevator, aileron, and rudder were accounted for at the accident scene and remained attached to the accident aircraft.

4.1.2.1 Elevator

4.1.2.1.1 System Description

The left and right elevators provide longitudinal control about the pitch axis of the aircraft. Each elevator is attached to the rear spar of the horizontal stabilizer at six hinge locations. Each elevator can travel 27° trailing edge up (TEU) and 16.5° trailing edge down (TED). Mechanical stops inhibit movement of the elevator in both the TEU and TED direction. The elevator control surfaces are mechanically controlled and operated by aerodynamic boost control surfaces which consist of control tabs, geared tabs and an anti-float tab, see Figure 6. The control tabs are operated by the control columns in the cockpit and the control columns do not directly move the elevator surface. On the ground the elevators are free to move independently within the confines of the mechanical stops.

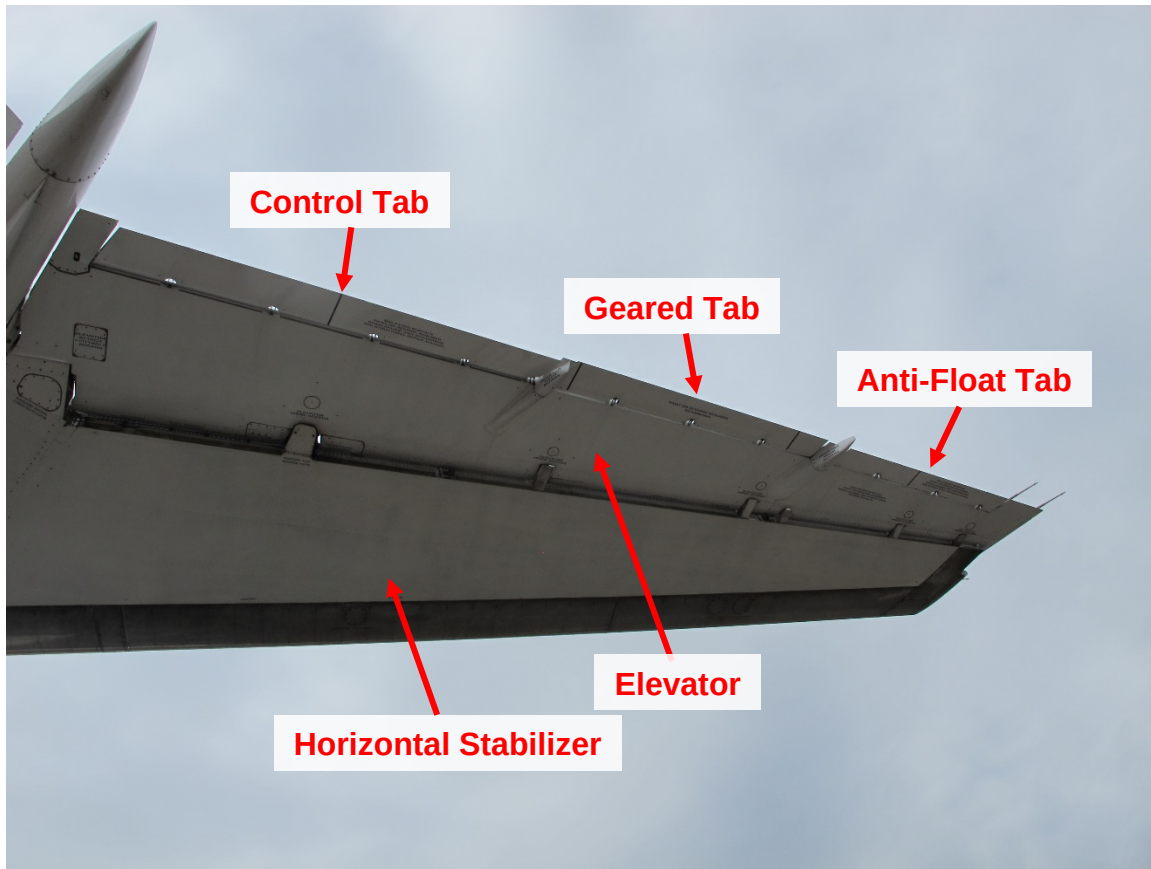


Figure 6 - Right hand side of horizontal stabilizer and elevator

4.1.2.1.1.1 Elevator Damper

Each elevator has a damper installed just outboard of the elevator power control boost cylinder to the leading edge of the elevator and connected to the horizontal stabilizer rear spar, Figure 7. The damper prevents elevator flutter during flight and dampens rapid movement of the elevator caused by gusty winds when the aircraft is on the ground.

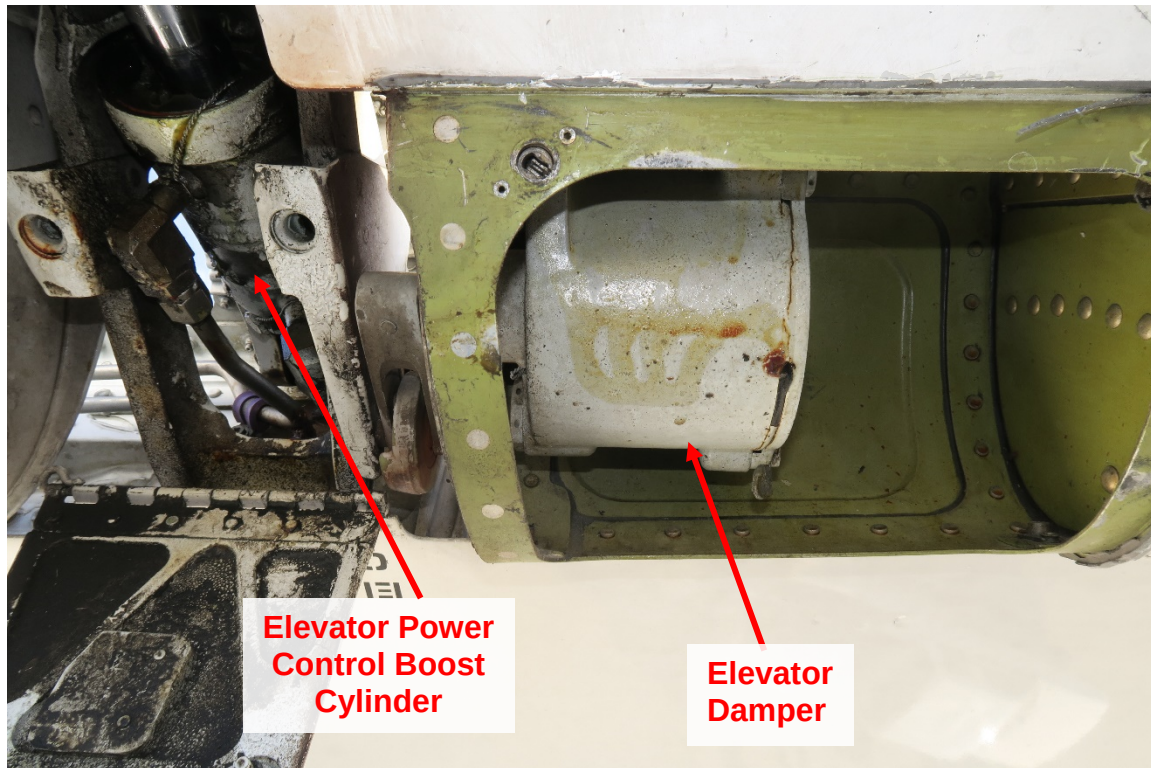


Figure 7 - Elevator damper and elevator power control boost cylinder installed on right elevator (access panels removed)

4.1.2.1.1.2 Elevator Control Tab

The control tab on each elevator's trailing edge is deflected by mechanical inputs from the captain or first officer's control column. When the elevator control tab is deflected, the aerodynamic forces will move the elevator surface. When the control column is pushed forward, commanding an aircraft nose down direction, the control tab will deflect in a control tab trailing edge up direction and the resultant aerodynamic forces will move the elevator surface in a trailing edge down direction. The movements of the tab and surface are opposite if the control column is pulled aft for an aircraft nose up command.

If 10° or more of control tab movement is required to move the elevator trailing edge down (aircraft nose down), a hydraulically operated elevator power control system will activate and drive the elevator in a trailing edge down (AND) direction. The control tabs for the left and right elevator are interconnected below the cockpit floor via the control columns, but the left and right elevator surfaces are not interconnected.

4.1.2.1.1.3 Elevator Geared Tab

The geared tab drive linkages are directly connected to the horizontal stabilizer rear spar at two places approximately in line with the inboard and outboard ends of the geared tab. The connection to the horizontal stabilizer rear spar consists of an eye bolt, two links, and an actuating crank, Figure 8. Each geared tab pushrod connects to a crank fitting on the

geared tab. The geared tab movement directions are identical to the control tab movement but based on elevator surface movement, not control column input.

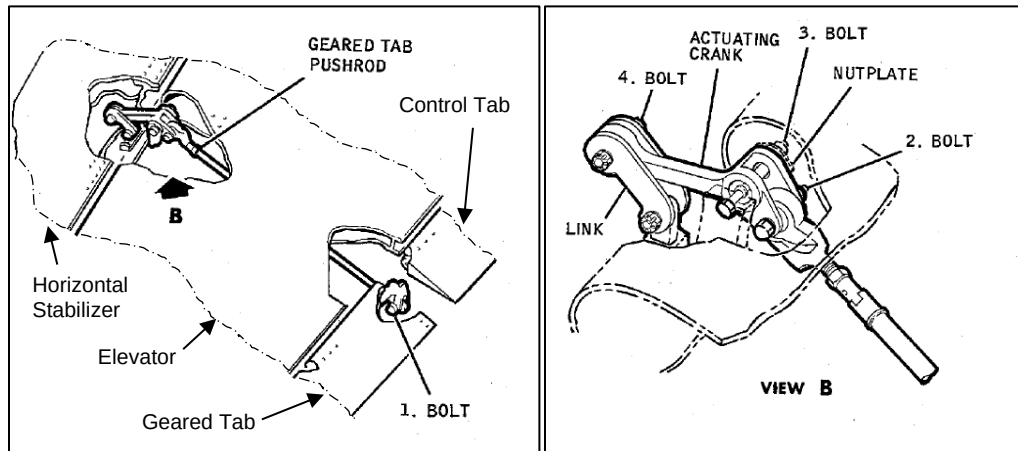


Figure 8 - Maintenance Manual Excerpt of Gear Tab Components (Courtesy of Boeing)

4.1.2.1.1.4 Elevator Anti-Float Tab

The anti-float tab is the outer most elevator tab. The anti-float tab prevents down-float of the elevator when the horizontal stabilizer position is greater than 10° aircraft nose-up. The anti-float tab is mechanically connected to the horizontal stabilizer and movement is driven by the stabilizer position. The anti-float tab will remain faired with the elevator when the stabilizer position is less than 10° aircraft nose-up.

4.1.2.1.1.5 Elevator Stop, Stop Arm and Torsion Bar

Elevator travel is limited to 27° TEU and 16.5° TED due to mechanical stops on the horizontal stabilizer, see Figure 9. The elevator contacts the stop via a stop arm and

torsion bar arrangement mounted in the leading edge of the elevator near the root, see Figure 10 and Figure 11.

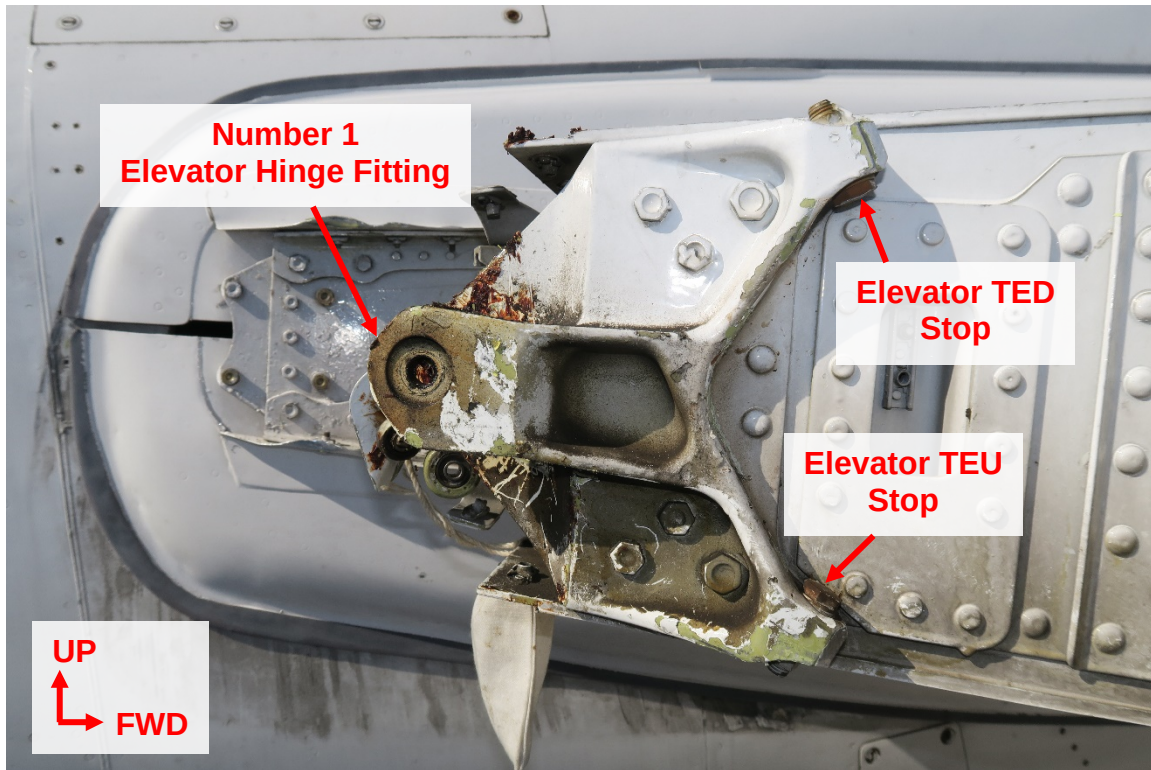


Figure 9 - Right Hand Elevator Stops on Horizontal Stabilizer (Elevator Removed)

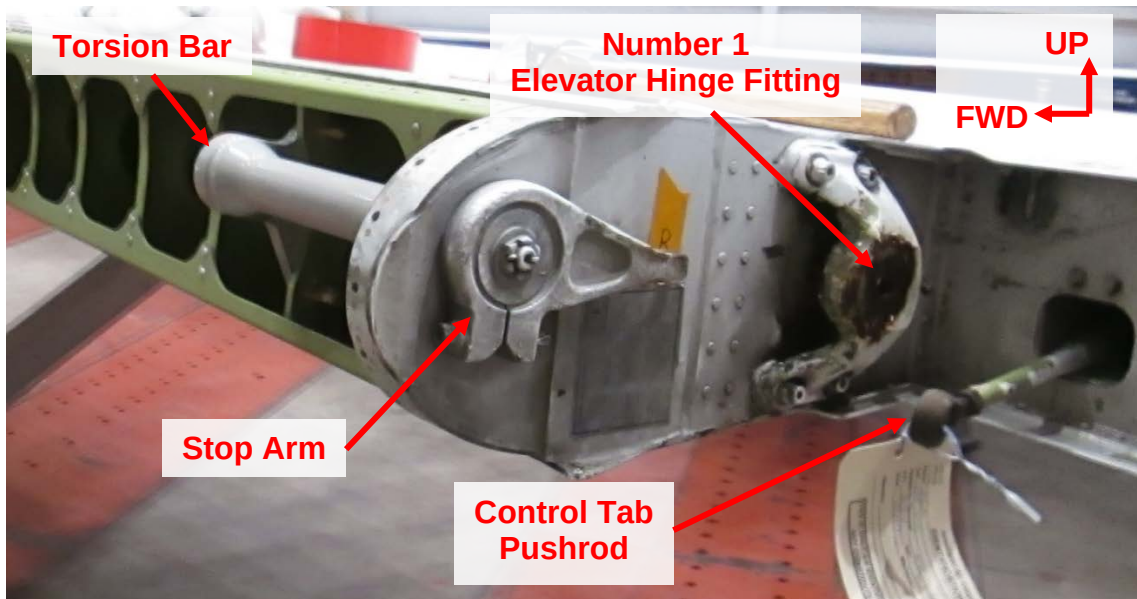


Figure 10 - Right Hand Elevator Stop Arm and Torsion Bar (Leading Edge skin Removed)

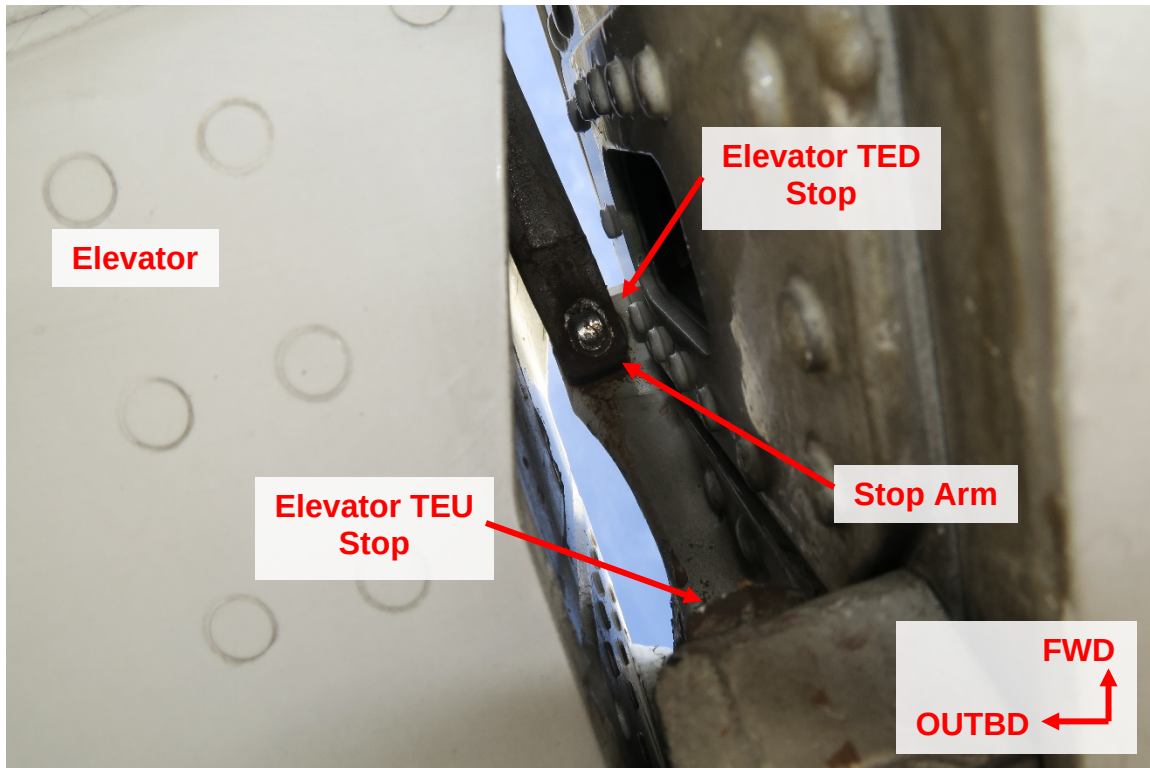


Figure 11 - Right Hand Elevator Stop in contact with stop arm with elevator in full TED position

The torsion bar is attached to a structural rib in the elevator to distribute increased loading due to an increase of force on the stop arm when the elevator is in contact with the elevator stops. The torsion bar passes through the closeout rib via a bushing to allow for torsion bar rotation.

4.1.2.1.1.6 Elevator Power Control Boost Cylinder

As stated in 4.1.2.1.1.2, if large control tab input is required and resultant elevator position cannot be aerodynamically achieved, an elevator power control system will activate and directly drive the elevator to an aircraft nose down position. A hydraulic

boost cylinder is installed at the number 2 hinge location on each elevator, below the number 2 hinge attachment, see Figure 12.

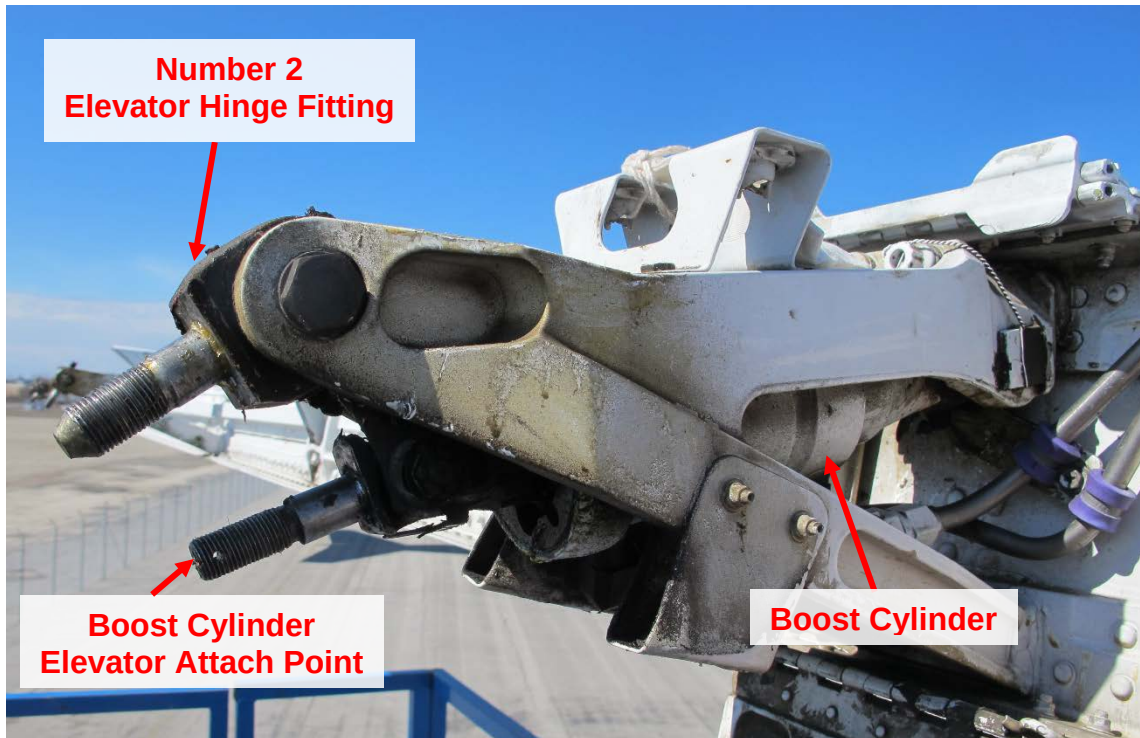


Figure 12 - Left hand side boost cylinder and number two hinge location (elevator removed)

Hydraulic pressure is supplied at 3000 pounds per square inch (psi) to the elevator system hydraulic components from the left hydraulic system, ref. Figure 13. An accumulator is installed to allow for limited hydraulic operation of the boost system in the event of a loss of hydraulic pressure. A series of mechanical linkages from the control tab and elevator surface are connected to two control valves, one for each elevator side. As the difference between the elevator surface and the control tab reaches 10° degree in a nose down command, the control valves will open and supply hydraulic pressure to the boost cylinders driving the elevator towards an aircraft nose down position. Both control valves are required to be open in order for hydraulic pressure to be applied to the boost cylinders. Once the hydraulic pressure increases to over 700 psi, a pressure switch is activated and illuminates a blue indicator light, “Elevator Power On” in the cockpit. Hydraulic pressure within the boost cylinders is limited to 2300 psi, due to an internal pressure limiter. When the control valves are closed, hydraulic fluid in the boost cylinders is free to cycle between the pressure and return ports to allow for actuator movement during normal elevator operations. The elevator movement will be partially dampened due to the shuttling of fluid within each actuator.

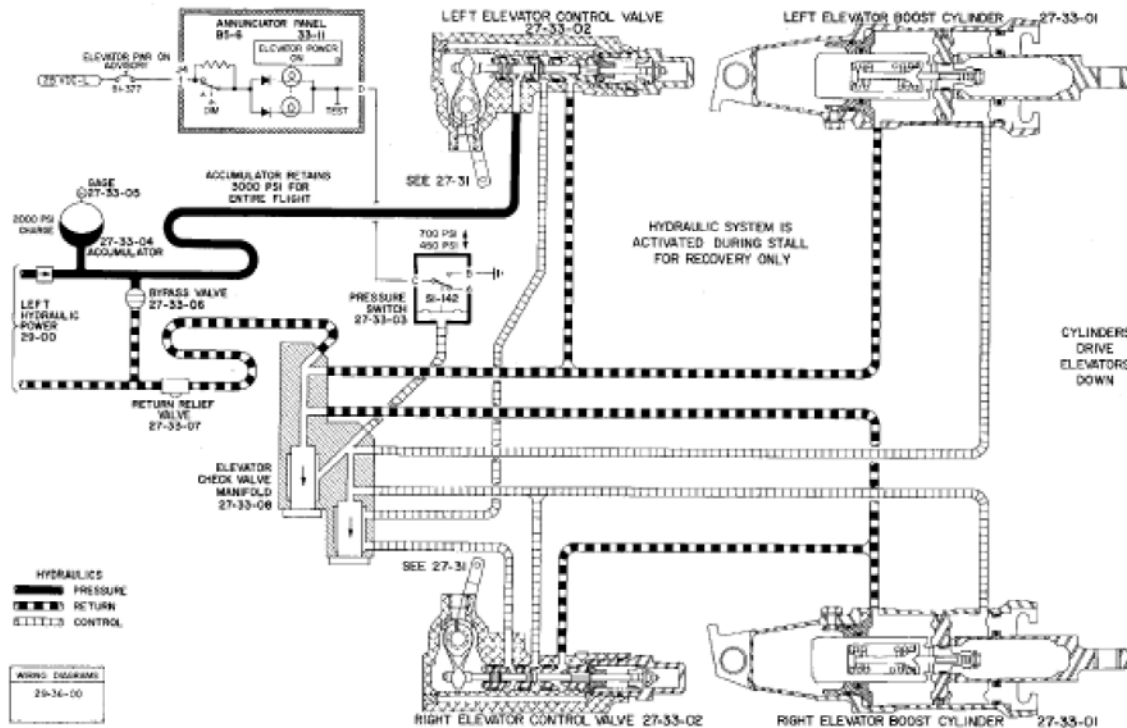


Figure 13 - Elevator hydraulic system (excerpt from aircraft maintenance manual)

4.1.2.1.2 Wreckage Examination

4.1.2.1.2.1 On-Scene Examination

From the ground, when viewed from behind, the left elevator was in a trailing edge up position and the right elevator was in a trailing edge down position, ref Figure 14 and Figure 15. Flight control continuity for the elevator system was established by exercising the control column in the cockpit from both the pilot and copilot's side to the control column stops in both the aircraft nose up and aircraft nose down directions. The left and right control tabs responded with movement in the appropriate directions.

Multiple checks of the control column in the forward and aft direction were performed. The movement of the control columns in the aircraft nose up range had more than one area where it needed to be forced past a catch, and there were tactile and audible indications that a riding condition existed under the cockpit floor. The movement of both control columns in the aircraft nose down range was smoother.

The group used a lift to inspect the elevators and attempted to move the elevators by hand. The right elevator could not be moved by hand from its trailing edge down position. The left elevator moved freely when moved by hand to the stops in the TED and TEU direction.

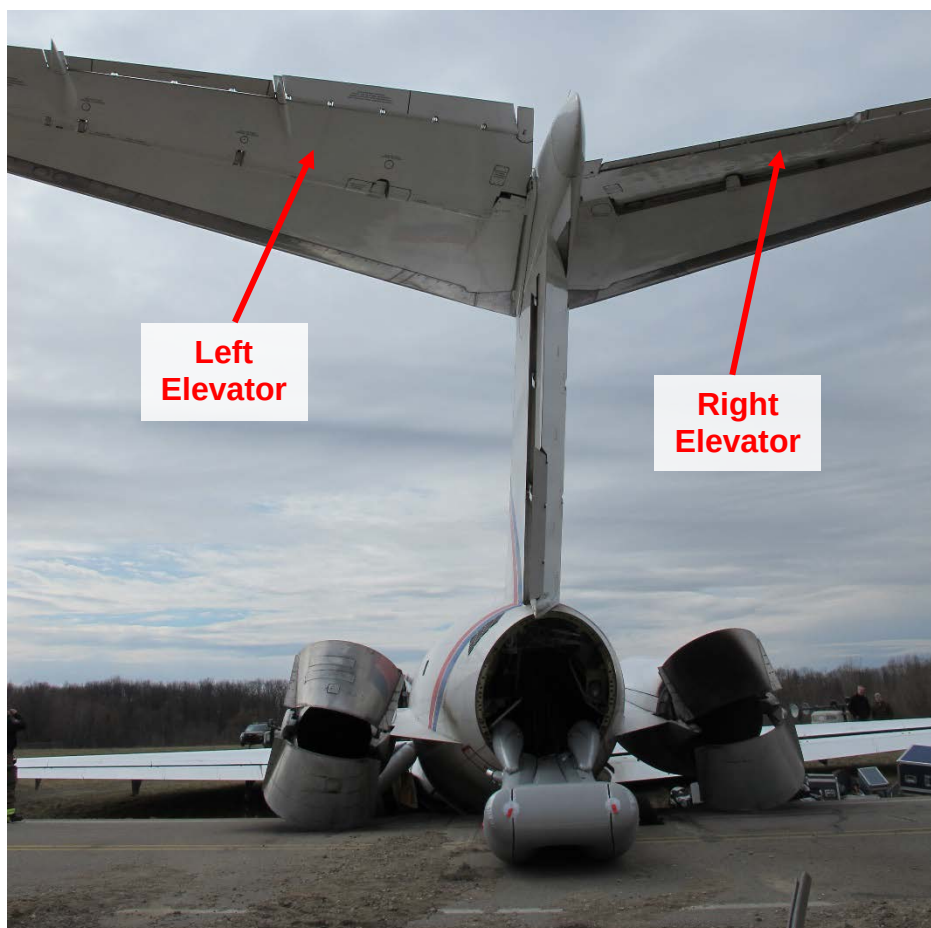


Figure 14 - Elevator (and Rudder) position as viewed from behind the aircraft

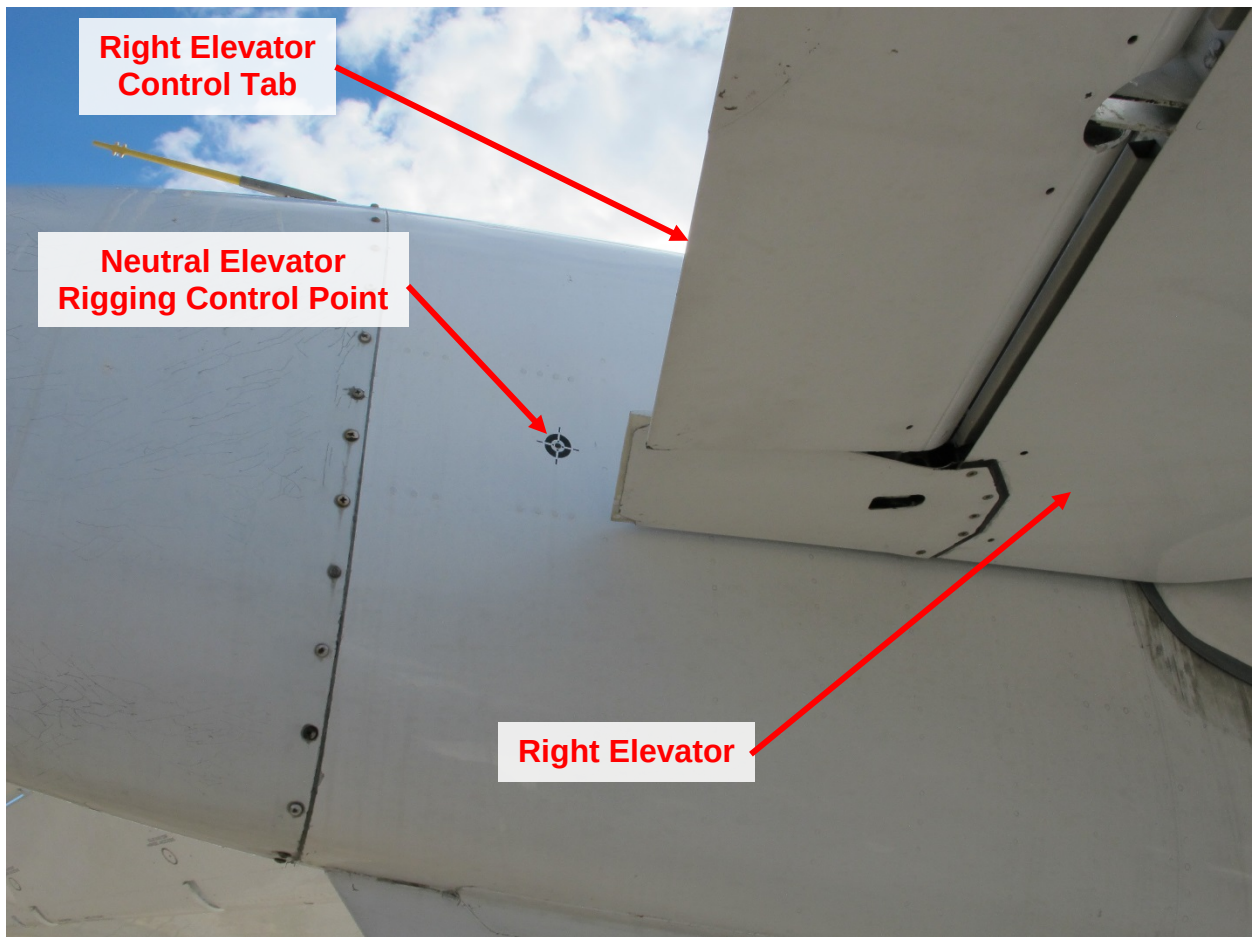


Figure 15 - Trailing edge of the right-hand elevator (jammed position)

A visual examination of the tab hinges and control linkages found that the inboard right geared tab links and actuating crank were damaged and in an over-centered position. The two links and the actuating crank arm were bent in an outboard direction, Figure 16 and Figure 17.

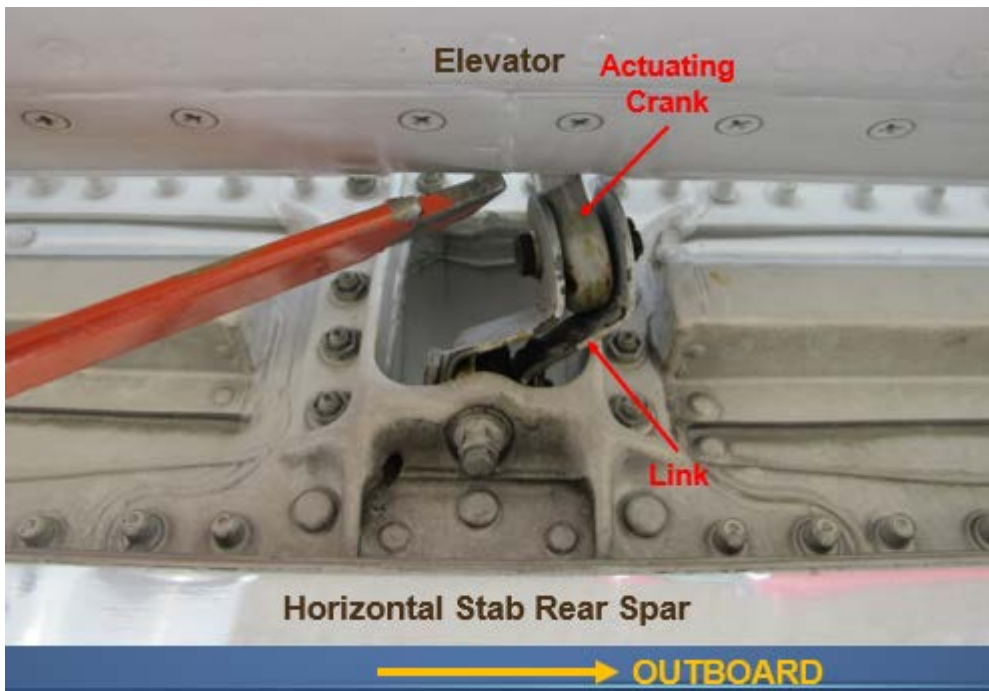


Figure 16 - Inboard right hand geared tab attachment at horizontal stab rear spar as found (orange bar used by group to point to damaged links)

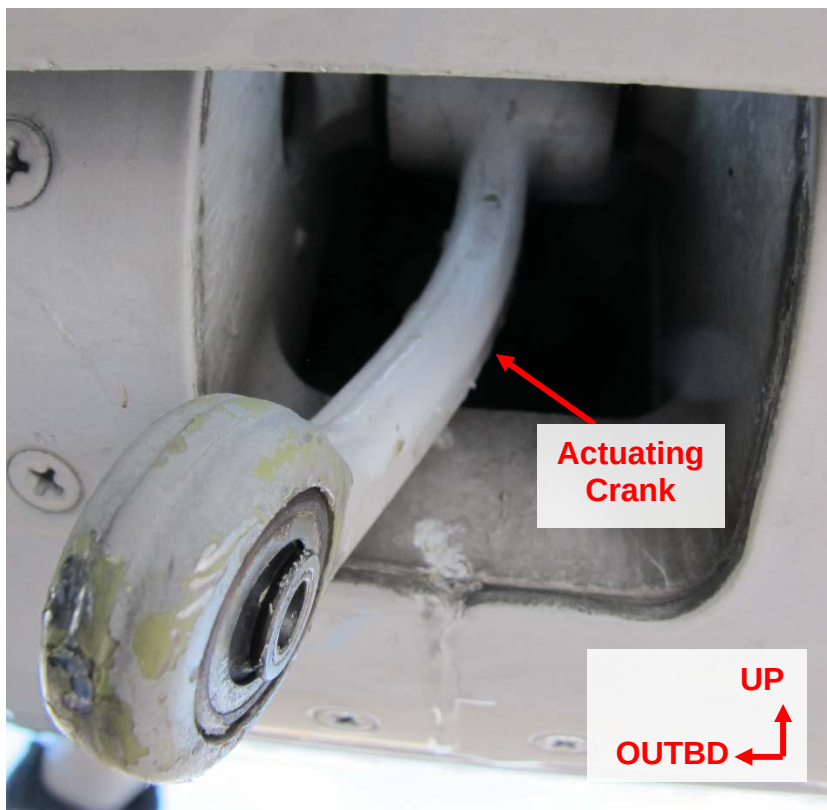


Figure 17 - Damaged Actuating Crank Arm after links removed

A visual examination of the remaining drive linkages for the outboard end of the right geared tab (ref. Figure 18) and both ends of the left geared tab found no defects or obstructions. All appropriate attachment hardware was present for all hinge fittings and control linkage connections on the control, geared and anti-float tabs.

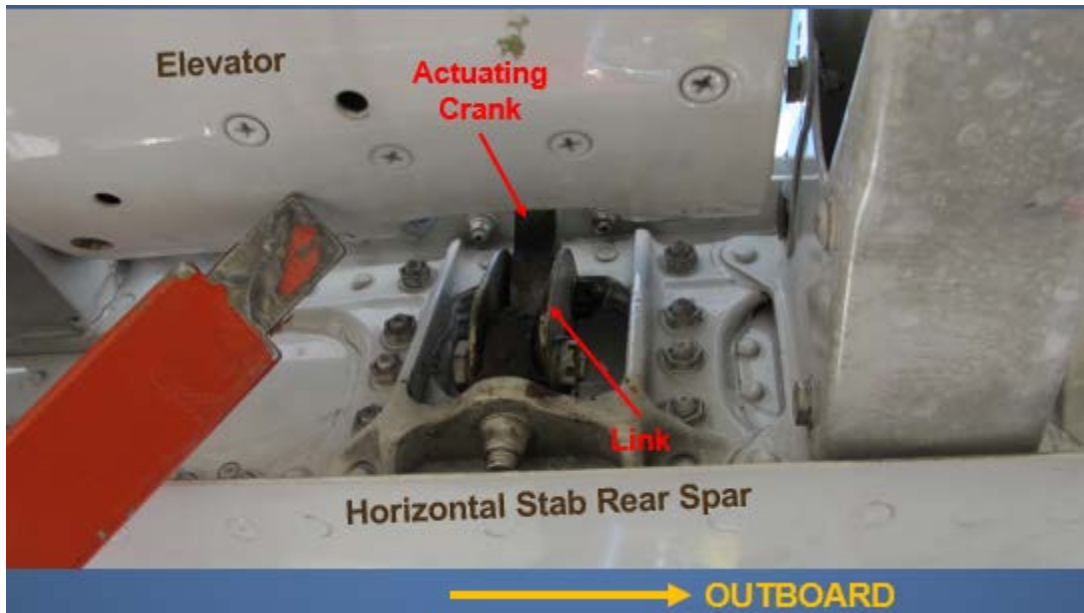


Figure 18 - Outboard right hand geared tab attachment at horizontal stab rear spar (orange bar used by group to point to links)

The damaged links and associated attachment hardware were removed. After the links were removed, the right elevator was free to move, by hand, within the confines of the elevator stops.

The position of the horizontal stabilizer prevented control tab travel checks per the aircraft maintenance manual (AMM) procedure², but improvised checks were performed to approximate the total control tab travel. The total control tab travel was compared to travel values as specified in the AMM.

The improvised control tab travel checks were done from a bucket lift with the elevator visually faired with the stabilizer by hand. Measurements were taken using a digital inclinometer, Figure 19.

² The AMM required that the horizontal stabilizer be placed in a neutral position for flight control rigging checks.



Figure 19 - Digital inclinometer used for travel checks

The total quantity of control tab travel specified in the AMM is 42° to 50° .³ The total travel measured for the right elevator control tab was 44.2° (25.2° TED and 19.0° TEU). The total travel measured for the left elevator control tab was 45.9° (25.9° TED and 20.0° TEU).

Access panels for the elevator dampers were removed to allow inspection of both dampers. The left damper and area around the installation was clean. The right damper outer surface and the inside of the access panel had a brown, tacky substance, Figure 20. All attachment hardware was present and accounted for both dampers.

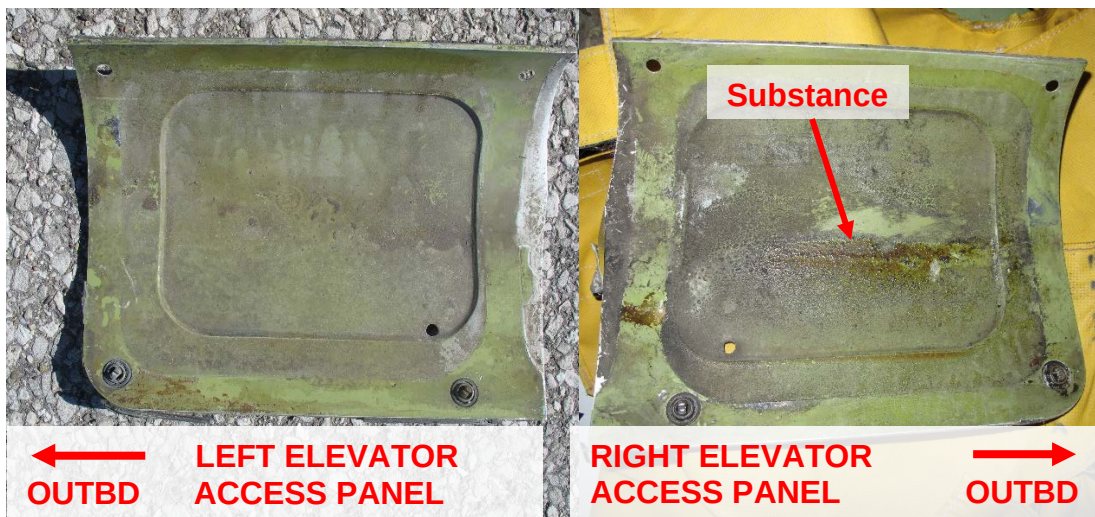


Figure 20 - Left and right elevator damper access panels (interior side shown)

³ The total travel readings include the allowable tolerances specified in the AMM. Nominal control tab travel is $20^{\circ} \pm 2^{\circ}$ in the trailing edge up direction and $26^{\circ} \pm 2^{\circ}$ in the trailing edge down direction when the stabilizer and elevator are fixed in a neutral position.

Both the left and right elevators, the elevator dampers and boost cylinders were removed from the aircraft for further examination and testing.

4.1.2.1.2.2 Elevator Examinations after removal

Both elevators were removed from the aircraft and shipped to a Boeing Company laboratory in Huntington Beach, California. The laboratory utilized an exemplar MD-83 horizontal stabilizer mounted to a ground based fixture to allow for mounting of either elevator in order to simulate surface and tab movements.



Figure 21 - Overview of accident aircraft elevators on test stand at test facility

4.1.2.1.2.2.1 Left Elevator

Data plate information:	Hawker de Havilland Line
Assembly Number:	5930557-405
Ch Ltr:	R
Model:	83
Serial Number:	MDM (or HDH) 1168
Fuse Number:	1907
Date:	21/12/91

No damage was noted on the elevator from the shipment of the elevator to the lab.

A visual inspection conducted of the stop arm noted that the sealant that is located between the stop arm and the closeout rib showed cracking along the circumference of the torsion bar, Figure 22.



Figure 22 - Sealant (cracking noted by arrow) between the LH elevator stop arm and closeout rib.

A straight edge was placed on the center of the torsion bar and aligned with the center of the elevator hinge bearing. A measurement was taken from the straight edge to the upper surface of the stop arm, Figure 23. For the left elevator the measurement was approximately 0.22 inches. The measurement was slightly outside of the manufacturer's drawing tolerance but within the range of adjustment for the elevator stops.

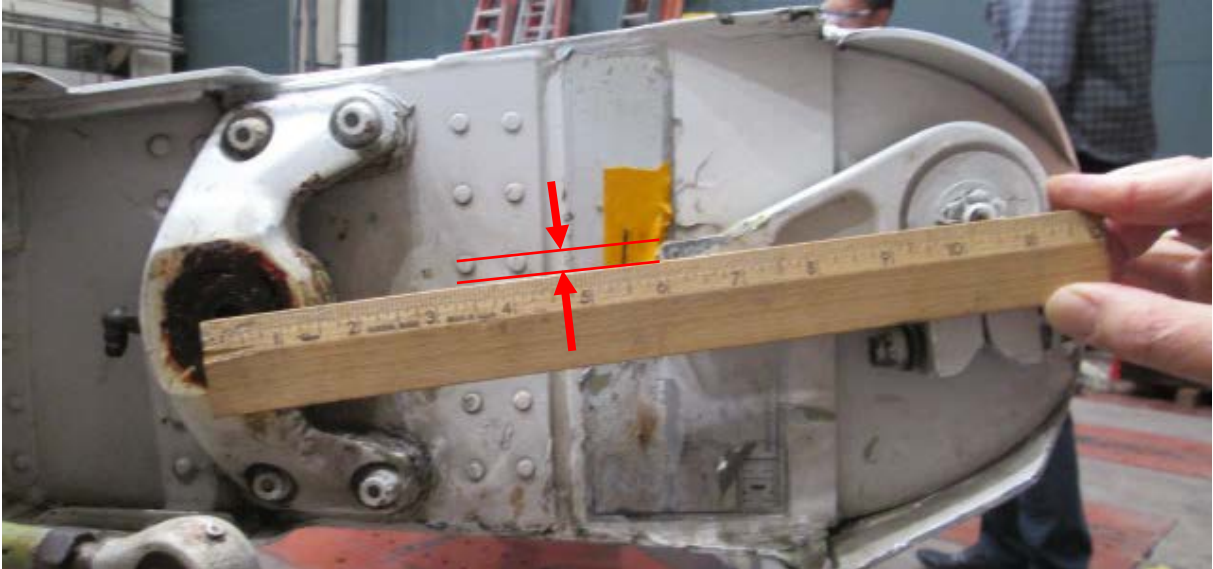


Figure 23 - Alignment check of the LH stop arm with respect to the elevator hinge point

The damper linkages were inspected and no notable witness marks on the damper linkage were noted.

The elevator nose cap was removed to allow for inspection of the torsion bar, Figure 24. No signs of visible damage to the torsion bar was noted. The torque stripes on the mounting hardware were present and showed no signs of displacement.



Figure 24 - Torsion bar installation on LH elevator

The torsion bar removal could not be accomplished by the overhaul manual procedure. Additional force was required to remove the torsion bar. During the removal process, the threaded end which is used to secure the stop arm was damaged. The splines on the

torsion bar and stop arm did not show signs of damage, Figure 25. Sealant filled portions of the spline in the vicinity of the wing rib bearing. A visual inspection of the inner surfaces of the bearing and the mating surface of the torsion bar revealed small areas of sealant adhered to both surfaces, Figure 26.



Figure 25 - Mating spline surfaces of the left elevator stop arm and torsion bar

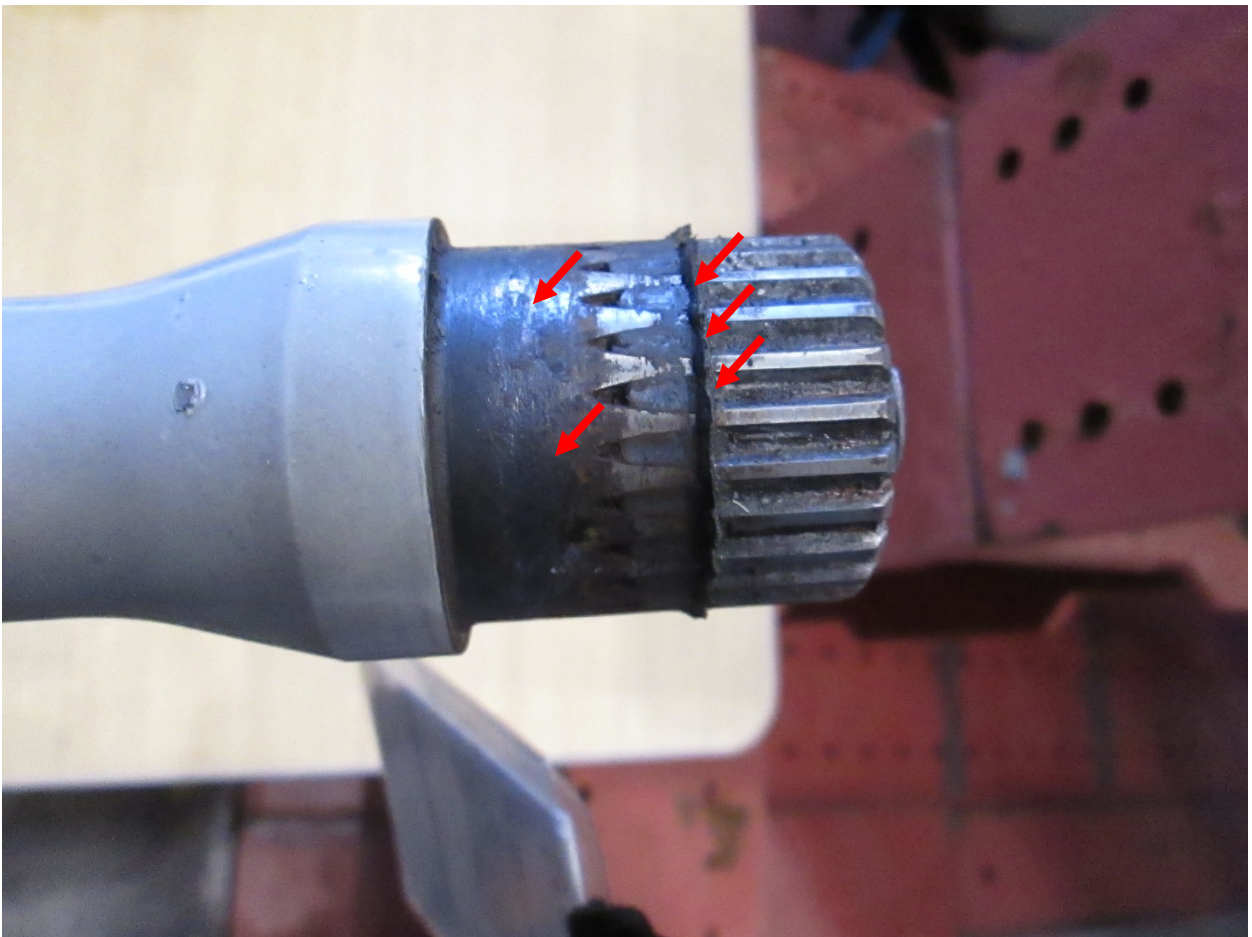


Figure 26 - Torsion bar spline and bearing surface with sealant after removal from elevator (arrows highlight sealant areas, not all areas highlighted)

4.1.2.1.2.2.2 Right Elevator

Data plate information: Hawker de Havilland Line
Assembly Number: 5930557-404
Ch Ltr: R
Model: 83
Serial Number: MDM (or HDH) 1174
Fuse Number: 1985
Date: 10/1/02

No damage was noted from the shipping of the elevator to the lab.

A visual inspection was conducted of the stop arm and the sealant that is located between the stop arm and the closeout rib. No visible sealant cracking, similar to what was present on the left elevator was found, Figure 27.



Figure 27 - Sealant between the RH elevator stop arm and closeout rib (noted by red arrow).

A measurement was taken from the straight edge to the upper surface of the stop arm, Figure 28. For the right elevator the measurement was approximately 0.30 inches. The measurement was consistent with the manufacturer's drawing.

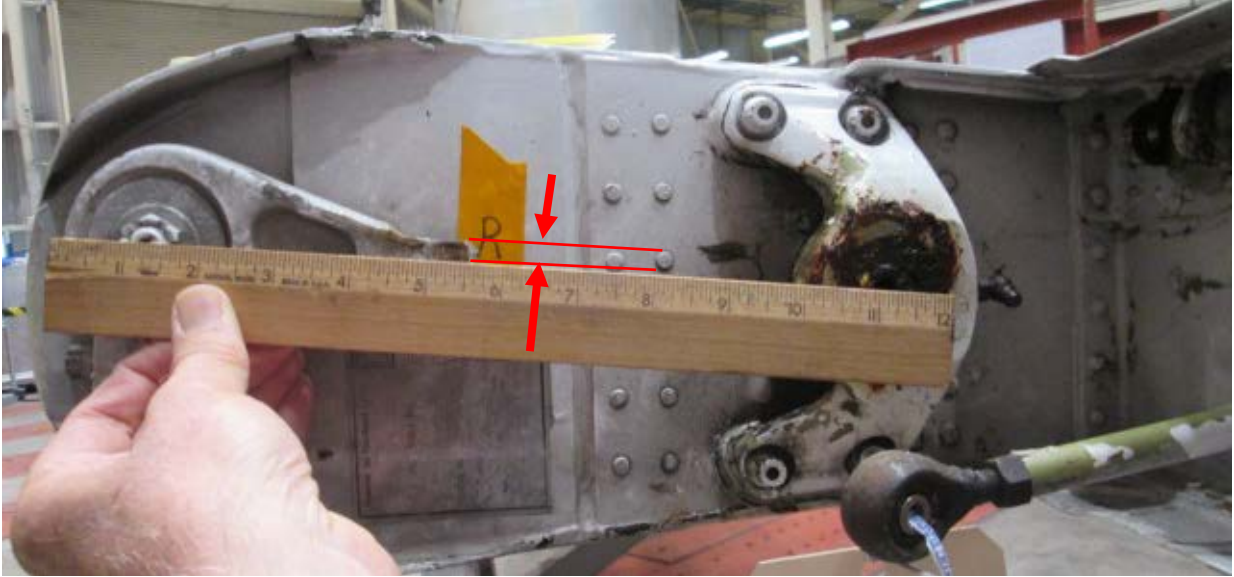


Figure 28 - Alignment check of the RH stop arm with respect to the elevator hinge point

The RH elevator damper linkage was inspected and a witness mark on the linkage was noted approximately 1.9 inches from the attachment bolt. A corresponding mark was noted on the elevator damper arm, Figure 29.

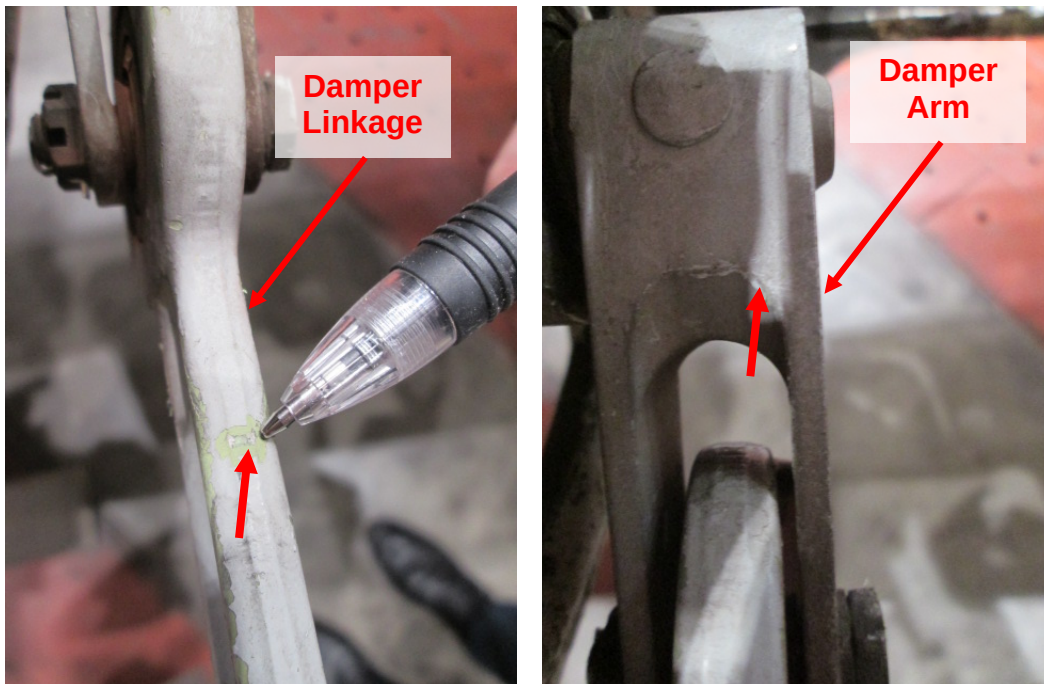


Figure 29 - Witness marks on RH elevator damper (arrow highlights witness mark)

As noted on scene the crank assembly for the inboard geared tab pushrod was found damaged. The crank arm was displaced in an outboard direction, approximately 0.95 inches from its normal position, Figure 30.



Figure 30 - RH Elevator actuating crank arm displacement

The elevator nose cap was removed and no signs of visible damage to the torsion bar was noted, Figure 31. The torque stripes on the mounting hardware were present and showed no signs of displacement. After the mounting bolts were removed, a large wrench was placed on the torsion bar mounting plate, the torsion bar could be easily rotated and removed. The bushing between the torsion bar and the closeout rib remained attached to the torsion bar after removal from the elevator.



Figure 31 – Torsion bar installation on RH Elevator

The inboard geared tab pushrod and actuating crank were removed, Figure 32. The inboard geared tab pushrod did not exhibit any signs of bending. The adjustable rod end, which connects with the geared tab control horn, jam nut, stop washer and safety wire were present and secure. The pushrod (not including the rod ends) was measured to be 26 15/16 inches. The measurement from the angled rod end to the fixed rivet was 3 inches. Both measurements were consistent with manufacturer drawings.



Figure 32 - RH Inboard geared tab pushrod and actuating crank

As previously noted, the actuating crank was bent in an outboard direction. The bearings were free to rotate with no noticeable signs of binding. Figure 33 and Figure 34 show the actuating crank with an exemplar unit. The exemplar unit was obtained from Boeing spares and is an acceptable substitute part for field replacement. The original and accident parts were made from a forging and the current manufactured substitute part is a machined unit.



Figure 33 - Side view comparison of accident and exemplar RH actuating crank



Figure 34 - View looking down at accident and exemplar RH elevator actuating crank

4.1.2.1.2.3 Elevator Damper Examination and Testing

Both elevator dampers were taken to an overhaul facility for examinations and performance testing. The facility also manufactures new elevator dampers to the manufacturer's original specifications. Dataplate information is contained in Table 2.

Table 2 - Elevator Damper Data Plate Information

	Left	Right	Exemplar
Part Number	N/A ¹	5918125-501	5918125-503
Serial Number	N/A ¹	DCC-2-623N	5062

1 – No dataplate was attached to the unit

The accident aircraft dampers were visually inspected. The LH damper had a broken safety wire in the vicinity of one of the aircraft mounting tabs, Figure 35. None of the bolts secured by the safety wire appeared to be displaced.

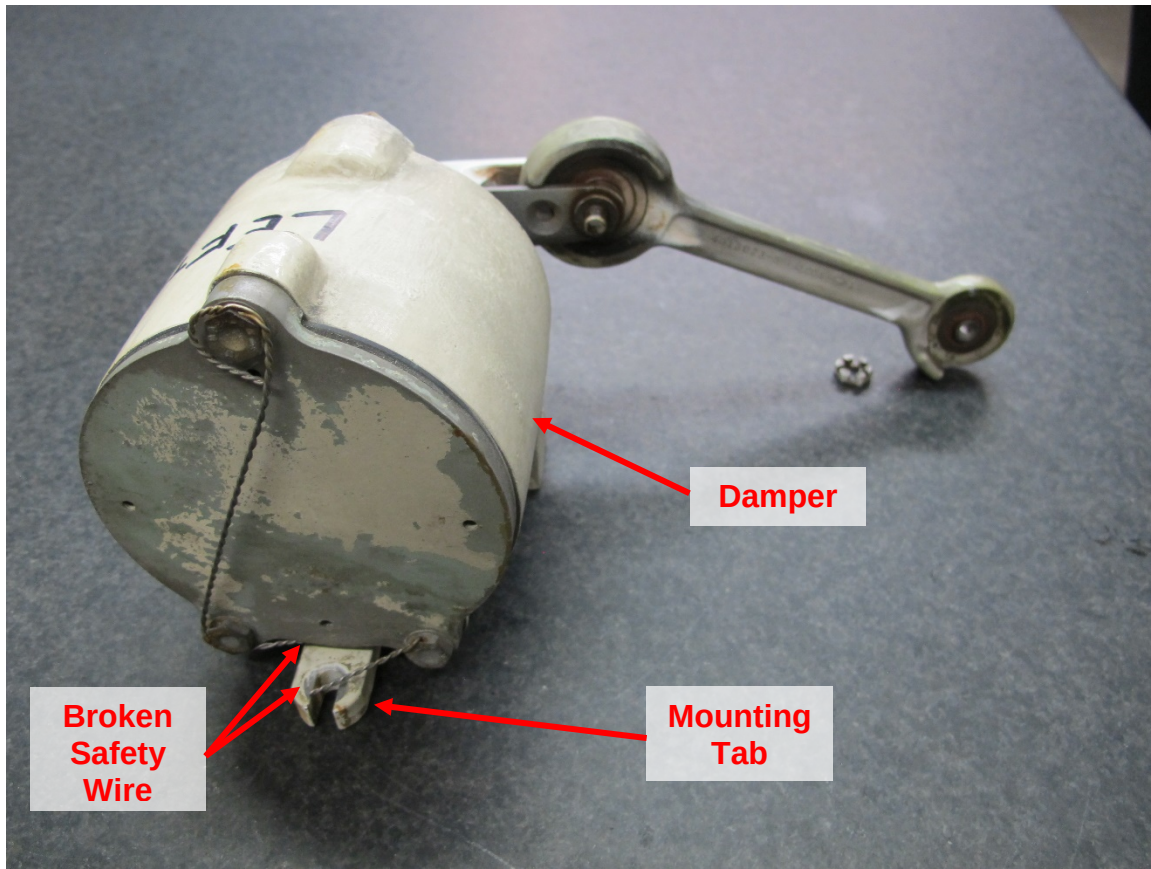


Figure 35 - LH Elevator Damper with broken safety wire noted

The RH damper had a broken safety wire in the vicinity of one of the aircraft mounting tabs, Figure 36. None of the bolts secured by the safety wire appeared to be displaced. The unit case had an area covered in a brownish, tacky, substance, Figure 37. Careful examination of the rear cap diaphragm, pins, plug and shaft did not reveal a source of a possible leak from the damper assembly. Overhaul facility personnel stated that the color of the substance was inconsistent with the manufacturer's specified silicone oil used in the damper assembly, which is typically clear and colorless.

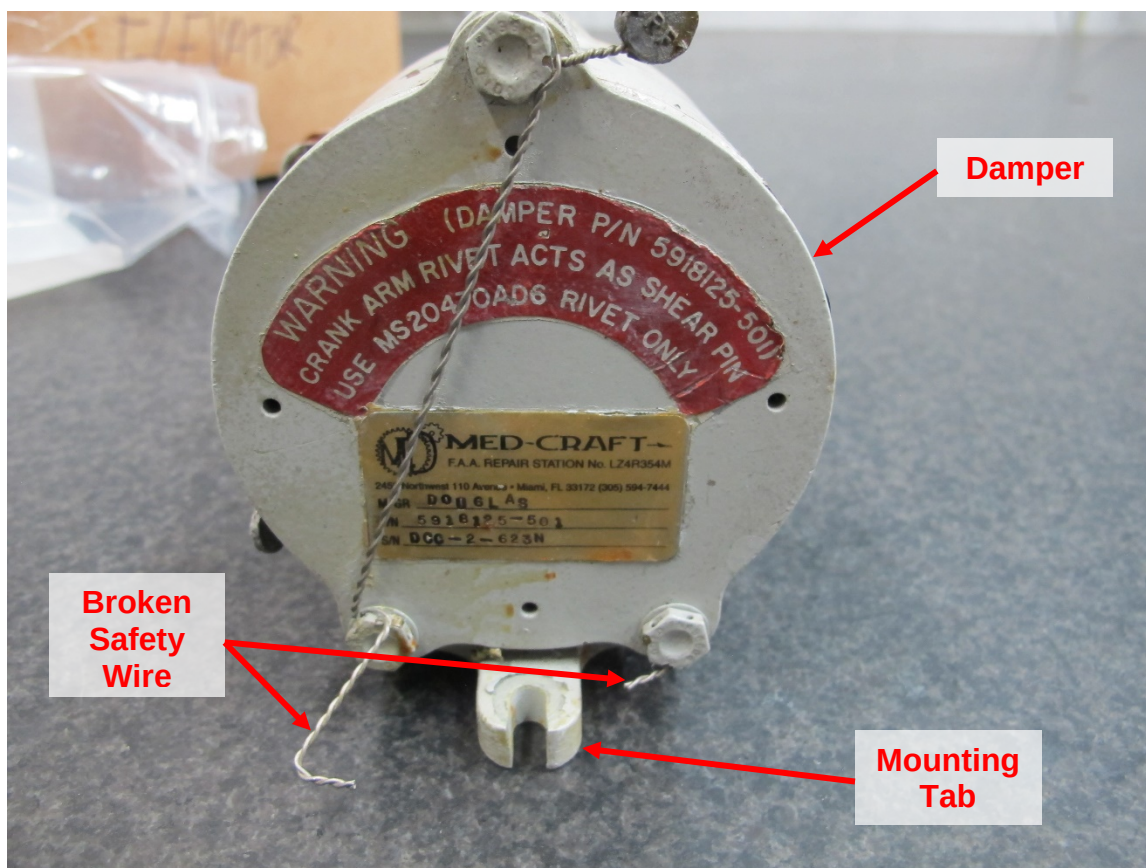


Figure 36 - RH Elevator damper with broken safety wire noted

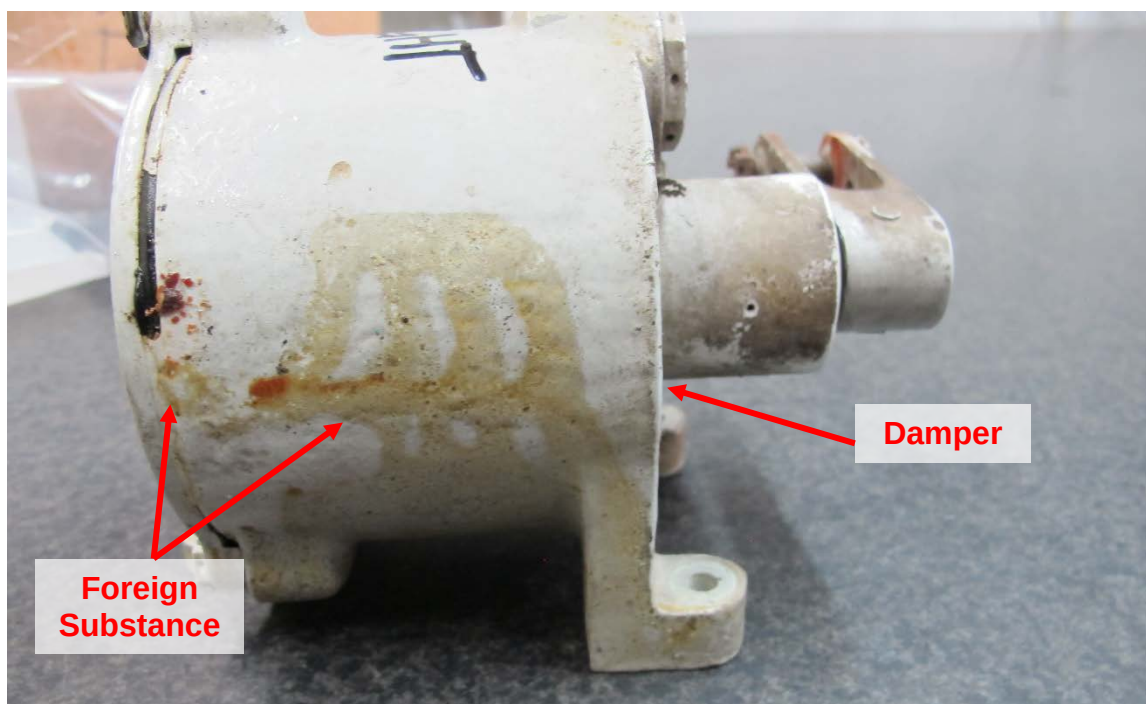


Figure 37 - RH Elevator damper case showing areas of foreign substance

The overhaul facility performed a functional test using their procedure which is based on the component's overhaul manual. Each damper assembly was mounted to the test table and rotated at 16 RPM. The torque was measured during the rotation in both a forward and reverse direction and then averaged. The tests were conducted at a room temperature of 69° F for all the units. The accident units were also tested after a cold soak to 32° F +/- 6° F for 23.5 hours. Table 3 contains the results of the damper tests and Table 4 contains acceptable test ranges from the unit's overhaul manual.

Table 3 - Damper Test Results

Unit (P/N)	Average Torque Ambient Temp (in-lb)	Average Torque Cold Soaked (in-lb)
Left (Unk)	41	49
Right (-501)	44	55
Exemplar (-503)	51	N/A ¹

¹ – Unit was not subject to the cold soak test

Table 4 - OHM acceptable torque ranges for damper

Unit	Acceptable Torque Range (in-lb)
-1	55-75
-501	35-75 ¹
-503	35-65 ¹

¹ - Torque measured after cold soak

4.1.2.1.2.4 Boost Cylinder Examination and Testing

Both elevator boost cylinders were taken to a manufacturing/overhaul facility for examinations and performance testing. Data plate information is in Table 5.

Table 5 - Elevator Boost Cylinder Data Plate Information

	Left	Right
Part Number	5934212-5501	5934212-5001
Serial Number	EFS-22846	AV01

The accident aircraft boost cylinders were visually inspected, Figure 38 and Figure 39. No defects were noted in either visual inspection. Prior to the testing, the u-joints on each cylinder were removed to allow for installation in the test fixture.



Figure 38 - LH Elevator boost cylinder prior to bench testing



Figure 39 - RH Elevator boost cylinder hooked up to test bench

The overhaul facility performed a functional test of each boost cylinder using their procedure which is based on the component's overhaul manual. The left cylinder passed all tests that were performed. The right cylinder passed all tests except for the relief valve reseal test. The reseal test required a minimum reseal pressure of 2,050 psi and the unit tested at 1,950 psi. The test was repeated an additional three times with results of 1,950 psi, 1,950 psi and 2,000 psi). Test results for both cylinders are included in Attachment 1.

4.1.2.1.2.5 Link and Crank Assembly Materials Testing

The damaged actuating crank and links were inspected by the Boeing Materials Laboratory in Huntington Beach, CA. Two tests, Rockwell Hardness and Conductivity were conducted to check the characteristics of the material of the actuating crank, Figure 40. Only the Rockwell Hardness was conducted to check the characteristics of the material of the links, Figure 41. Each test was conducted using approved Boeing material lab processes. The parts were cleaned, and exterior paint was removed prior to conducting the tests. The test and inspection results were compared to the part requirements stated on the manufacturer's engineering drawings. The parts were consistent with the manufacturer's drawings.

Table 6 - Link and Actuating Crank Hardness Test Results

Part	Average Hardness^{1,2}	Expected Hardness Range²
Inboard Link	30.9 HRC	26-32 HRC
Outboard Link	30.9 HRC	26-32 HRC
Actuating Crank	81.7 HRB	74.5-83.5 HRB

¹ – Hardness testing was conducted at various locations on the part, the average value was recorded.

² – Rockwell Hardness “B” (HRB) and “C” (HRC) scale

The actuating crank conductivity measurement was 37% IACS, with an expected requirement of 36-42% IACS.⁴

⁴ Electrical conductivity measurements are typically expressed as a percentage of conductivity of the International Annealed Copper Standard (IACS)

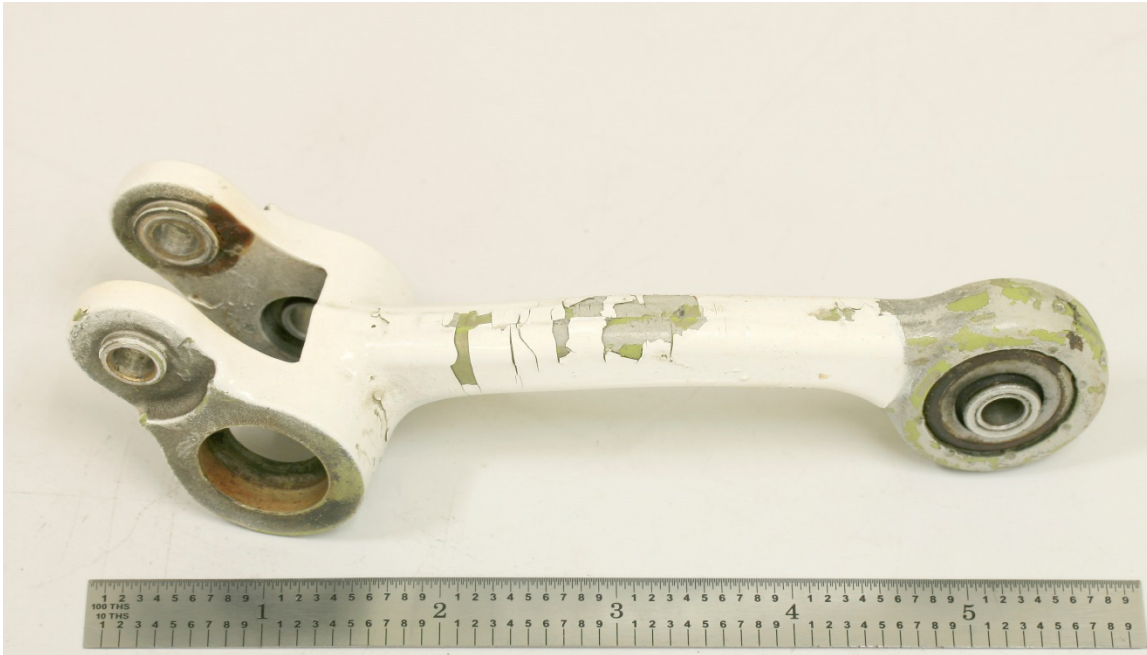


Figure 40 - Actuating crank prior to hardness and conductivity testing



Figure 41 – Outboard (O) and inboard (I) links prior to hardness testing

4.1.2.1.2.6 Torsion Bar and Stop Arm Examination and Materials Testing

Both torsion bars and stop arms were inspected by the Boeing Materials Laboratory in Huntington Beach, CA. Rockwell Hardness tests were conducted to check the characteristics of the material of each torsion bar, Figure 42. Each test was conducted using approved Boeing material lab processes. Prior to cleaning and paint removal, none of the parts showed any damage to the painted surfaces such as cracking or crazing. The parts were cleaned, and exterior paint was removed prior to conducting the tests. The

inspections and test results were compared to the part requirements stated on the manufacturer's engineering drawings, ref. Table 7. The parts were consistent with the manufacturer's drawings.

Table 7 - Torsion bar and stop arm Hardness Test Results

Part	Average Hardness^{1,2,3}	Expected Hardness Range²
Left Torsion Bar	49.5 HRC	47-49.5 HRC
Right Torsion Bar	49.3 HRC	

¹ – Hardness testing was conducted at various locations on the part, the average value was recorded.

² – Rockwell Hardness “C” (HRC) scale

³ – Due to the circular nature of the part a correction factor of 0.5 HRC was added to the average value.

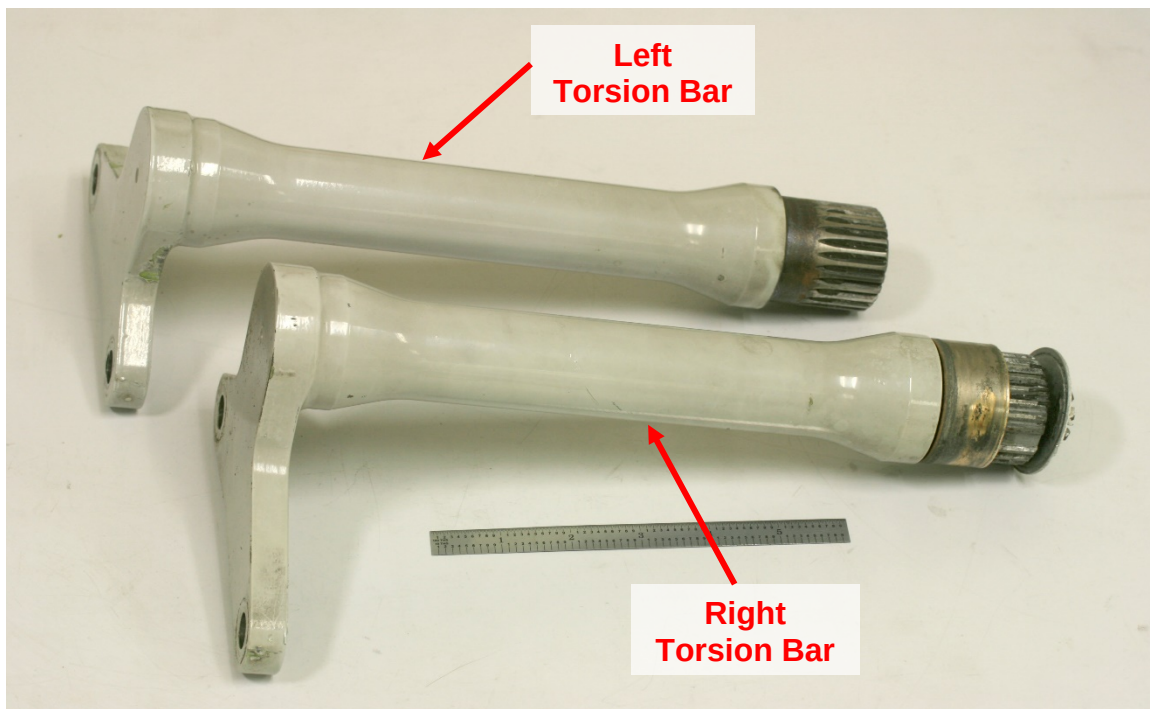


Figure 42 - Torsion bars prior to hardness testing

Due to fixture issues, hardness testing was not performed on the stop arms, Figure 43. To permit testing, the lab recommended that the stop arms be sectioned, and the sectioned pieces be placed in the test equipment and tested. The group decided against the sectioning of the stop arms, in order to allow use of the arms in the planned elevator testing.

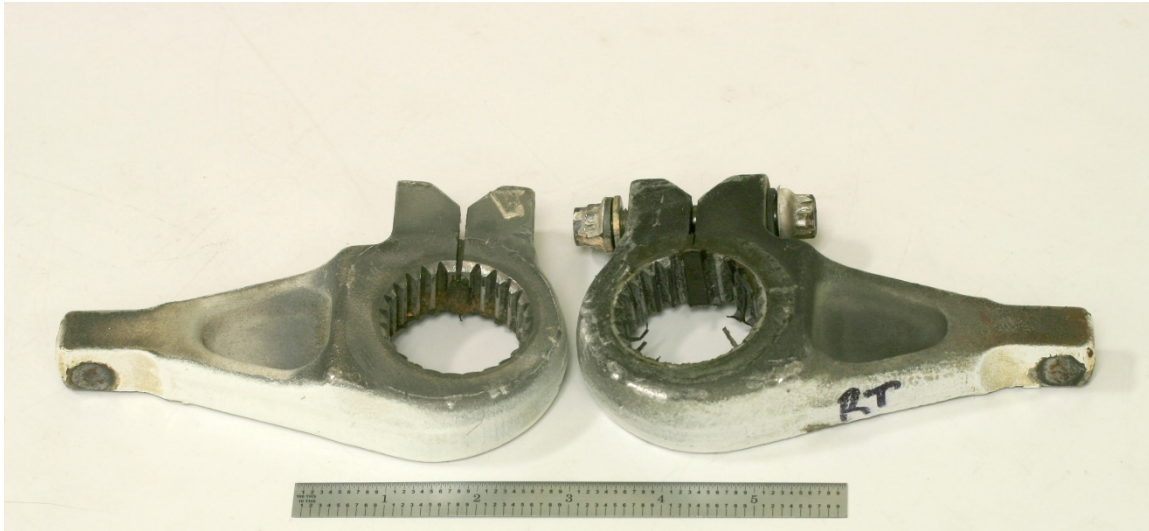


Figure 43 - Left and right stop arms prior to hardness testing

The right torsion bar and right stop arm was also subjected to magnetic particle tests in order to inspect the splines for cracks and damage. The magnetic particle test can detect a crack size down to 0.010 in. Prior to the testing, electrical tape was used to seal the gap between the bushing and the torsion bar. Any remaining sealant in the spline valleys was removed using a razor blade. It was also noted that, under a 10x microscope, the cadmium plating on the splines created surface features and area of material buildup.

The torsion bar was then subjected to a 550 A electrical charge to create a magnetic field, Figure 44. A second inspection using a portable yoke type electro magnet was also performed on the torsion bar. During both tests, magnetic particles did not reveal any distinct indications of cracks along the spline valleys or the spline ends.



Figure 44 - Right torsion bar splines during magnetic particle testing

The stop arm was subjected to 970 A to create the magnetic field, Figure 45. A second inspection using a portable yoke type electro magnet was also performed on the stop arm. During both tests, magnetic particles did not reveal any distinct indications of cracks along the spline valleys or the spline ends.



Figure 45 - Right stop arm splines during magnetic particle testing

The testing lab recommended that the cadmium plating be removed to reveal the entire surface of the torque bar splines if additional testing was to be performed. The group did not perform any additional material testing on the torsion bars or stop arms.

4.1.2.1.2.7 Exemplar Aircraft Elevator System Testing

The operator provided the group access to an exemplar MD-83, N787TW. The group drafted a test plan that checked elevator and control tab travel with and without hydraulics. The testing also included operation of the boost cylinders and bleed down rates of the hydraulic accumulator on the elevator system. The test plan is included in Attachment 2. The following paragraphs summarize the test results.

The horizontal stabilizer was set to its neutral position. With the hydraulics off, each elevator surface was moved by hand to its TEU and TED position limits and measurements were taken using a digital inclinometer. Table 8 contains the elevator surface travel measurements.

Table 8 - N787TW Elevator surface travel measurements (hydraulics off)

Elevator	Left (°)	Right (°)	Rig Tolerance (°)
Trailing Edge Up (TEU)	27.6	26.6	27.0 ± 0.5
Trailing Edge Down (TED)	16.6	17.0	16.5 ± 0.5

Elevator control tab travel was measured with the elevator held in place in three positions (neutral, Full TEU, Full TED) and the control tab deflected using the First Officer's control column. The tab travel was measured using a Boeing supplied rigging protractor, Figure 46. Table 9 contains the control tab surface travel measurements.



Figure 46 - Rigging protractor used during control tab travel tests

Table 9 - N787TW Control tab travel measurements (hydraulics off)

Elevator	Right Control Column	Left (°)	Right (°)	Rig Tolerance (°)
Neutral	Neutral	0.25 TED	1.00 TEU	0.00 ± 0.25
	Forward	21.5 TEU	23.25 TEU	20 ± 2
	Aft	26.25 TED	25.25 TED	26 ± 2
TED	Full Forward	15.375 TEU	16.5 TEU	18.5 ± 3.5
TEU	Full Aft	25.625 TED	25.0 TED	26.5 ± 2.5

An additional test was performed with hydraulics off and the horizontal stabilizer placed at 8 degrees nose up which was consistent with the as found condition of the accident aircraft. Readings of the elevator and control tab positions with the elevator at neutral were taken in a manner consistent with the measurements taken the day after the accident using the digital inclinometer only, ref Table 10 and Table 11.

Table 10 - N787TW Elevator surface travel measurements, Horizontal Stab. Position 8° ANU (hydraulics off)

Elevators	Left (°)	Right (°)
Trailing Edge Up (TEU)	28.0	29.9
Trailing Edge Down (TED)	15.0	16.8

Table 11 - N787TW Control tab travel measurements, Horizontal Stab. Position 8° (hydraulics off)

Elevator	Right Control Column	Left (°)	Right (°)
Neutral	Forward	21.1/21.7	21.6
	Aft	23.4/25.0	26.4

Hydraulics were turned on and the control column was pushed forward in order to activate the elevator boost system and allow for elevator surface position measurements. The elevator boost system was activated, and the elevator surface positions were measured using the digital inclinometer. Table 12 contains the elevator surface positions with the boost system active and compared to the surface positions with the hydraulic systems off.

Table 12 - N787TW Elevator surface position TED with and without boost system active

Elevator	Left (°)	Right (°)
EPAS Active (TED)	17.5	18.1
<i>Without Hydraulics (for Ref)</i>	<i>16.6</i>	<i>17.0</i>
<i>Difference</i>	<i>+0.9</i>	<i>+1.1</i>

Each elevator was checked to determine the TEU position of the control tab at the first activation of the boost cylinders. The position would be noted when the opposite elevator started to move. The state of the “Elevator Power On” was noted at the point of initial boost cylinder operation.

Table 13 - N787TW Elevator position at first activation of boost cylinders

Control Tab	Left (°)	Right (°)
EPAS Active (TED)	7.25	8.75
<i>EPAS Light</i>	<i>Not Lit</i>	<i>Not Lit</i>
Control Tab TEU (No Hyd)	20.125	20.625

Upon completion of the position tests with the hydraulic system on, the hydraulic system was turned off and checks of the elevator accumulator were performed. The purpose of the testing was to determine the length of time that the accumulator would remain charged after the hydraulics were turned off. Prior to the test the accumulator pressure holding capability was checked per AMM criteria. The accumulator passed the accumulator holding test after the 30-min hold.

The hydraulic system was pressurized and held stable for 4 minutes and then hydraulics were turned off, the accumulator pressure reading was 3000 psi. The elevators were fixed in a neutral position to ensure that no inadvertent movement of the elevators due to winds and the boost system actuating would occur. After 300 minutes (5 Hours) the accumulator pressure reading was approximately 2100 PSI.

After 300 minutes (5 Hours), the boost cylinders were activated by pushing the control column forward. The elevators moved to a full TED down position, however no blue light was visible in the cockpit and the speed of the elevators was slow when it contacted the stops.

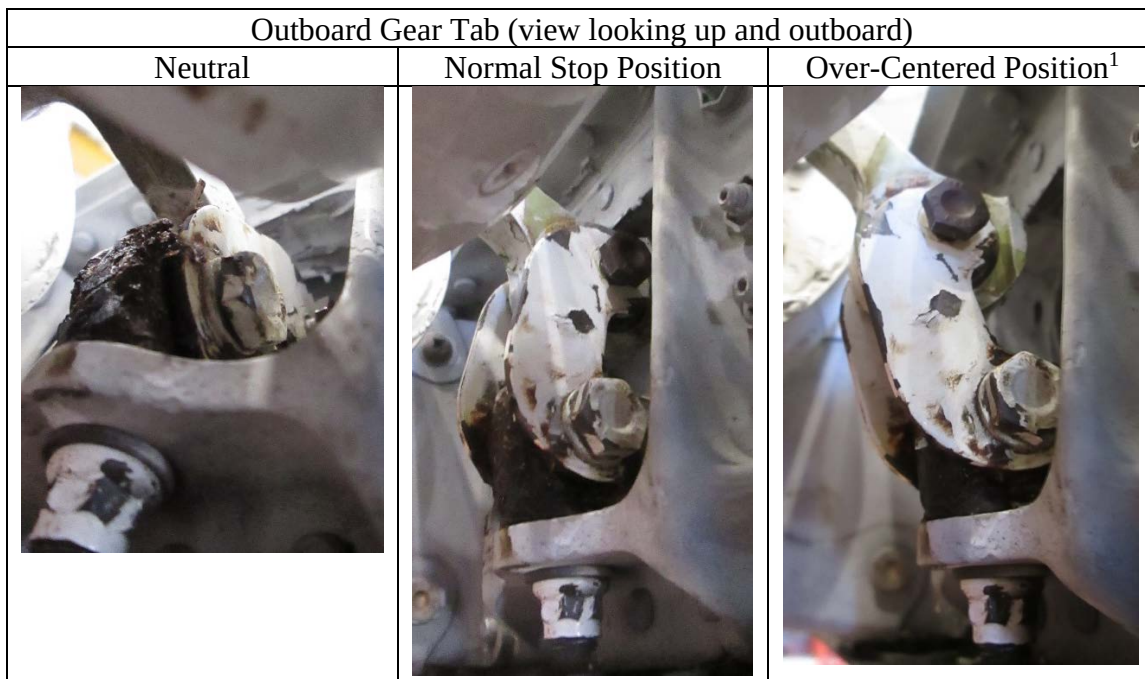
4.1.2.1.2.8 Initial elevator testing on test rig

The left elevator, without the torsion bar and stop arm installed, was installed on an exemplar horizontal stabilizer. The elevator was not rigged prior to testing. Without the torsion bar/stop arm installed the range of motion of the elevator is greater than the rigged limits. The hydraulic lines of the elevator boost cylinder were not connected to a hydraulic source and the hydraulic fluid was free to circulate in the boost cylinder.

The elevator was placed in a faired position corresponding to elevator neutral. A digital inclinometer was placed on the trailing edge structure between the geared tab and the control tab and zeroed. The elevator was moved in a trailing edge down (TED) direction until the inclinometer read 16.6° , which corresponds to the AMM lower stop position $16.5^\circ \pm 0.5^\circ$. The elevator was then moved further in a TED direction until the elevator travel was impeded at 24.1° . After the measurement was taken, the elevator was raised in a TEU direction and then moved abruptly in a TED direction, with a force (applied by hand) also added to the gear tab. The elevator locked in a TED direction and the inboard geared tab links and crank assembly over centered. The elevator surface position in this locked position read 23.3° , the geared tab position read 20.3° . The locked elevator could be released with a quick application of force in a TED direction and in some cases followed by a TEU direction. The test was repeated multiple times and the locked/over-center condition of the inboard geared tab links could be repeated. In all cases of locking/over-centering on the inboard gear tab linkages, the outboard gear tab linkage did not over-center. Figure 47 and Figure 48 show the positions of the links and the actuating crank for various elevator positions.



Figure 47 - Inboard geared tab link and actuating crank position compared to elevator position



1 – The over-centered position is based on the inboard geared tab link position. The outboard geared tab did not over-center during the testing.

Figure 48 - Outboard geared tab link and actuating crank position compared to elevator position

The torsion bar and stop arm were reinstalled on the left elevator. The elevator damper was removed, and the boost cylinder was disconnected from the elevator. The elevator was placed in the neutral position and the inclinometer was zeroed. The elevator was then moved to the TED stop and a reading of 17.8° was recorded ($16.5^{\circ} \pm 0.5^{\circ}$ is the AMM specified limit). The elevator was then moved to the TEU stop and a reading of 25.7° was recorded ($27.0^{\circ} \pm 0.5^{\circ}$ is the AMM specified limit). A total travel of 43.5° was calculated (43.5° is the calculated total travel based on the AMM specified limits). Similar to the test with the torsion bar and stop arm removed, the elevator was raised in a TEU direction and then moved abruptly in a TED direction, with a force (applied by hand) also added to the gear tab. After several repeated attempts, the elevator did not lock in a TED direction using a force applied by hand.

4.1.2.1.2.9 Static and dynamic elevator load testing on test rig

The group created a follow-on set of tests simulating both static and dynamic gust loading conditions. The purpose of the testing was to measure torsion bar deflections due to wind loading on the elevator while parked and/or boost cylinder activation.

The test rig utilized the left elevator, left torsion bar, and left stop arm from the accident aircraft. The test setup also included the right elevator damper and the right boost cylinder⁵. All components were used after successful completion of their respective component tests.

The hinge moments used to simulate the gust loading conditions were based from 14 CFR 25.415, Ground Gust Conditions (Amd. 25-91 07/29/1997).

$$H = 0.0034 * K * c * S * V^2$$

Where Hinge moment (H) = $\frac{K}{c} S V^2$
 K = constant (+/-0.75 for Elevator)
 c = mean chord aft of hinge (in feet)
 S = area aft of hinge (in square feet)
 V = velocity (in knots)

Based on information from the Meteorology group, the maximum recorded wind gust was 55 knots⁶. For the initial tests, velocities of 25, 55 and 75 knots were used in the calculation of the hinge moments. Additional tests were later performed for velocities of 60, 65 and 70 knots.

Along the trailing edge of the elevator, eleven hinge points for the control, geared and anti-float tab, were used to apply loads to simulate the elevator hinge moment. The assumed loading profile was 60% load on the control tab, 30% loading on the geared tab and 10% loading on the anti-float tab.

⁵ The elevator damper and boost cylinders can be mounted on either elevator and are not location specific to the left or the right elevator.

⁶ Further information on weather conditions can be found in the Meteorology Group Chairman's Factual Report

The test rig also utilized a hydraulic test bench which provided 3000 psi to the installed boost cylinder to represent the aircraft hydraulic system. Pressure transducers were installed to measure system and return pressures within the setup. Operation of the boost cylinder was controlled by applying pressure directly to the cylinder and did not utilize the control valves in the system.

A beam deflection gage was installed on the elevator and connected to the stop arm in order to measure stop arm/torsion bar deflection (rotation), Figure 49. The deflection was calibrated such that a zero-deflection equated to when the stop arm was in initial contact with the elevator unloaded at the TED stop.

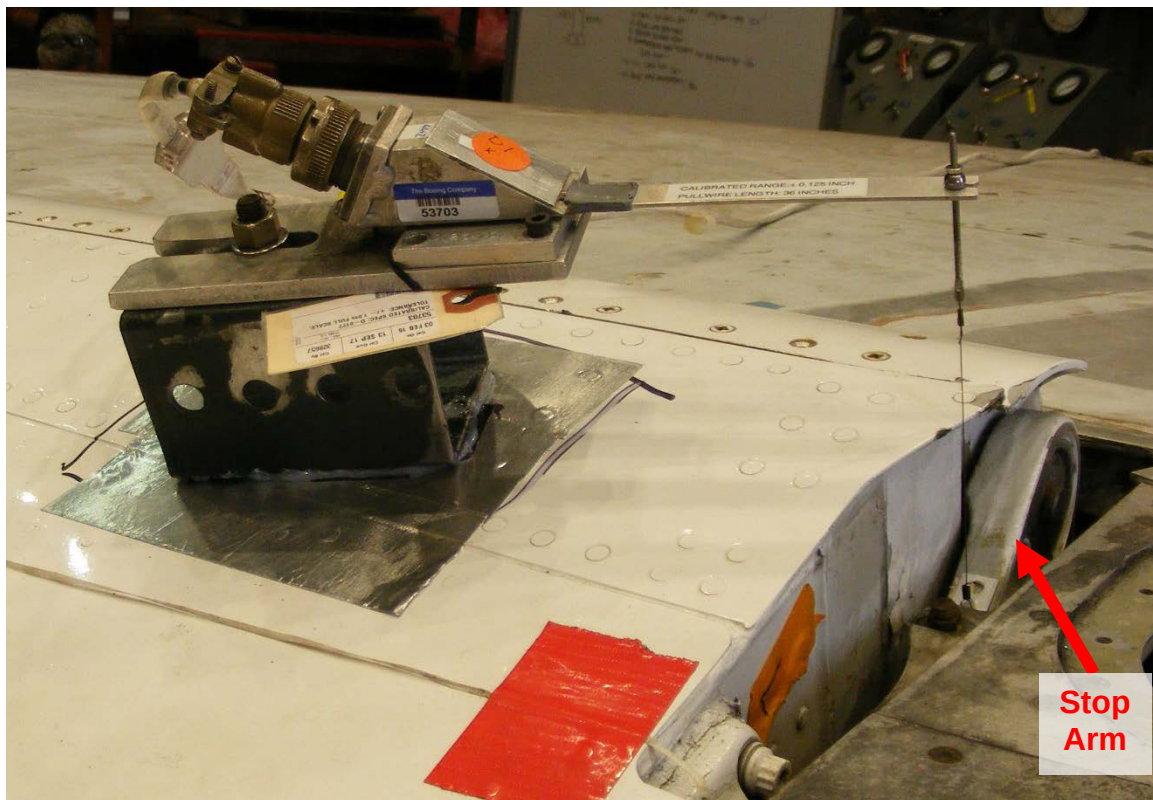


Figure 49 - Beam Deflection Gage setup

Both an analog and digital inclinometer were used to measure elevator surface position during static loading tests. Prior to the testing, both inclinometers were zeroed with the elevator in a neutral (faired with stabilizer) position.

For dynamic tests, a load cell was mounted on the forklift to record the load on the elevator prior to releasing the load and allowing the elevator to dynamically contact the TED stop. A quick release mechanism was used to remotely release the elevator, Figure 50. The loaded elevator was lifted by the forklift via lifting straps fixed to the number 2 and number 4 elevator control tab hinge points.

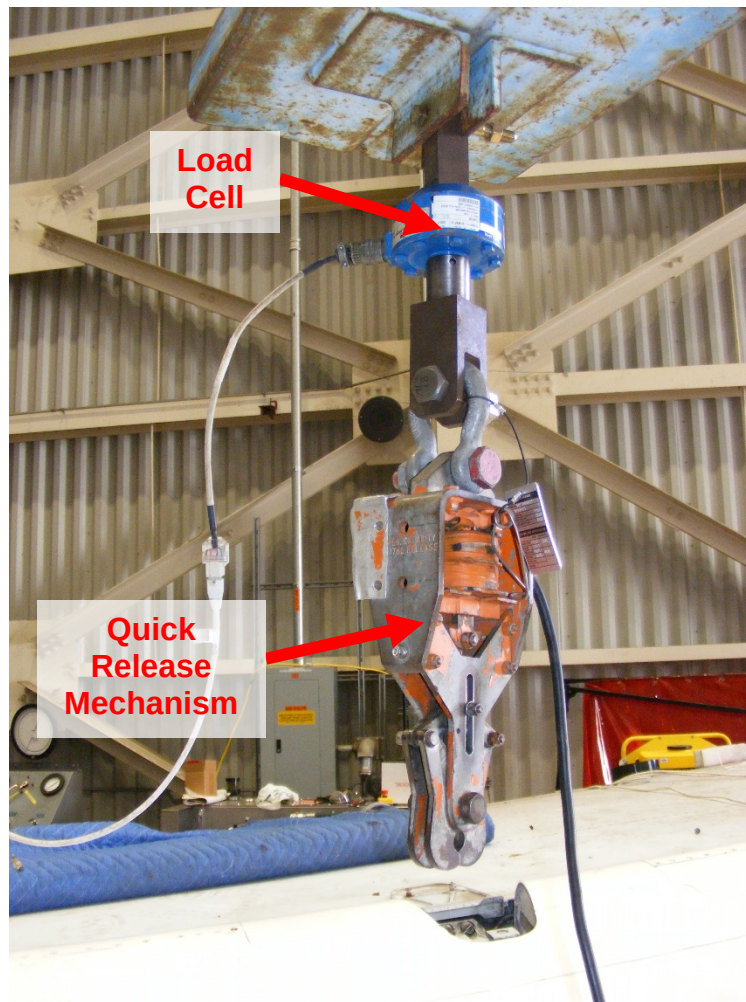


Figure 50 - Load Cell and Quick Release set-up

Weights were placed on the elevator hinge points for the control tab, geared tab and anti-float tab. The eleven hinge points were numbered starting nearest the root of the elevator (the control tab). Weights were secured to the hinge points using nylon rope, Figure 51.

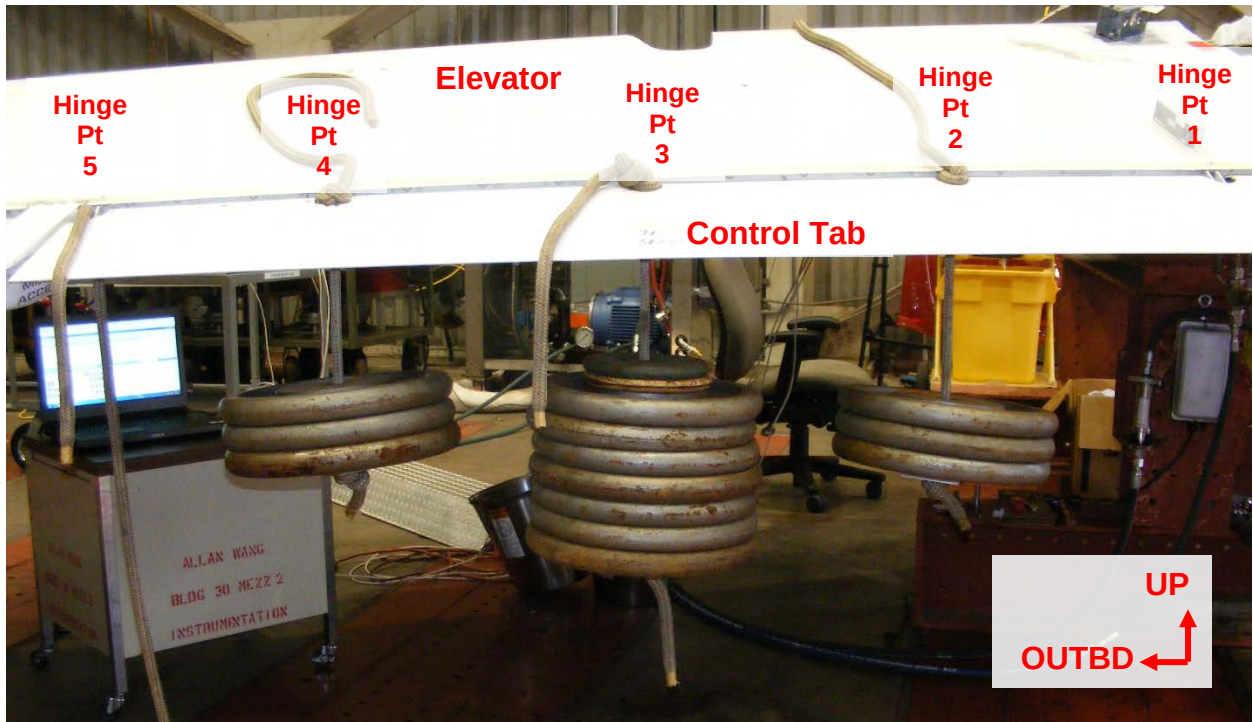


Figure 51 - Exemplar picture of weights loaded on elevators

Based on the test plan, seven series of tests were planned.

- Series 1 – Torsion bar deflection due to boost cylinder activation (hydraulics on)
- Series 2 - Torsion bar deflection due to boost cylinder activation (simulated)
- Series 3 – Static Loading without boost cylinder activated
- Series 4 – Static Loading with boost cylinder activated
- Series 5 – Dynamic Loading without boost cylinder activated
- Series 6 – Dynamic Loading with boost cylinder activated
- Series 7 – Static/Dynamic Loading with 100 kt wind condition

Plots and detailed information related to the testing and test plan is included in Attachment 3.

4.1.2.1.2.9.1 Series 1 and 2 test results

Series 1 and series 2 tests were performed to determine the amount of deflection that occurs to an unloaded elevator when the boost cylinder is activated, and the elevator is in contact with the TED stop. Series 1 was performed with hydraulics applied to the boost cylinder, similar to aircraft operation. Series 2 was performed with loading applied to hinge points 2, 3 and 4 simulating a boost cylinder activation. For series 1, the stop arm/torsion bar rotation was 2.04° and for series 2, 1.88° .⁷

⁷ All stop arm/torsion bar rotations noted in the report are based on the beam deflection gage reading converted to degrees and are degrees past the TED stop position. Information on the calculation rotation angle is included in Attachment 3.

4.1.2.1.2.9.2 Series 3 test results

Series 3 tests were performed to determine the amount of deflection that occurs to an elevator loaded to various gust conditions without the boost cylinder activating. During this testing, the hydraulic boost cylinder was not installed. The group determined that for the static cases, the boost cylinder was not necessary. Damping due to porting of hydraulic fluid only factors in during elevator movement in the dynamic cases. Table 14 contains the series 3 test results.

Table 14 - Series 3 Static Loading, no boost cylinder, results

Gust Speed (kts)	Stop Arm/Torsion Bar Rotation (°)	Est. Elevator Surface Position (deg) ¹	Geared Tab Linkage Over-Centered (Yes/No)
25	0.27°	16.68°	No
55	1.34°	17.39°	No
75	2.37°	18.08°	No

¹ – Estimated elevator surface position is torsion bar rotation * 0.667 + nominal elevator TED stop position of 16.5°

4.1.2.1.2.9.3 Series 4 test results

Series 4 tests were performed to determine the amount of deflection that occurs to an elevator loaded to various gust conditions concurrent with the boost cylinder activating. After the static load was applied, hydraulics were applied to the boost cylinder. Table 15 contains the series 4 test results.

Table 15 – Series 4, Static Loading, with boost cylinder, results

Gust Speed (kts)	Stop Arm/Torsion Bar Rotation (°)	Est. Elevator Surface Position (deg) ¹	Geared Tab Linkage Over-Centered (Yes/No)
25	2.29°	18.02°	No
55	3.24°	18.66°	No
75	4.18°	19.29°	No

¹ – Estimated elevator surface position is torsion bar rotation * 0.667 + nominal elevator TED stop position of 16.5°

4.1.2.1.2.9.4 Series 5 test results

Series 5 tests were performed to determine the amount of deflection that occurs to an elevator loaded to various gust conditions concurrent without the boost cylinder activating and the elevator is not initially resting on the TED stop. The calculated loads were applied and the elevator was raised to a neutral elevator position and then released. This would allow the loaded elevator to come in contact with the stop. The test was then repeated raising the elevator to a full TEU position and then releasing the loaded elevator.

During the 75 kts neutral test, the inboard geared tab linkage over-centered and the elevator remained jammed in a TED position. Figure 52 shows the inboard geared tab linkage in a normal condition when the elevator is at the TED stop. Figure 53 shows the inboard geared tab after an over-centered condition occurs.

Based on these results the group added additional gust conditions at 60, 65 and 70 knots. During the 60 kts TEU test, the inboard geared tab linkage over-centered and the elevator remained jammed in a TED position. The group did not perform TEU tests at 65 and 70 kts due to the 60 kts TEU test result. During the 70 kts neutral test, the inboard geared tab linkage over-centered and the elevator remained jammed in a TED position.

Table 16 contains the series 5 test results, plots of the dynamic response are included in Attachment 3.

Table 16 – Series 5, Dynamic Loading, without boost cylinder, results

Gust Speed (kts)	Elevator Initial Position (Neutral/TEU)	Maximum Stop Arm/Torsion Bar Rotation (°)	Maximum Est. Elevator Surface Position (deg) ¹	Geared Tab Linkage Over-Centered (Yes/No)
25	Neutral	1.98°	17.82°	No
	TEU	2.91°	18.44°	No
55	Neutral	4.84°	19.73°	No
	TEU	6.20°	20.64°	No
60	Neutral	5.43°	20.12°	No
	TEU	7.16°	21.28°	Yes
65	Neutral	6.17°	20.62°	No
70	Neutral	6.65°	20.94°	Yes
75	Neutral	6.90°	21.10°	Yes

¹ – Estimated elevator surface position is torsion bar rotation * 0.667 + nominal elevator TED stop position of 16.5°



Figure 52 - Gear Tab Inboard Linkage in nominal condition



Figure 53 - Gear Tab Inboard Linkage in over-centered condition

4.1.2.1.2.9.5 Series 6 test results

The series 6 testing which combined dynamic wind loads and the boost cylinder actuation was performed only using the 25 kts test case from an elevator neutral position and an elevator full trailing edge up position. The tests at 25 kts did not result in a jammed elevator condition. The group was concerned with damaging the test fixture at higher loading conditions. After the dynamic wind loads without boost cylinder actuation were performed the group determined that the 55 kts and 75 kts dynamic test cases with boost cylinder actuation were not to be performed.

4.1.2.1.2.9.6 Series 7 test results

The series 7 test was part of the original test plan based on the theoretical calculations of the torsional characteristics of the torsion bar. The possibility existed of not achieving an over-centered condition based on the lower gust velocities in the static loading conditions. Based on the results from series 1 through series 6, the group elected to not perform the series 7 test.

4.1.2.1.2.9.7 Additional test results

Upon completion of the planned tests and the 70 kt dynamic test, the group added an additional test to see the effects on the links and the link arm, to try and reproduce the damage seen in the accident. Hydraulic pressure was first applied in this condition to simulate a boost cylinder activation. The application of the hydraulics did not affect the positions of the links or the actuating crank.

The weights simulating the 70-knot condition were removed to see if normal torsion bar loading would affect the links or the link arms. The links and actuating crank were not affected.

The final test simulated a lifting force on the elevator using the forklift to simulate the ANU air loading that would be experienced during the take-off roll at rotation. An upward force was applied to control tab hinge locations 2 and 4 (Same locations used for lifting the elevator during the dynamic tests). At approximately 800 lbs on the load cell the links started to fail and eventually folded over, Figure 54. The load cell peaked at 975 lbs prior to the final failure.

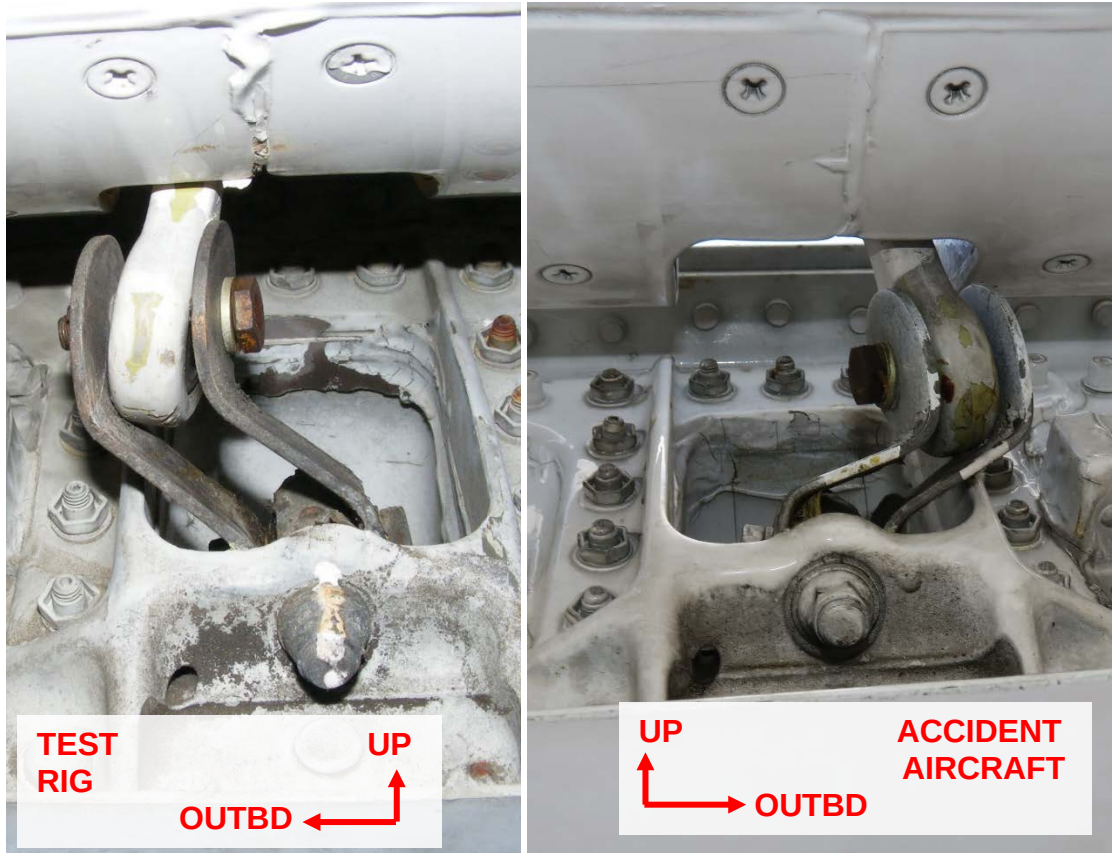


Figure 54 – Side by Side comparison of final test rig results with accident aircraft damage after lifting load application

4.1.2.2 Horizontal Stabilizer

4.1.2.2.1 System Description

The primary means of longitudinal trim for the aircraft is accomplished using the horizontal stabilizer. The horizontal stabilizer is located on top of the vertical stabilizer and hinged forward of the stabilizer rear spar. The stabilizer is electrically actuated through a system of cockpit controls, trim motors, acme jack screw and position sensors. The stabilizer can move through a range of motion from 12.2° stabilizer leading edge down (LED) to 2.1° stabilizer leading edge up.

The stabilizer trim position is calculated using the takeoff condition computer, located in the control pedestal, ref 4.1.1.4. The computer uses calculated takeoff values for center of gravity (CG) and flap setting to compute the takeoff stabilizer setting. After the settings are input to the computer, the resultant stabilizer position would be positioned by the crew using either the Long Trim Handles or the pilots' control wheel trim switches.

4.1.2.2.2 Wreckage Examination

The horizontal stabilizer trim actuator was inspected through the access panel on the right-hand side of the vertical fin. The jack screw was found to be lubricated, and a measurement was taken to determine the position of the stabilizer. The position of the jack screw was determined by measuring the acme screw protrusion below the acme nut in the stabilizer actuator, the measurement was 9.5 inches. Based on that measurement, the horizontal stabilizer position was determined to be consistent with 8° aircraft nose up. Due to damage to the aircraft electrical system, operation of the trim motors could not be performed.

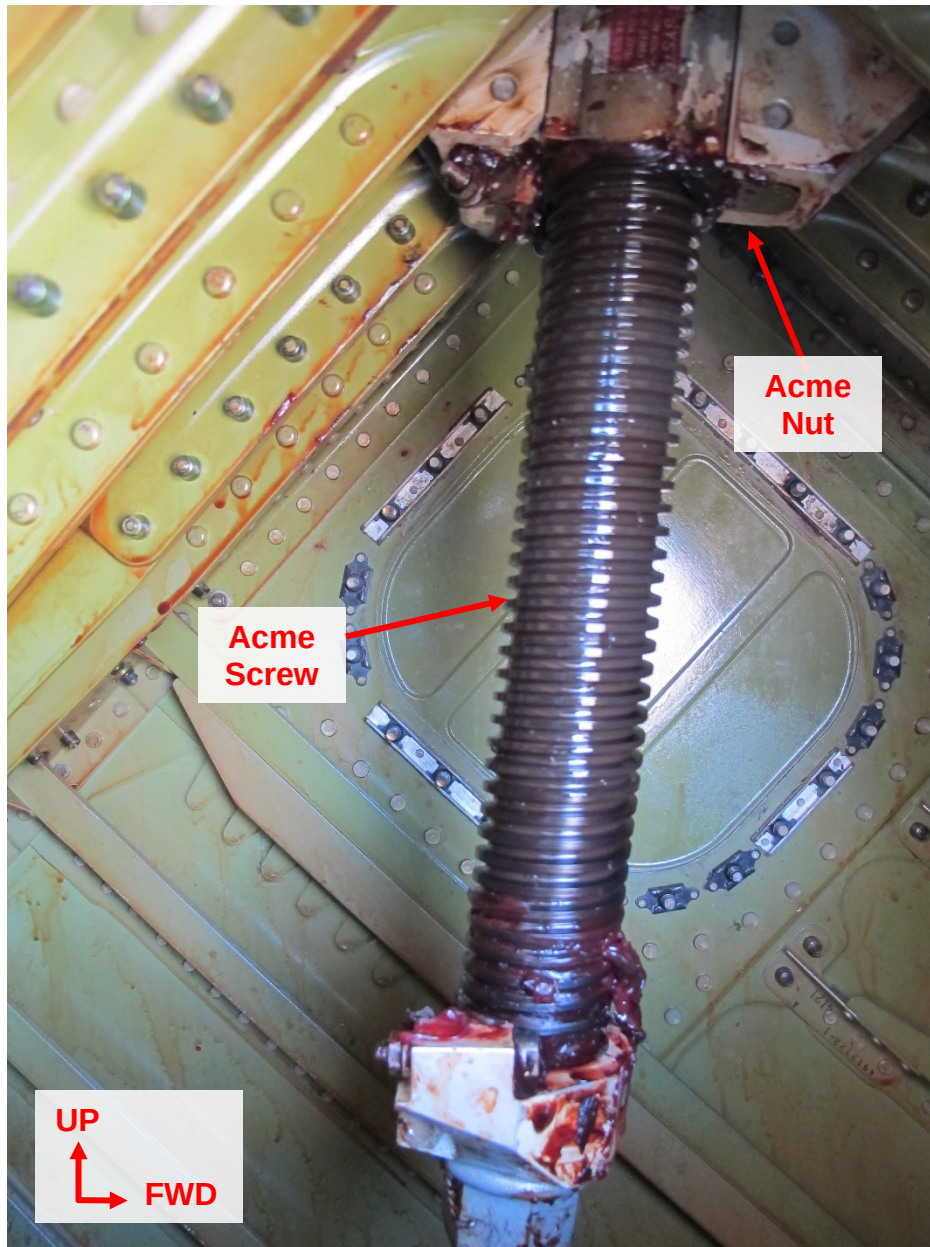


Figure 55 - Horizontal Stabilizer Jack Screw

4.1.2.3 Aileron

4.1.2.3.1 System Description

The ailerons provide lateral control about the roll axis of the aircraft. The control surfaces are mechanically controlled and operated by aerodynamic boost control surfaces, i.e. control tabs. A control tab on the trailing edge of each aileron is deflected by mechanical inputs from the captain or first officers control wheel. When the tab is deflected, the aerodynamic forces will move the aileron surface. On the ground the ailerons are free to move within the mechanical stops. Each aileron has a damper installed at the leading edge of the aileron and connected to the rear spar. The damper prevents aileron flutter during flight and dampens rapid movement of the aileron caused by gusty winds when the aircraft is on the ground.

The aileron trim control system provides a means to adjust the lateral trim. Aileron trim is adjusted mechanically by a knob located in the control pedestal. By rotating the knob in either a left or right wing down direction, each aileron trim tab will travel to a corresponding position. If the aileron trim knob is rotated in the left wing down direction, the left aileron trim tab will move in a trailing edge down direction and this will aerodynamically cause the aileron to move in a trailing edge up direction. The right aileron trim tab will move in a trailing edge up direction and this will aerodynamically cause the aileron to move in a trailing edge down direction.



Figure 56 - Left aileron control surfaces (right aileron similar)

4.1.2.3.2 Wreckage Examination

The left aileron was found in a trailing edge down position, approximately 1 and 1/8 inches from the wing trailing edge. The trim tab was faired with the aileron and the control tab was slightly trailing edge down from the aileron trailing edge.

The right aileron was found in a trailing edge up position. The trim tab was faired with the aileron and the control tab was slightly trailing edge up from the aileron trailing edge.

Flight control continuity for the aileron system was established by exercising the control wheel in the cockpit from both the pilot and copilot's side to the stops on both the left wing and right wing down positions. The control tabs responded with movement in the appropriate directions.

The group also noted that when actuating the control wheel, the roll left direction movement was smooth and in the roll right direction, there was some resistance in the 4 to 5 o'clock position. The feeling of the control was consistent from both the captains and first officer's position.

The aileron trim knob in the cockpit was rotated to both extents and the trim tab were visually observed responded with movement in the appropriate directions of travel.

4.1.2.4 Rudder

4.1.2.4.1 System Description

The rudder provides directional control about the vertical axis and is actuated hydraulically, Figure 57. Dual rudder pedals in the cockpit mechanically control the rudder hydraulic components located in the rear of the aircraft. Rudder hydraulic power can be shut off by a lever in the control pedestal (ref. section 4.1.1.4). The lever has two positions, "PWR" and "MAN". When the lever is in the "PWR" position, a shutoff valve is open and allows hydraulic pressure to lock the rudder control tab in a faired position and allow hydraulic pressure to actuate the rudder in response to rudder pedal movements. When the lever is in the "MAN" position, the shutoff valve is closed which will unlock the rudder control tab. The rudder would then be positioned as a result of the rudder pedal movement of the rudder control tab without hydraulic power. On the ground if hydraulic power is not available, the rudder is free to move within the mechanical stops.

The rudder trim control system provides a means to adjust the neutral position of the rudder. Rudder trim is adjusted mechanically by a knob located in the control pedestal. By rotating the knob in either a nose left or nose right direction, the control system neutral position (position of system with no pilot input) will be relocated correspondingly. If the rudder trim knob is rotated in the aircraft nose right direction, the rudder control system neutral position will move in a direction that causes an aircraft nose right command. In this case, if hydraulic power is available, the rudder trailing edge

will move to a position to the right of faired when no pilot input is present. If hydraulic power is not available, the control tab will move in a trailing edge left direction, which will aerodynamically cause the rudder to move in a trailing edge right direction.

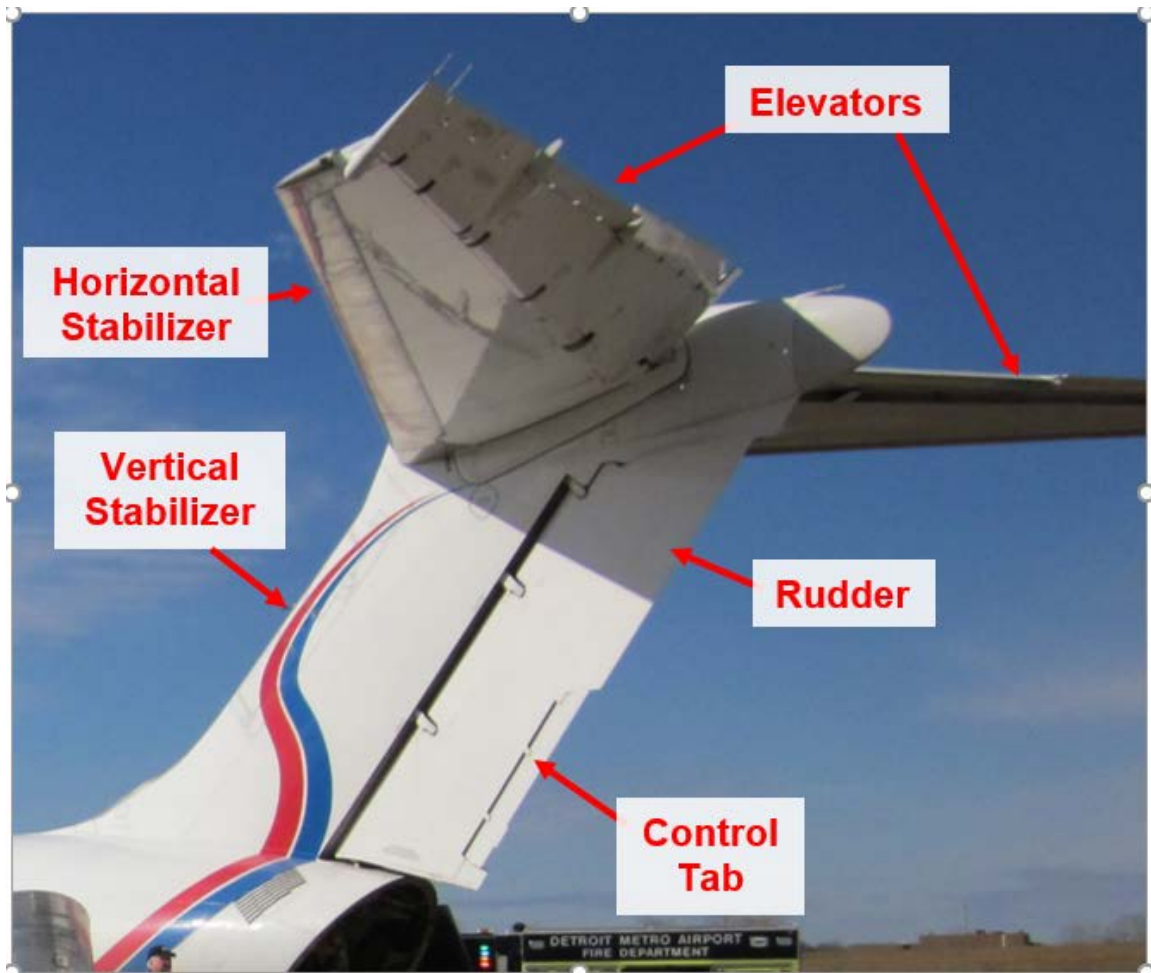


Figure 57 - Rudder control surfaces, as viewed from aircraft left hand side

4.1.2.4.2 Wreckage Examination

The rudder was found in a trailing edge left position. Flight control continuity for the rudder system was established by exercising the rudder pedals in the cockpit from both the pilot and copilot's side to the stops on both the nose left and nose right positions. The rudder control tab responded with movement in the appropriate directions. The group also noted that when actuating the rudder pedals, the rudder nose left moved freely, and the rudder nose right was heavy from both the captains and first officers position.

The control tab was slightly trailing edge left from the rudder trailing edge, consistent with an aircraft nose right direction. The rudder trim knob in the cockpit was rotated to both extents and the control tab was visually observed responding with movement in the appropriate directions.

4.1.3 Secondary Flight Controls

All secondary flight controls, flaps, slats, flight and ground spoilers were accounted for at the accident scene and remained attached to the accident aircraft.

4.1.3.1 Flaps

4.1.3.1.1 System Description

The aircraft has an inboard and an outboard flap on each wing. The flaps are mechanically controlled and hydraulically actuated. The crew moves the flap lever to the appropriate detent depending on the flight condition (i.e. take-off, landing). The flap lever has fixed detents at UP, 0, 11, 15, 28, and 40. The lever can also be positioned in one-degree increments for takeoff settings using the Dial-A-Flap from 0 to 24, except for a small do-not-use range at 14. Through a series of cables and pulleys, control valves are exercised and provide hydraulic pressure to the flap actuators to extend or retract the flaps.

4.1.3.1.2 Wreckage Examination

The left-hand (LH) side inboard and outboard flaps were found extended and symmetrical along the length of the flaps. The LH inboard flap sustained damage consistent with impacting the LH main gear. The inboard flap was resting on the LH main gear.

The right-hand (RH) inboard and outboard flaps were found extended and symmetrical along the length of the flaps. The RH inboard flap sustained damage consistent with impacting the RH main gear. The inboard flap was resting on the RH main gear. The RH flap hinges impacted the ground just prior to the aircraft coming to rest.



Figure 58 – Left hand wing flap panels

The flaps do not contain any visual indications of their position on the wing or flap surface. Position markings exist on the inboard flap track; however, these markings were inaccessible because of the landing gear collapse. In lieu of taking the inboard measurements, a measurement was taken from the left outboard flap hinge stop. The measurement was 1.5 inches, the right outboard flap hinge stop measurement was 4.75 inches.

Due to damage from the accident, hydraulic power was not available to check the operation of the flaps. Upon relocation of the wreckage, when the aircraft was raised from the ground, both the left and right flaps extended without any external assistance to a position consistent with full extension. After the access was available due to the aircraft recovery, a bolted flap bus cable fuse connection at a turnbuckle was found separated in the main landing gear wheel well.



Figure 59 – Right hand wing flap panels

4.1.3.2 Slats

4.1.3.2.1 System Description

There are six slat sections on both the left and right-hand wing. The slats are controlled by the flap handle on the control pedestal and hydraulically actuated. The slats are up (UP) when the flaps are retracted, partially extended (MID) during takeoff flap angles and fully extended (EXT) for landing and approach flap angles.

4.1.3.2.2 Wreckage Examination

All six left hand slats were found extended and symmetrical along the length of the wing. The slat tracks all showed signs of lubrication and grease marks were found on the leading-edge wing skins. The slats did have impact marks consistent with a collision with the airport perimeter fence posts.



Figure 60 – Left hand wing slat panels

All six right-hand slats were found extended and symmetrical along the length of the wing. The slat tracks all showed signs of lubrication and grease marks were found on the leading-edge wing skins.



Figure 61 – Right hand wing slat panels

The slats do not contain any visual indications of their position on the wing or slat surface. A position measurement was taken from the mid slat track on both the left and right-hand number 3 slat. The measurement was 18 inches on both sides.

Due to damage from the accident, hydraulic power was not available to check the operation of the slats.

4.1.3.3 Flight and Ground Spoilers

4.1.3.3.1 System Description

The aircraft has three spoiler panels mounted on the upper surface of each wing. The two most outboard spoilers on each wing can be used in flight, and the inner most spoiler is available for use on the ground only. The spoilers are mechanically controlled using a lever in the cockpit on the control pedestal and hydraulically actuated.

4.1.3.3.2 Wreckage Examination

Both the left and right-hand side flight and ground spoilers were in the down position and flush with the upper surface of the wing. Due to damage from the accident, hydraulic power was not available to check the operation of the spoilers.

4.2 Aircraft Parking Guidance and Location

4.2.1 AMM Guidance

The Boeing AMM Chapter 10 for the aircraft contains the following information related to parking of the aircraft.

3. Parking

A. General Procedures

WARNING: IF WIND GUSTS ARE EXPECTED TO EXCEED 69 MPH (60 KNOTS), AIRCRAFT SHOULD BE HEADED INTO WIND TO PREVENT STRUCTURAL DAMAGE TO PRIMARY CONTROL SURFACES.

CAUTION: IF THERE IS ANY POSSIBILITY THAT AIRCRAFT HAS BEEN SUBJECTED TO WINDS IN EXCESS OF 75 MPH (65 KNOTS), AND AIRCRAFT HAS NOT BEEN HEADED INTO WIND OR WIND DIRECTION CHANGED DURING PARKING, PERFORM VISUAL AND PHYSICAL INSPECTIONS (MOVING THE SURFACES BY HAND) OF ALL FLIGHT CONTROLS AND AN OPERATIONAL CHECK OF THESE SYSTEMS.

4.2.2 Airport locations

The aircraft arrived at YIP on March 6th at 0605 GMT (0105 LCL) and was parked on the west ramp (Figure 62, Area 1). According to ramp personnel and the operator's station manager the aircraft was parked with the nose of the aircraft pointing in a northerly direction on the west ramp. The day of the accident, the aircraft was repositioned from the west ramp to the east ramp to board the passengers, (Figure 62, Area 2). The aircraft then proceeded to RWY 23L for takeoff. The aircraft, after departing the runway, came to rest just past the perimeter fence, (Figure 62, Area 3).

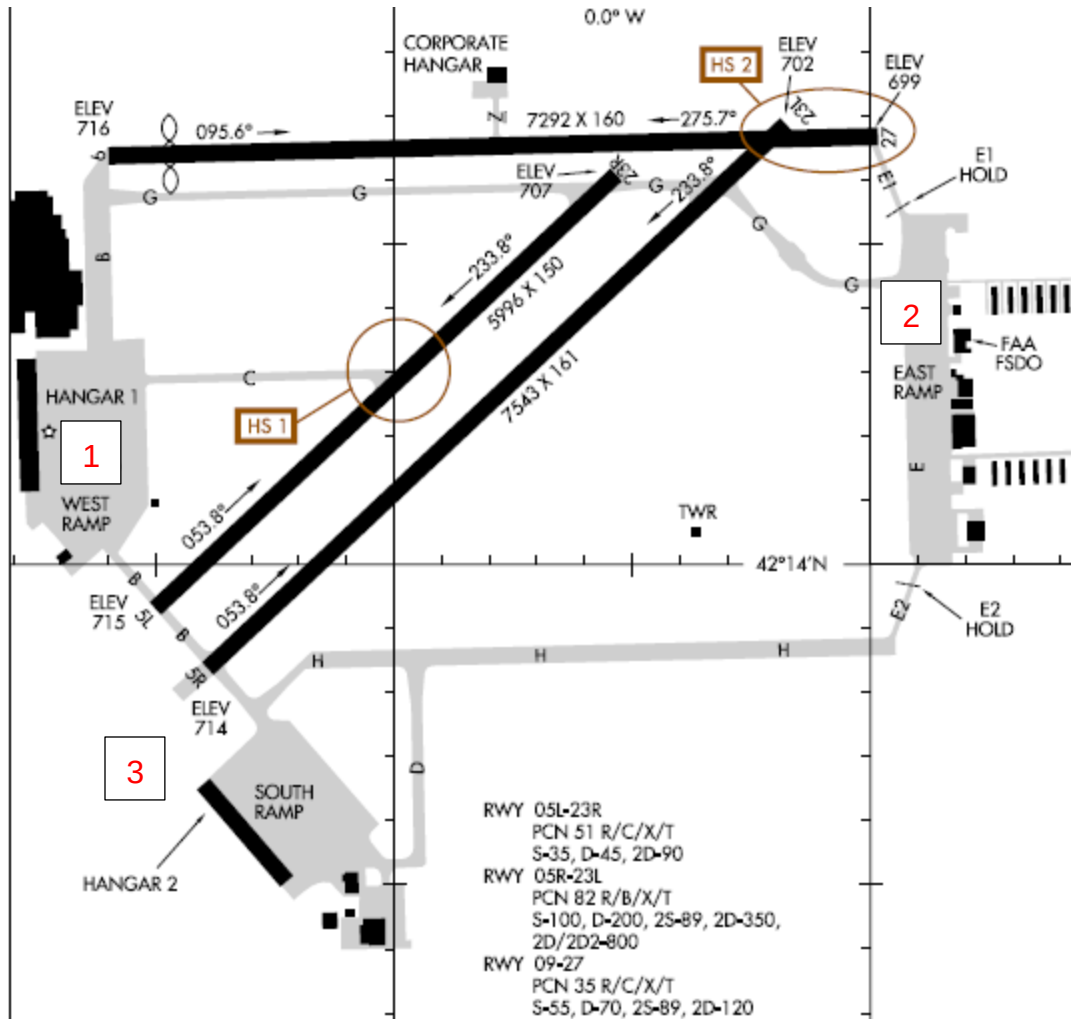


Figure 62 –Excerpt of FAA Airport Diagram for KYIP

Position (Ref. Figure 62)	North Latitude (°)	West Longitude (°)
1 – West Ramp	42.23633°	83.54446°
2 – East Ramp	42.24002°	83.51450°
3 – Wreckage Site	42.22814°	83.54242°

Figure 63, Figure 64 and Figure 65 shows various views looking in noted directions showing the area around where the aircraft was parked prior to movement on the accident day. The photos were taken on March 12th, 2017.



Figure 63 - View looking in a southerly direction from approximate aircraft parking location



Figure 64 - View looking in a south-westerly direction from approximate aircraft parking location



Figure 65 - View looking in a westerly direction from approximate aircraft parking location

4.3 EGPWS Information

Due to the condition of the EGPWS circuit breaker after the accident, the EGPWS unit was removed from the forward equipment bay in order to download the non-volatile memory. The unit did have some external damage to the handle, but the connectors did not show any signs of damage. The unit was functionally tested and the NVM downloaded in the presence of NTSB investigators. The download of the NVM was successful and no anomalies with the unit were noted during the functional test. The last flight leg (flight record 613 in the NVM) recorded three landing event records when the aircraft arrived at YIP, Table 17. According to the EGPWS manufacturer, a landing record is recorded when the EGPWS sees the landing gear down, flaps down and a radio altitude transition to less than 50 feet.

Table 17 - EGPWS NVM Data from flight 613 landing records

Landing Record	EGPWS Time (HH:MM:SS) ¹	Latitude (°)	Longitude (°)	Geometric Altitude (ft)	True Heading (°)
1	26100:01:40	42.23039°	-83.54028°	774.0	-126.56°
2	26104:18:39	42.23647°	-83.54478°	728.0	1.41°
3	26105:11:44	42.23647°	-83.54478°	728.0	1.41°

¹ – The EGPWS NVM logs time based on hours of power on operation.

The EGPWS will record a runway entry and takeoff event after the aircraft climbs above 25 feet radio altitude. This did not occur on the accident flight.

4.4 Wind shear Computer Information

Due to the condition of the wind shear circuit breaker after the accident, the wind shear computer unit was removed from the forward equipment bay in order to download the non-volatile memory. The unit did have some external damage to the unit's case. The unit was functionally tested and the NVM downloaded in the presence of NTSB investigators. The download of the NVM was successful and no anomalies with the unit were noted during the functional test.

4.5 Gust Certification Requirements

According to Type Certificate Data Sheet⁸ (TCDS) A6WE, revision 30, dated March 25, 2014, type certificate approval for the Model DC-9-83 (MD-83) was granted on October 17, 1985, under 14 CFR Part 25 (the airworthiness standards for transport-category airplanes). The Model DC-9-83 was added as the most recent model in a series of derivative models (or "changed aeronautical products") that were approved and added to the type certificate (TC), originally issued for the Douglas Aircraft Models DC-9-11, -12, -13, and -14 on November 23, 1965.

The applicable certification basis for the Model DC-9-83 was the FAA's 14 CFR Part 25 Airworthiness Standards, effective February 1, 1965, including Amendments 25-1 through 25-40, effective May 2, 1977, with some exceptions and special conditions (SC) as noted in the TCDS.

The particular regulation regarding ground gust conditions is found in 14 CFR 25.415 (original) and states:

"§ 25.415 Ground gust conditions.

(a) The control system must be designed as follows for control surface loads due to ground gusts and taxiing downwind:

(1) The control system between the stops nearest the surfaces and the cockpit controls must be designed for loads corresponding to the limit hinge moments H of subparagraph (2) of this paragraph. These loads need not exceed--

(i) The loads corresponding to the maximum pilot loads in Sec. 25.397(c) for each pilot alone; or

(ii) 0.75 times these maximum loads for each pilot when the pilot forces are applied in the same direction.

⁸ A Type Certificate Data Sheet (TCDS) is a formal description of the aircraft, engine or propeller. It lists limitations and information required for type certification including airspeed limits, weight limits, thrust limitations, etc.

(2) The control system stops nearest the surfaces, the control system locks, and the parts of the systems (if any) between these stops and locks and the control surface horns, must be designed for limit hinge moments H obtained from the formula,

$$H = KcSq,$$

where--

H = limit hinge moment (ft. lbs.);

c = mean chord of the control surface aft of the hinge line (ft.);

S = area of the control surface aft of the hinge line (sq. ft.);

q = dynamic pressure (p.s.f.) based on a design speed not less than $14.6\sqrt{W/S} + 14.6$ (f.p.s.), except that the design speed need not exceed 88 f.p.s.; and

K = limit hinge moment factor for ground gusts derived in paragraph (b) of this section.

(b) The limit hinge moment factor K for ground gusts must be derived as follows:

Surface		K	Position of Controls	
(a)	Aileron	0.75	Control column locked or lashed in mid-position	
(b)	Aileron	*±0.50	Ailerons at full throw	
(c)	Elevator	*±0.75	(c)	Elevator full down
(d)			(d)	Elevator full up
(e)	Rudder	0.75	(e)	Rudder in neutral
(f)			(f)	Rudder at full throw

*A positive value of K indicates a moment tending to depress the surface, while a negative value of K indicates a moment tending to raise the surface”

The particular regulation regarding control system gust locks is found in 14 CFR 25.679 (original) and states:

“§ 25.679 Control system gust locks.

(a) There must be a device to prevent damage to the control surfaces (including tabs), and to the control system, from gusts striking the airplane while it is on the ground or water. If the device, when engaged, prevents normal operation of the control surfaces by the pilot, it must—

(1) Automatically disengage when the pilot operates the primary flight controls in a normal manner; or

(2) Limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff.

(b) The device must have means to preclude the possibility of it becoming inadvertently engaged in flight.”

The original FAR states a design speed for the limiting hinge moment, need not exceed 88 fps (approx. 52.1 knots). Beginning with FAR amendment 25-91 (07/29/1997), the ground gust velocity was increased to 65 knots. The current FAR found in 14 CFR 25.415 (amendment 25-141) states in part:

“§ 25.415 Ground gust conditions.

(a) The flight control systems and surfaces must be designed for the limit loads generated when the airplane is subjected to a horizontal 65-knot ground gust from any direction while taxiing and while parked. For airplanes equipped with control system gust locks, the taxiing condition must be evaluated with the controls locked and unlocked, and the parked condition must be evaluated with the controls locked.

(b) The control system... “

4.6 Previous Event

On December 26, 1999, a charter flight Douglas DC 9-83 (MD-83), successfully executed a rejected takeoff at Munich Airport (EDDM), Munich, Germany. The incident was investigated by the German Federal Bureau of Aircraft Accident Investigation (BFU)⁹. The following information contains excerpts from the BFU report. The report was only released in German and was translated for use by the investigation.

The inspection of the aircraft after the rejected takeoff revealed the aircraft's left elevator to be jammed in a trailing edge down direction. Closer inspection showed that the inboard linkage of the geared tab was jammed and cause the elevator to remain in a trailing edge down direction.

The aircraft had arrived in Munich earlier that day and was parked in between flights. During that time, the aircraft was exposed to gusty tailwinds with speeds up to 70 knots. The crew did witness the aircraft control surfaces striking their respective stops with considerable force and requested the entire flight controls be inspected prior to the accident flight.

The BFU issued recommendations included (as translated from the BFU report):

- 07/00 - The AFM should include the information that the elevator control can jam and that a special examination of the entire flight control becomes necessary, whenever the plane is not parked in the wind's direction when winds exceed 65 knots.
- 08/00 - The checklists should include the direction that the examination of the elevator hydraulic's availability should, if possible, only happen in the position of

⁹ Details of the investigation can be found in the BFU's released report number 5X011-0/99 in November 2000 regarding the incident.

start, but never while the area over the start's permissible component is being exposed to tailwinds. To assure the elevator's movability, the control column should once more be pulled as far as possible in the starting position, but after the elevator hydraulics have been checked.

- 09/00 - AMM, chapter 5, should add directions for a special examination in the case the plane was not parked facing the wind whenever wind speeds exceed 65 knots. Both the directions for a special examination and the warnings included in several chapters should mention the possibility of a jammed elevator.

On June 25, 2001, Boeing transmitted Flight Operations Bulletin (FOB) no MD-80-01-02 to its operators which addressed a flight control jam with the left elevator jammed in the aircraft nose down position¹⁰. The FOB was released after the completion of BFU investigation into the jammed elevator event which occurred in December 1999.

¹⁰ The complete FOB can be found in attachment 4