NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

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MATERIALS LABORATORY FACTUAL REPORT Report No. 12-029

A. ACCIDENT INFORMATION

Place : Reno, Nevada.
Date : September 16, 2011.
Vehicle : North American P-51D, N79111.
NTSB No. : WPR11MA454.
Investigator : Clint Crookshanks, AS-40.

B. COMPONENTS EXAMINED

1. Left elevator with trim tab and actuator pieces.
2. Elevator torque tube assembly.
3. Right elevator with trim tab and link assembly.
4. Left aileron trim tab.
5. Tail wheel retract lock.

C. DOCUMENTS REVIEWED

1. USAF Series P-51D, TF-51D and F-51F illustrated parts catalog (IPC), T.O. 1F-51D-4.
2. Army-Navy specification AN21 THRU AN37. Bolt, clevis.
3. Military Standard MS27039. Screw, pan head, structural, cross recessed.
4. Military Specification MS51866. Nut-spline.
5. North American drawing 99-52526. Link assembly, elevator and rudder trim tab.
6. North American drawing 73-525124. Rod assembly, elevator and rudder trim tab.
7. Military specification AN4 THRU AN20. Bolt - machine, aircraft.
8. North American Aviation (NAA) manual NA-5913. P-51B/C Maintenance Manual dated July 31, 1944. Figure 79
9. NAA manual AN 01-60-3. Structural Repair Instructions for Airplanes. Army models A-36. P-51, A, B, C, D, K and M. F-6B, C, D and K. TF-51D. British model Mustang. March 15, 1952 revision.

D. DETAILS OF THE EXAMINATION

The left elevator pieces received for examination are illustrated in Figure 1, the elevator torque tube assembly is illustrated in Figure 30, the right elevator pieces are illustrated in Figure 43, the left aileron trim tab is illustrated in Figure 63 and the tail wheel retract lock is illustrated in Figure 76.

A review of the empennage section of the IPC, document 1 in section C, revealed that the elevator trim tab is attached to the elevator by outboard, center and inboard hinges, allowing it to move up and down. An elevator hinge fitting is riveted to the rear spar of the elevator and attached to a trim tab hinge fitting by a bolt which is retained by a castellated nut and a cotter pin. The bolt passes through a sleeve, which is also the inner race of a needle roller bearing located in the trim tab hinge fitting, and a washer that fits over the sleeve. The IPC specifies the bolt as AN23-17 which is contained in AN21 through AN37, document 2 in section C, and described as a clevis bolt. The bolt has a nominal length of 1 3/32-inch and a 3/64-inch wide groove separates the plain shank and the threaded portion. The specification requires that the head is to be marked with a raised or depressed double "X" and has a slot in the head suitable for a straight bladed screwdriver. AN23 bolts are produced from alloy steels designated as 4130 or 8740 (steels also specified for the NAS221 screws detailed below) and are cadmium plated. The tensile load capacity of the AN23-17 bolt is specified as 1,105 pounds and as it is a clevis bolt, the shear load capacity is specified as 2,125 pounds. Calculations were made using the load capacities in the specification and the bolt dimensions to estimate the tensile strength of the material the screw was produced from for conversion to hardness. The approximated tensile strength derived from the tensile load was 61 ksi, which converts[3] to 70 HRB[1], and the approximated tensile strength derived from the shear load was 105 ksi, which converts[3] to 97 HRB. The calculated figures were found to be significantly different to each other, and lower than the NAS221 screws, and considered consistent with the specified load capacities having an unknown factor of safety included.

The trim tab hinge fitting is attached to the trim tab by a single screw. The IPC specifies the screws as NAS221-18[2] for the inboard and outboard hinges, which has a nominal length of 1.156 inches under the head, and NAS221-19 for the center hinge, which has a nominal length of 1.219 inches under the head. The specification requires that the head is to be marked with a dash and has a cross recessed head suitable for a screwdriver with a cross point tip. NAS221 screws are produced from alloy steels designated as 8630, 8740 or 4130 with a tensile strength of 125 – 145 ksi[3] (which converts[4] to a hardness of 26 – 32 HRC[5]) and are cadmium plated. The screws engage in a locknut, MS51866, document 4 in section C, which is pressed into the trim tab hinge and staked in place. The longer screw on the trim tab center hinge is required for the control horn which was observed on the underside of the left elevator and on the upper side of the right elevator as illustrated later in Figure 43. The location of the horn

[1] Hardness, Rockwell, B scale.
[2] NAS221 was superseded by MS27039, document 3 in section C, which provided the screw data.
[3] Abbreviation for thousands of pounds per square inch.
[4] ASTM E-140. Standard Hardness Conversion Tables for Metals. ASTM International, West Conshohocken, PA, 19428.
[5] Hardness, Rockwell, C scale.

was explained by a review of the IPC which revealed that the left and right elevators had the same part number, 122-22001.

Left elevator.

The left elevator pieces received for examination are illustrated in Figure 1, viewed from above with the forward (FWD) and inboard (INBD) directions indicated. The outboard and intermediate hinges attaching the elevator to the horizontal stabilizer are indicated and identified. The trim tab consisted of two pieces namely the inboard piece still attached to the elevator by its outboard (OUTBD) and center (CTR) hinges and the inboard piece indicated by the blue arrow. The inboard piece was clean compared to the outboard piece still attached to the elevator and had reportedly departed the aircraft prior to its impact with the ground. The trim tab inboard hinge was recovered and is identified in Figure 1. The trim tab actuator pieces identified in Figure 1 are illustrated later in Figure 20 with a piece removed from the inside of the elevator. The piece removed from the inside of the elevator was still attached to its horn on the center hinge of the trim tab. Although there is a cut-out in the elevator skin forward of the horn for the trim tab actuating mechanism to enter the elevator the skin forward of the cut-out had been damaged and is illustrated later in Figure 4. The purple box encloses a roughly rectangular area of the skin where it had been bulged outwards and the paint was missing. On the left elevator trim tab the horn and the screws attaching it to the elevator are accessible from the underside. On the accident aircraft the left elevator trim tab was adjustable by the pilot; the right elevator trim tab was fixed, faired with the elevator.

Left elevator trim tab outboard hinge.

The portion of the outboard trim tab hinge identified in Figure 1 and indicated by the red dashed lines was excised and is illustrated in Figure 2 with the installed forward direction indicated. The elevator rear spar, the elevator hinge, the hinge bolt, the trim tab hinge and the trim tab are identified. The yellow arrow indicates the original trim tab upper skin and the white arrow indicates filler that had been applied to the skin and was thinner at the trailing edge as indicated by the green arrow. The trim tab hinge was loose on the trim tab and could be rotated around the screw, limited by the clearances of the trim tab hinge lug in the trim tab recess.

Examination of the hinge hardware, as installed, revealed that it consisted of a bolt, a washer, a nut and a cotter pin as illustrated in the IPC. Manipulation of the bolt revealed that it was loose and could be hand rotated easily with a screwdriver. The trim tab hinge was found to move laterally and a 0.011-inch feeler gauge could be inserted between it and the elevator hinge. During disassembly of the hinge, the bolt was found to rotate easily until deposits on the exposed threads entered the nut. Examination of the inner faces of the elevator hinge revealed an annular contact mark that matched the end of the sleeve. The removed bolt displayed a dull gold color, consistent with chromated cadmium plating and the head displayed a raised double “X”. Measurement revealed that the bolt had a length of 1.09 inches under the head with a plain shank of

0.75-inch. A groove approximately 3/64-inch wide separated the shank from the threaded portion of the bolt. The end of the bolt was ground flat, cleaned and subjected to XRF[6] analysis which displayed a composition satisfying the material requirement in AN23. A fixture enabling hardness tests[7] to be performed on the ground end of the bolt, and the screw, was fabricated and the hardness of the bolt was measured at 27 HRC.

The screw attaches the trim tab to the trim tab hinge and was found to be loose. The upper skin directly above the trim tab hinge was removed and the protrusion of the screw above the locknut was measured at 0.236-inch. The screw was extracted easily with a screwdriver and examination revealed coloration consistent with chromated cadmium plating and a head that was marked with a dash. Measurement revealed that it had a length of 1.03-inches under the head. Difficulty was experienced re-engaging the screw in the locknut but once engaged the screw could be screwed in and out by hand with negligible resistance from the red plastic material in the locking portion of the insert. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 31 HRC.

Examination of the mating faces of the trim tab and trim tab hinge revealed areas where paint had been removed. The mating surfaces are illustrated and identified in the left image in Figure 3 with the locknut insert in the trim tab hinge also identified. The black arrows indicate areas where the paint had been removed to reveal the underlying green primer and the blue arrows indicate a band at the forward edge where green primer and base metal had been exposed.

The threads in the locknut were examined after experiencing the difficulty re-engaging the screw and damage was noted on the initial threads. The locknut identified in the left image in Figure 3 is illustrated and identified in the right image. The yellow arrow indicates a flattened portion of a thread crest and the blue arrows indicate concave grooves on two adjacent thread crests, normally associated with an attempt to engage a screw that is not aligned (cross threading).

Left elevator trim tab center hinge.

Before excising the center hinge damage observed in the lower skin of the elevator forward of the horn was examined. The examination revealed that the skin immediately forward of the cut-out for the trim tab controls had been deformed inwards and the skin forward of the deformed portion had been ripped in a short zigzag pattern with skin deformed inwards and outwards. The damaged area is enclosed within the yellow dashed circle in the left image in Figure 4 with a yellow arrow indicating the inwardly deformed skin and a blue arrow indicating the fractured edge produced by the deformation. The elevator and the trim tab are identified. The rod end which is the rear

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[6] Thermo Scientific Niton XL3t-980 x-ray fluorescence (XRF) alloy analyzer

[7] ASTM E-18 - 03. Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials. ASTM International, West Conshohocken, PA, 19428.

fitting for the trim tab control, the horn, which is part of the trim tab hinge fitting and to which the rod end is bolted, and the screw which attaches the trim tab fitting to the trim tab hinge are also identified. Excising of the center hinge revealed areas where bare metal had been exposed immediately forward of the damage illustrated in the left image. The exposed areas are illustrated in the right image in Figure 4 with the damaged area indicated by the yellow dashed circle in the left image similarly indicated. Yellow arrows indicate thin, shallow, laterally oriented indentations where the material had been deformed forward and blue arrows indicate wide smears in longitudinally oriented bands.

The rod end identified in the left image of Figure 4 was removed and the portion of the center trim tab hinge indicated by the red dashed lines in Figure 1 was excised and is illustrated in Figure 5 with the installed forward and inboard directions indicated. The elevator rear spar, the elevator hinge, the hinge bolt, the trim tab hinge and the trim tab are identified. A portion of the trim tab upper skin was missing, revealing the screw and the locknut which are also identified. The white arrow indicates filler similarly indicated in Figure 2. The center trim tab hinge illustrated in Figure 5 was inverted and is illustrated in Figure 6 with similar components identified. The horn, to which the rod end identified in the left image in Figure 4 was bolted, and the screw attaching the trim tab to the trim tab hinge, are also identified. The white arrow indicates a filler that had also been applied to the lower skin and was thinner at the trailing edge as indicated by the green arrow. The trim tab hinge was loose on the trim tab and could be rotated around the screw, limited by the clearance between the rear face of the trim tab hinge and the trim tab.

Examination of the hinge hardware, as installed, revealed that it consisted of a bolt, a washer, a nut and a cotter pin as illustrated in the IPC. Manipulation of the bolt revealed that it was loose and could be rotated easily with a screwdriver. The trim tab hinge was found to move laterally and a 0.011-inch feeler gauge could be inserted between it and the elevator hinge. The removed bolt displayed areas of a dull gold color, consistent with chromated cadmium plating and the head displayed a raised double “X”. Yellow paint was observed in the slot on the head and on the threads[8]. An imprint on the grip length of the bolt matched the length of the sleeve. Measurement revealed that the bolt had a length of 1.09 inches under the head with a plain shank of 0.75-inch. A groove approximately 3/64-inch wide separated the shank from the threaded portion of the bolt. The end of the bolt was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 28 HRC.

The screw identified in Figure 5 and 6 attaches the trim tab to the trim tab hinge and was found to be loose. The upper trim tab skin normally above the trim tab hinge was missing, as illustrated in the left image in Figure 5, and the tip of the screw was found to be flush with the locknut. The locknut is illustrated and identified in Figure 7 with the screw identified and a blue arrow indicating a portion of the first thread of the

[8] It was reported that the aircraft had been painted yellow for the 1985 National Champion Air Races.

screw protruding through the locknut. The black arrow indicates yellow paint below the grey layer. The screw was extracted easily with a screwdriver and examination revealed an unmarked head. Measurement revealed that it had a length of 0.96-inches under the head. The screw could be screwed in and out of the locknut insert by hand with negligible resistance. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 27 HRC.

Examination of the mating faces of the trim tab and trim tab hinge revealed areas where paint had been removed. The mating surfaces are illustrated and identified in the left image in Figure 8 with the locknut in the trim tab hinge also identified. The black arrows indicate areas where the paint had been removed to reveal the underlying green primer and the blue arrows indicate a band adjacent to the trim tab where paint and green primer had been removed to expose base metal.

The head of the locknut is illustrated and identified in the right image in Figure 8 with a purple arrow indicating the intact metal threads. A red arrow indicates the red insert in the locknut which also displayed an intact thread form. The IPC specifies the locknut as “Nut-Spline (ELASTIC)” which was manufactured by the “Elastic Stop Nut Corporation” (now ESNA®) which was founded in the late 1930’s and eventually become part of SPS Technologies®. Inquiries with SPS® revealed that the color of the insert indicated the manufacturer and the color for ESNA® was red. SPS® also indicated that their records did not go far enough back in time to indicate in which year ESNA® began using the red insert. In the right image in Figure 8 the blue arrows indicate three of the four stakes which retain the pressed-in-place locknut and were found to be shorter than the fourth stake indicated by the yellow arrow. The black arrow indicates the yellow paint similarly indicated in Figure 7.

Left elevator trim tab inboard hinge.

The inboard hinge identified in Figure 1 was supplied separated from the elevator and is illustrated in the left image in Figure 9 with the elevator hinge, the trim tab hinge, the hinge bolt and the locknut insert identified. The screw was observed fractured flush with the locknut and is indicated by the yellow arrow. A side view of the inboard hinge is illustrated in the right image in Figure 9 with the elevator hinge, the trim tab hinge and the bolt identified. The yellow arrow indicates the location of the fracture similarly indicated in the left image and the purple arrow indicates the protruding tip of the screw. The protrusion was measured at 0.08-inch. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The trim tab hinge containing the portion of screw was placed on an annular spacer to protect the fracture face and a hardness test performed on the ground end of the screw. The hardness of the screw was measured at 24 HRC.

Examination of the hinge hardware, as installed, revealed that it consisted of a bolt, a washer, a nut and a cotter pin as illustrated in the IPC. Manipulation of the bolt revealed that it was loose and could be rotated easily with a screwdriver. The trim tab hinge was found to move laterally and a 0.008-inch feeler gauge could be inserted between it and the elevator hinge. The removed bolt displayed areas of a dull gold color, consistent with chromated cadmium plating and the head displayed a raised double “X”, although the slot had bisected one of the “X’s”. Yellow paint was observed in the slot on the head and in the threads. An imprint on the grip length of the bolt matched the length of the sleeve. Measurement revealed that the bolt had a length of 1.09 inches under the head with a plain shank of 0.75-inch. A groove approximately 3/64-inch wide separated the shank from the threaded portion of the bolt. The end of the bolt was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 26 HRC.

The trim tab skin located above the mating surface for the trim tab hinge was removed after the examination of the trim tab detailed later and the surface is illustrated in Figure 10 with the mating trim tab hinge surface. The black arrows on the trim tab hinge indicate areas where the base metal was exposed. The yellow arrow, as in Figure 9, indicates the hinge screw fracture face and the white arrow indicates a gap between the screw and the locknut. The blue arrows on the trim tab indicate areas where the paint had been removed exposing the primer and the brown arrow indicates a partial chamfer which would normally be located adjacent to the screw at the location indicated by the white arrow in the left image. The green arrow indicates an arced indentation in the trim tab lower skin which is described later and indicated by the white arrow in the right image in Figure 18.

Examination of the fracture face indicated by the yellow arrow in Figure 10 revealed ratchet marks[9], and crack arrest marks originating at opposing sides, consistent with reverse bending fatigue that produced two fatigue zones with an overload region between them. The fracture face, with the trim tab hinge, was triple solvent cleaned then cleaned further by several applications of acetate replica tape and is illustrated in the left image in Figure 11. Red arrows in one fatigue zone indicate crack arrest marks emanating from multiple ratchet marks indicated by the green arrows in the root of the thread and terminating at the red dashed line. Yellow arrows in the second fatigue zone indicate crack arrest marks emanating from multiple ratchet marks indicated by the blue arrows in the root of the thread and terminating at the yellow dashed line. Measurements revealed that the fatigue zones were approximately even in area and the overload region between them occupied approximately 16% of the fracture face. The white arrows indicate the gap between the screw and the locknut similarly indicated in Figure 10. The purple arrow indicates the end of a thread, located between the dashed terminus lines, where the fracture had jumped from one thread root to another. A side view of the fracture face is illustrated in the right image in Figure 11 with the dashed terminus lines and similarly colored arrows transferred from the left

[9] Slight vertical steps in the fracture that link slightly offset planes of fatigue cracking at a fatigue origin area. Ratchet marks generally are aligned in the direction of cracking and taper off as distance from the origin is increased and a unified crack front is produced.

image. It was noted that the red-arrowed fatigue zone was relatively flat as it propagated from the root of the thread. The yellow-arrowed fatigue zone was initially flat but curved upwards as it approached the terminus of the red arrowed fatigue zone. The purple arrow indicates the fractured thread similarly indicated in the left image and the white arrow indicates the gap similarly indicated in the left image and in Figure 10.

The hole in the trim tab usually occupied by the screw is contained within the brown box in Figure 10 and appeared to be elongated. The hole is illustrated at a higher magnification in Figure 12 with a brown arrow indicating the partial chamfer similarly indicated in Figure 10. The diameter of the hole was measured at the locations indicated by the red arrows and was found to range between 0.195-inch and 0.193-inch. The depth of the partial chamfer indicated by the brown arrow was measured at 0.010-inch. Examination of the partial chamfer revealed that it was located on the forward edge of the hole and consisted of trim tab material that had been displaced forward.

The trim tab hinge was installed in an SEM[10] and the fracture face illustrated in Figure 11 examined. An examination of the area between the red and yellow dashed lines revealed ductile dimples consistent with an overload and an image of the area within the red box is illustrated in Figure 13. A survey in the fatigue zones revealed mechanical damage in the vicinity of the ratchet marks that had obliterated any features that may have been present and corrosion on the crack arrest marks that obscured any finer features that may be present. The trim tab hinge was submerged in Evapo-rust[11] to remove the corrosion on the fracture face, solvent cleaned and the fracture face re-surveyed in the SEM. The survey in the areas displaying crack arrest marks revealed that most of the corrosion had been removed to expose a rough surface containing corrosion pits but two areas containing discernible striations were found. The area displaying the more defined striations was located within the yellow box in Figure 11 and is illustrated in Figure 14 with red arrows indicating the fatigue striations. The spacing between the striations illustrated was approximately 1 micron (0.00004-inch).

Left elevator trim tab inboard portion.

The upper surface of the inboard portion of the left elevator trim tab that departed the aircraft is illustrated in Figure 15 with the forward (FWD) and inboard (IB) directions indicated and a red dashed line indicating the portion removed to reveal the trim tab mating surface illustrated in Figure 10. The red arrow indicates the fractured outboard edge normally located at the center hinge. The surface was smooth, consistent with the use of the filler previously noted, and clean. The black arrow indicates a dark line across the leading edge.

The lower surface of the inboard portion of the left elevator trim tab illustrated in Figure 15 is illustrated in Figure 16 with the forward and inboard directions indicated. The red arrows indicate partial rivet holes and the fractured edges between the holes

[10] Scanning Electron Microscope.
[11] A patent pending rust removing chemical compound that is non-toxic, non-corrosive, biodegradable and contains no acids or alkalis.

were found to match the fractured edges indicated by the yellow arrows in Figure 6. The black arrow indicates a dark line across the leading edge, similar to that observed on the upper surface and considered consistent with the trim tab contacting the adjacent edges of the elevator. The blue arrow, in this figure and in Figure 15, indicates an area of the leading edge, adjacent to the center hinge, which had been deformed rearwards. The white arrow indicates where the trim tab center hinge screw would have been located.

Examination of the outboard end of the trim tab indicated by the red arrow in Figure 15 revealed a fracture face oriented on a slant plane, consistent with an overload event. The outboard end is illustrated in Figure 17 with a black arrow indicating the filler and a yellow arrow indicating an upward and forward curl on a portion of the upper skin. The red arrows indicate the partial rivet holes similarly indicated in Figure 16.

Prior to removal of the skin indicated by the red dashed lines in Figure 15, the trim tab center hinge inboard fitting at the location indicated by the green arrow in Figures 15 and 16 was examined. A view of the fitting, looking aft, is illustrated in the left image in Figure 18 with a white arrow indicating the mating surface illustrated in Figure 10 and blue arrows indicating where paint and primer had been scraped off. The red dashed line, as in Figure 15, indicates the skin that was removed in order to examine the mating surface. The green and purple arrows indicate partial rectangular imprints and measurements revealed that the width of the imprint indicated by the green arrow matched the thickness of the trim tab hinge identified earlier in Figure 9. The red arrows indicate a portion of the lower skin that had been deformed upwards and its length matched the length of the imprint indicated by the purple arrow. The black arrow indicates a cupped impression that was in alignment with the impression indicated by the white arrow in the right image.

A view of the inboard fitting from below is illustrated in the right image in Figure 18 with red arrows indicating the deformed skin indicated by the red arrows in the left image, and blue arrows indicating where paint and primer had been scraped off. The black arrow indicates the original location for the screw and the white arrow indicates a distinctly arced indentation between the red arrows. A closer view of the screw location is illustrated in Figure 19 with a black arrow indicating the surface normally contacted by the head of the screw, which displayed a black textured surface consistent with a fretting action. The white arrow indicates the arced indentation similarly indicated in the right image in Figure 18 and measurements revealed that it had a diameter that closely matched the diameter of the screw hole indicated by the yellow arrow. Diameter measurements of the lower end of the screw hole were found to range between 0.196-inch and 0.193-inch, similar to the measurements taken of the upper end illustrated in Figure 12.

Left elevator trim tab actuator pieces.

The actuator pieces identified in Figure 1 and the portion of the link removed from the horn on the center hinge are illustrated in Figure 20 with the forward direction, as installed, indicated. The pieces consisted of the link assembly and the rod assembly as identified in Figure 20. The IPC identifies the link assembly as part number 99-52526 and drawing 99-52526, document 5 in section C, shows it consisting of a rod, a clevis and rod end. The rod consists of a tube with threaded fittings that are resistance welded at each end of the tube and the welds are indicated by the blue arrows in Figure 20. The clevis is screwed onto one end of the rod and pinned in place. The rod end is screwed on to the other end of the rod and locked in place with a jam nut. Examination of the rod end revealed that the bearing rotated freely and that there was minimal play in all directions. Laterally oriented grooves were observed on the threaded fitting adjacent to the rod end, at the location indicated by the brown arrow in Figure 20.

Examination of the pieces revealed that the link assembly now consisted of three pieces with fractures at the threaded adapter to the clevis, the mating fracture faces identified as “LE-1” and “LE-2 in Figure 20, and in the tube, the mating fracture faces identified as “LE-3” and LE-4” in Figure 20. The rod assembly displayed a fracture face identified as “LE-5”, sheared rivets at “LE-6” and a fractured bolt identified as “LE-7”.

The mating fractures identified as “LE-1” and “LE-2” in Figure 20 are illustrated and identified in the left image in Figure 21 with a yellow arrow indicating the pin that locks the clevis to the threaded fitting. Examination revealed that the threaded portion of the fitting had fractured leaving a portion of the thread in the clevis. Matching the fracture faces, as illustrated, indicated that the adapter had been subjected to bending. Threads with a reduced pitch, as indicated by the black arrows, and threads with an enlarged pitch, as indicated by the green arrows, confirmed that the bending direction was as illustrated in the figure and in Figure 20. The fracture face “LE-1” is illustrated in the right image in Figure 21 and displayed a rough grainy surface consistent with an overload event. The white arrow indicates the portion of thread similarly indicated in the left figure. “LE-2” was separated from the link by cutting along the red dashed line in the left image and an examination of both cut ends revealed the drilled interior indicated by the blue dashed lines, consistent with drawing 99-52526.

The mating fractures identified as “LE-3” and “LE-4” are illustrated and identified in Figure 22. Examination revealed that both had been subjected to bending and mechanical damage. On “LE-3” the yellow line was drawn parallel to the tube to illustrate the bending deformation indicated by the yellow arrow. On “LE-4” the red line was drawn parallel to the tube to illustrate the bending indicated by the red arrow. The purple arrow indicates an inwardly bent lip, which, with the bending indicated by the yellow and red arrows, confirms that the bending direction was as illustrated in the figure and in Figure 20. The black arrows indicate circumferential cracks in the plating specified in drawing 99-52526, also consistent with the bending direction.

Examination of the fracture face identified as “LE-3” revealed bending and mechanical damage in the form of notches that had obliterated any fracture features. The examination also revealed that, in addition to the bending, the end of the tube had been compressed. The fracture face is illustrated in the left image in Figure 23 with white arrows indicating distinct notches in the fracture face that were through the wall thickness of the tube. The blue arrow indicates a rippled surface consistent with compression of the surface on the inside of a bend and the location is also indicated by the blue arrow in Figure 22. The black arrow adjacent to the fracture face indicates cracks in the plating consistent with tension.

Examination of the fracture face identified as “LE-4” revealed bending and mechanical damage in the form of notches that had obliterated most of the fracture features. The fracture face is illustrated in the right image in Figure 23 with red arrows indicating areas containing fracture features that displayed a rough grainy surface consistent with an overload event. The green arrow indicates a rippled surface, consistent with compression of the surface on the inside of a bend and the location is also indicated by the green arrow in Figure 22.

A side view of the notches in “LE-4” is illustrated in Figure 24 with the cut end of the tube indicated by the red dashed line in Figure 21. The blue arrow indicates the weld similarly indicated adjacent to “LE-2” in Figure 20 and the red dashed line indicates the cut indicated by the red dashed line in the left image in Figure 21. The notches were through the wall thickness of the tube and the square-cut end of the link was found to match the more distinct profile of the notch indicated by the white arrow and the less distinct notches indicated by the purple arrows.

The trim tab link assembly and a portion of the rod assembly are normally located between ribs in the elevator. Examination between the ribs revealed a relatively long upward bulge in the upper skin and mechanical damage to the front spar. The bulge was evident on the upper skin of the elevator and is contained within the purple box in Figure 1. Prior to cutting the portion of the link assembly indicated by the purple arrow in Figure 20 it was found to match the length of the bulge. In Figure 25 the bulge is contained within the purple box and the adjacent portion of the link assembly is indicated by the purple arrow. A view between the ribs, looking forward, is illustrated in Figure 26 with the bulge in the upper skin indicated by the purple arrow. The yellow arrow on the rear face of the front spar indicates the original hole through which the trim tab control assembly is normally positioned and the red arrow indicates a second adjoining hole.

A closer view of the holes in the front spar illustrated in Figure 26 is illustrated in the left image in Figure 27. The original hole is indicated by the yellow arrow with a black arrow indicating a portion of it that did not follow the circular outline and was located in opposition to the second hole indicated by the red arrow. The red arrow indicates the second hole with the blue arrow indicating spar material that had been displaced rearwards and outboard and the green arrow indicating spar material that had been displaced rearwards and upward. The purple arrow indicates the forward end of the bulge indicated by the purple arrow in Figure 26. A view of the holes in the front spar looking aft is illustrated in the right image in Figure 27 with a yellow arrow indicating the original hole. The red arrow indicates the second hole and the white arrow indicates smearing of the surface, similarly indicated in the left image, and associated with the displaced material indicated by the green arrow in the left image.

A review of the IPC revealed that the rod assembly part of which is identified in Figure 20 was assigned part number 73-525124. Drawing 73-525124, document 6 in section C, illustrates the rod assembly and indicates that the rod normally slides in a guide bolted to the rear face of the horizontal stabilizer rear spar which is also utilized for the fixed trim tab assembly on the right elevator illustrated later in Figure 55. The bolt fits in a hole in the guide and passes through the slot in the rod maintaining the orientation of the rod and limiting its fore and aft travel. Forward of the guide, the end of the rod is plugged and inserted in a tube and the three are permanently riveted together with two flat head rivets. Drawing 73-525124 identified the material for the tubular portion of the rod as “C.M. STL TUBE” that was “5/8 OD x .125 x 7½” and XRF analysis identified it as steel alloy 4130.

The fracture identified as “LE-5” in Figure 20 was located on a tubular portion of the rod assembly that was connected to the rod by two rivets. The fractured tube is illustrated in the left image in Figure 28 with red arrows indicating the fracture face which displayed a rough texture and was oriented on a slant plane, consistent with an overload event. The yellow arrow indicates the manufactured end of the rod.

Examination of the rivets attaching the tubular portion to the rod revealed that the two flat head portions of each rivet were missing leaving a fracture surface at the rod surface. A typical fracture observed at location “LE-6” in Figure 20 is illustrated in the right image in Figure 28 with the forward direction indicated. The fracture is one of the two on the rearmost rivet and displayed features similar to the two fractures on the forward rivet. The red arrow indicates the fractured shank of the rivet which was partially obscured and the blue arrow indicates the deformed chamfered hole originally occupied by the rivet head. The yellow arrow indicates the rod and measurement revealed a relative displacement of 1/16-inch. The fractured surface of the rivet shank displayed surface lines oriented on the rod axis consistent with a shearing action.

The bolt identified as “LE-7” in Figure 20 displayed a distinct bend and a fractured end. A side view of the bolt in the rod is illustrated in the left image in Figure 29 with the rod identified and the forward direction, as installed, indicated. The red arrow indicates the fracture face and the yellow arrow indicates the remaining edge of a groove normally located between the threaded portion and the shank of a bolt. The white arrows indicate the shank of the bolt normally located in the guide. The fracture face indicated by the red arrow in the left image is illustrated in the right image with the rod identified and yellow arrows indicating the edge of the groove indicated by the yellow arrow in the left image. The fracture face displayed a uniformly grainy surface with a slightly cupped profile initiating in the vicinity of the green arrow and lines on the surface were oriented toward the shear lip indicated by the white arrow, features consistent with a shearing action.

The examination also revealed that the nut attaching the link clevis to the rod assembly had been impacted, deforming one of its castellations and the threaded end of the bolt forward. The clevis displayed a slightly arced, circumferentially oriented indentation at the location indicated by the green arrow in Figure 20 with material displaced forward. A straight edge placed along the length of the rod assembly tube revealed that the tube had been bent and the maximum bend was measured at 1/32-inch.

Elevator torque tube assembly.

The elevator torque tube assembly was supplied with a portion of the left elevator still attached as illustrated in Figure 30. The purple arrow indicates the elevator’s trailing edge, the yellow arrow indicates the leading edge and the black arrows indicate the inner edge. The torque tube assembly is attached to the airframe by a center hinge bracket which is bolted to an eyebolt which is bolted to the connecting fitting identified in Figure 30. The left and right fittings are normally part of the elevator assembly and are bolted through their respective horns to the connecting fitting with three bolts. The mounting face of each fitting is triangular and is installed with one side oriented vertically at the rear of the torque tube assembly as illustrated in Figure 30. The hexagonal heads of the mounting bolts at the rear of the torque tube assembly are indicated and identified as left upper (LU), left lower (LL), right upper (RU) and right lower (RL) in Figure 30 and later in Figure 38. The third hexagonal headed bolt in each fitting is identified as left forward (LF) and right forward (RF) later in Figures 32 and 38. The hexagonal head of the fitting attachment bolts were located on the fitting flange with their shanks oriented inwards. With the exception of the left forward bolt, as described later, the fitting attachment bolts were retained by locknuts with a plastic insert. The left and right torque tubes are part of the elevator frame and are riveted to the left and right fittings respectively. The torque tubes extend into the elevator to the second rib and the elevator is riveted to them at the first and second rib. The lower portion of the left horn displayed a significant inward bend and the upper and lower portions of the right horns displayed slight inward bends. Control cables extend from below the cockpit to the upper and lower attachment holes in the left and right horns and portions of the cables are evident in the lower attachment holes of the left and right horns.

Examination noted that the leading edge of the left elevator portion was oriented vertically and aligned with the horns, consistent with the elevator being rotated clockwise when viewed from the left. The examination also revealed an outboard displacement of the elevator which had exposed some of the attaching rivets. The left torque tube is illustrated in the left image in Figure 31 with the exposed rivets contained within the red box. The purple arrows indicate foam occupying the inboard end of the elevator for comparison with the inboard end of the right elevator illustrated in Figure 44.

The rivets in the red box in the left image in Figure 31 are illustrated in the right image with the up and outboard directions indicated. The black arrow indicates the fracture surface of a typical rivet which displayed score lines oriented in the direction indicated by the yellow arrow. The yellow arrow also indicates a gap between the fracture face and the rivet hole in the torque tube, features consistent with a shearing action. The red arrow indicates a band of exposed tube metal that emanated from the rivet hole and was also oriented down and outboard as indicated by the yellow arrow. The blue arrow indicates smearing on the green torque tube primer that was oriented down and more significantly outboard than indicated by the yellow arrow. The green arrow indicates residual foam that extended inwards to within 1/4” of the left fitting.

A view of the central portion of the torque tube assembly looking aft is illustrated in Figure 32 with the connecting fitting, the left fitting and the right fitting identified. The hexagonal heads of the forward attaching bolts for the fittings are indicated and identified as left forward (LF) and right forward (RF). A portion of the center hinge bracket was still attached and is identified (when intact, the center hinge bracket is attached to the airframe). The four yellow arrows indicate the fractured ends of the center hinge bracket legs which displayed similar rough uniformly grainy surfaces consistent with an overload event. The examination revealed a gap between the left fitting and the left horn adjacent to the forward attachment bolt. The gap was measured at 0.082-inch and is indicated by the purple arrow in Figure 32. The green arrows indicate bands of grey paint extending from the left and right fittings and measurements reveal widths of approximately 1/8-inch and 1/2-inch respectively.

The area in the vicinity of the gap indicated by the purple arrow in Figure 32 is illustrated in the left image in Figure 33 with the gap similarly indicated. The left fitting, the left horn, the connecting fitting and the center hinge bracket are identified. The examination revealed that the nut was missing from the left forward bolt and the bolt was visibly longer than the right forward bolt. The white arrow indicates the damaged threads where the nut should have been and the yellow arrow indicates an indentation in the lower left leg of the center hinge bracket.

The indentation in the lower left leg of the center hinge bracket indicated by the yellow arrow in the left image in Figure 33 is illustrated in the right image with the indentation indicated with a yellow arrow. Manipulation of the center hinge bracket revealed that the indentation could be mated with the protruding end of the forward bolt.

The left forward bolt was extracted and an examination revealed that most of the threaded portion was bent. The bolt is illustrated in Figure 34 with the threaded end contained within the red box and a closer view of the thread is illustrated in the left image in Figure 35. In the left image in Figure 35 the yellow arrows indicate two full threads that exhibited no wear or damage, consistent with them not being originally engaged in the nut. The red line is a continuation of the shank of the bolt, and the intact threads, to illustrate the damage to the threads and the bend. The blue dashed lines indicate the crests of the intact threads and what would have been the crests of the damaged threads and the black arrows indicate thread and/or nut material between the crests. The bolt was rotated and a view of the threaded end is illustrated in the right image in Figure 35. The red lines are a continuation of the shank to illustrate the damage to the threads. The black arrows indicate material between the threads and the red arrows indicate longitudinally oriented lines on the surface, features consistent with a shearing action between the threads in the nut and the threads on the bolt.

Examination of the right fitting revealed that approximately 2 inches of the torque tube protruded and the outboard end of the tube displayed fractures between each rivet hole. The right fitting and torque tube are illustrated and identified in the left image in Figure 36. The examination also revealed that the upper edge of the tube displayed a distinct deflection downward. The right image in Figure 36 illustrates a steel rule on the upper edge of the right torque tube and the red arrow indicates the deflection. Measurements were taken 3/8-inch inboard of the fracture face and revealed torque tube diameters of 1.764 inches in the fore and aft direction and 1.742 inches in the vertical direction.

Rivet holes and fractures at the rear facing edge of the right torque tube are contained within the yellow box in Figure 36 and illustrated in the left image in Figure 37. The yellow arrows indicate what remained of the rivet holes, estimated at approximately 50%, with a majority of the remaining hole located at their upper edges as illustrated. The white arrows adjacent to the holes indicate tube material that had been smeared downward and inboard. The purple arrows indicate fractured portions of the tube that were located between rivet holes and displayed outer edges that were smeared inwards. The rivet holes on the forward facing edge of the right torque tube are illustrated in the right image in Figure 37. The yellow arrows indicate what remained of the rivet holes, estimated at approximately 30%, with a majority of the remaining hole located at their lower edges, as illustrated. The fracture faces displayed rough grainy surfaces consistent with an overload event.

The examination of the elevator torque tube assembly revealed that the castellated nut indicated by the white arrow in Figure 30 was loose and the cotter pin was missing. Inquiries revealed that the components had to be separated on scene to facilitate their removal from the wreckage. The nut was removed and the center hinge bracket extracted to reveal mechanical damage in the center of the connecting fitting and nuts, with protruding threads, within the connecting fitting. The nuts were located central to the previously identified left and right fitting attaching bolts and are identified as left center (LC) and right center (RC) in the left image. The elevator torque tube is illustrated in the left image in Figure 38, looking aft with the center hinge bracket removed. The connecting fitting, left fitting, left horn, right fitting, right horn, attaching hardware and center hinge bracket are identified as in Figure 32. The center hinge bracket is bolted to an eye bolt containing the center hinge bearing for the elevator assembly and the bolt portion of the eye bolt is secured to the connecting fitting by the castellated nut previously removed. The purple arrow indicates the center hinge bracket attachment nut that was previously found loose and the black arrow indicates the mounting face for the eye bolt.

The original location of the eye bolt on the connecting fitting, within the yellow box in the left image in Figure 38, is illustrated in the right image. Examination of the eye bolt mounting face indicated by the black arrow in the left image revealed that it was essentially a rectangle. The black arrow indicates the original location of an edge of the rectangle and the yellow arrows indicate smeared surfaces consistent with rotation of the eye bolt while still attached firmly to the connecting fitting.

The remaining two bolts, LL and LU, in the left fitting were removed and the torque in inch-pounds (in/lb) required to loosen the nuts was recorded. The torque figures are presented later in a table. When the left fitting was separated from the left horn six (6) rivet reaction heads fell out. An inspection inside the left torque tube revealed that the rivet heads were from the circumferential rivet pattern illustrated earlier in Figure 31. The rivet heads retained a short length of the rivet shank which displayed a sheared fracture face similar to the rivets illustrated in the right image in Figure 31. Removal of the left fitting also revealed that the center attaching hardware consisted of a flat headed screw, a washer and a locknut. A preliminary examination revealed that the left fitting had been painted with a light green primer, a grey paint and a light grey paint and the horn had been painted with a dark green primer followed by a light grey paint. Examination of the left fitting's mounting face revealed dark green paint, consistent with paint transfer from the horn, and bare metal around the holes. The mounting face of the left fitting is illustrated in the left image in Figure 39 with the installed up and forward directions indicated and the holes identified with the bolt identification illustrated in Figure 38. The green arrows indicate dark green paint around each hole and the blue arrow indicates exposed grey paint. The red arrow indicates a letter “L” written in ink that had been partially obliterated by a significant rotation of the fitting as indicated by the adjacent arced line. The yellow arrow indicates an area of dark green paint that displayed a profile similar to, and in a matching location, to the bare metal area, indicated by the yellow arrow in the right image.

The mounting face of the left horn to the left fitting illustrated in the left image in Figure 39 is illustrated in the right image with the installed up and forward directions indicated and the bolt holes identified. The white arrow adjacent to the LL hole indicates grey paint that had transferred from the left fitting. The purple arrow indicates the flat head of the center screw identified as LC in the left image in Figure 38. The screw attaches the horn to the connecting fitting and a review of the IPC revealed that it was not illustrated or specified. The examination revealed that bare horn material that was undamaged displayed a uniformly unmarked surface.

In order to examine the mounting faces between the horn and the connecting fitting the center screw, LC, was removed and the torque required to loosen the nut was recorded. A preliminary examination revealed that the horn had been painted with a dark green primer followed by a light grey paint, as previously noted, and the connecting fitting was a casting that had been painted dark green. Examination of the mounting face of the horn revealed green paint and bare metal. The mounting face of the horn is illustrated in the left image in Figure 40 with the installed up and forward directions indicated. The yellow arrow indicates bare metal and the green arrow indicates green paint which, when a portion was removed, revealed bare metal. The purple arrow indicates an arced wear band that had exposed the underlying green primer and bare metal and the blue arrow indicates an arc at the outer edge of the lower hole. The white arrow indicates a distinctive "J"-shaped green deposit around the center hole.

The left mounting face on the connecting fitting displayed a polished surface around the forward hole, LF, and bare metal, with a black deposit, around the left upper hole, LU. The mounting face is illustrated in the right image in Figure 40 with the installed up and forward directions indicated. The brown arrow indicates the polished surface around the LF hole, consistent with relative movement between the mounting faces, and the yellow arrow indicates the bare metal around the LU hole, the black deposit being consistent with fretting wear. The purple arrow indicates an arced wear band that matched the profile and location of the band similarly indicated in the left image. The blue arrows indicate portions of an arc at the inner edge of the LL hole. The white arrow indicates a distinctive "J"-shape, matching that similarly indicated in the right image, where the green paint around the center hole, LC, had been removed and transferred to the horn. The red arrows indicate the remains of surface blowholes[12] in the connecting fitting that had been partially removed by the mounting face machining process.

The three bolts in the right fitting, RU, RL, and RF, were removed and the torque required to loosen the nuts was recorded. Examination of the right fitting mounting face revealed bare metal and material transfer adjacent to the mounting holes, consistent with fretting. The mounting face of the right fitting is illustrated in the left image in Figure 41 with the up and forward directions indicated and the holes identified with the bolt identification illustrated in Figure 38. The image illustrates the missing paint around the holes and the blue arrow indicates the light green primer below the light grey paint. The white arrow indicates the letter "R" written in ink and the green arrows indicate dark green paint that had been transferred from the horn. The red arrow indicates a distinctive, slightly arced rectangular patch of dark green paint at the forward hole and the yellow arrow indicates a distinctive, slightly arced rectangular patch of bare metal adjacent to the inside diameter of the fitting.

To separate the right horn from the connecting fitting the center screw, RC, was removed and the torque required to loosen the nut was recorded. The mounting face of the right horn to the right fitting illustrated in the left image in Figure 41 is illustrated in the right image with the installed up and forward directions indicated and the bolt holes similarly identified. The examination revealed that undamaged bare metal displayed a textured surface consistent with a grit blasted surface and the horn had been painted with a light green primer, a dark green paint and a light grey paint. The green arrows indicate the dark green paint originally below the light grey paint and the brown arrow indicates the light green primer originally below the dark green paint. The blue arrows indicate a black deposit that was imprinted with circumferential machining marks that were evident on the fitting mounting face. The red arrow indicates a distinctive, slightly arced rectangular patch of bare metal matching the patch of dark green paint indicated by the red arrow in the left image, consistent with paint transfer

[12] Surface blowholes are usually caused by improper core venting in the molding sand surface.

from the horn to the fitting. The yellow arrow indicates a distinctive, slightly arced rectangular parch of dark green paint matching the patch of bare metal indicated by the yellow arrow in the left image, consistent with paint transfer from the fitting to the horn. The purple arrow indicates the chamfer for the head of the center screw, RC.

The mounting face of the right horn to the connecting fitting is illustrated in the left image in Figure 42 with the installed up and forward directions indicated and the bolt holes identified as in Figure 38. Examination revealed that the dark green paint below the light grey paint had been exposed around the holes and bare metal had been exposed around the upper hole, RU. The green arrows indicate the dark green paint which displayed a circumferential orientation and the blue arrows at the upper hole, RU, indicate exposed bare metal. The yellow arrow indicates a distinctive spot of exposed dark green paint with an annulus of raised grey paint around it. Small spots of dark green paint were observed on the grey surface in the annulus.

Examination of the mounting face of the connecting fitting to the right horn revealed bare metal covered with a black deposit around the holes and patches of grey paint at the upper hole, RU. The mounting face is illustrated in the right image in Figure 42 with the installed up and forward directions indicated and the bolt holes identified as in Figure 38. The brown arrows indicate bare metal covered with a black deposit and the blue arrows indicate grey paint that had transferred from the horn, features consistent with fretting wear. The bare metal around the lower hole, RL, also displayed a distinct circumferential orientation, consistent with relative motion between the two mating components. The red arrows indicate surface blowholes and the green arrow indicates porosity in the larger blowhole. The yellow arrow indicates a bare metal spot that matched the spot indicated by the yellow arrow in the left view.

The torque required to release the nuts on the bolts and screws identified in Figure 38 was recorded during the previously detailed disassembly and examination process and is presented in the following table. Attempts were made to insert the bolts and screws into their respective nuts by hand, but resistance was felt when the thread started to engage the insert. The torque required for each of the threads to rotate in their respective nut (running torque) was also measured in inch–pounds (in/lb) and is presented in the following table with the release torque measurements.

BOLT/SCREW IDENTIFICATION	RELEASE TORQUE (in/lb)	RUNNING TORQUE (in/lb)
LU	11.3	4
LL	20.2	6
LF	*	*
LC	10.5	5
RU	50.0	6.5
RL	61.2	6
RF	53.2	4.5
RC	44.1	6

* Missing nut.

The lengths of the bolts and screws removed from the elevator torque tube assembly are presented in the following table using the identifications in Figure 38. Other distinguishing features such as the presence of a cotter pin hole, their head markings, the height of the locknuts and the color of the locknut insert are also presented.

BOLT/SCREW IDENTIFICATION	BOLT LENGTH (in)	COTTER PIN HOLE	HEAD MARKINGS	NUT HEIGHT (in)	INSERT COLOR
LU	1.531	YES	AFC X	0.316	GREEN
LL	1.536	NO	C X C	0.312	GREEN
LF	1.526	NO	AFC X	*	*
LC	1.165	NO	X	0.315	OPAQUE
RU	1.537	YES	AFC X	0.313	GREEN
RL	1.542	NO	AFC X	0.316	OPAQUE
RF	1.492	NO	OIDO X	0.206	OPAQUE
RC	1.170	NO	X	0.312	OPAQUE

* Missing nut.

A review of the IPC revealed that only the upper and lower rear bolts are illustrated and are identified as AN4-14A, bolt, 1/4-28[13], quantity 4 per assembly. The AN4 bolt specification, document 7 in section C, specifies the AN4-14A bolt length as 1 $^{17}/_{32}$-inches (1.53-inches) and the "A" indicates that the bolt is undrilled (no hole in the threaded portion for a cotter pin or in the head for locking wire). The head shall be marked with a single "X" (raised or depressed) and may include the manufacturer's markings. Under the AN4-14A bolt listing the IPC lists "NAS222-26[14], screw-brazier head, Phillips recess, 1/4-28, quantity 2 per assembly" and "NAS206-19[15], screw-brazier head, Phillips recess, 1/4-28, quantity 2 per assembly". There were no nuts or washers listed with the bolts and screws.

As the IPC lists, but does not illustrate, two types of screw with the upper and lower rear bolts and the torque tube assembly had hex-head bolts as the forward attaching hardware, with screws as the center attaching hardware, inquiries were made and figure 79, document 8 in section C, was provided. The figure illustrated the horizontal stabilizer and elevator installation and detail "A" illustrated the hardware attaching the left and right fittings to the connecting fitting but only identified the bolts and screws. Detail "A" identified the rear bolts as AN4-14A, agreeing with the IPC, and the forward attaching hardware as screws, 7S2-428-24. Detail "A" also clearly illustrated that the forward attaching hardware consisted of screws, washer and nuts and that screws were to be installed with the head on the inside of the connecting fitting. A review of manual AN 01-60-3, document 9 in section C, revealed specifications for

[13] A 1/4-28 thread has a nominal diameter of1/4-inch (0.025-inch) and 28 threads per inch of length.
[14] NAS222 screws are presently incorporated in MS27039, document 3 in section C. The screws have rounded heads and the -26 screw has a nominal length of 1.656-inches.
[15] A NAS206-19 screw has a flat countersunk head and a nominal length of 1.187-inches.

AN4 type bolts, 7S2 type screws and AC365 type nuts. The screw specification indicated that the 7S2-428-24 screws had a length of 24/16-inch, nominally 1.50-inches. Further review of manual AN 01-60-3 revealed table 41 on page 499 which specified the torque limits for bolts and nuts. The table specified that the torque for a bolt or a type 365 nut with a 1/4-28 thread was 50-70 in/lbs.

Right elevator.

The right elevator and trim tab received for examination are illustrated in Figure 43 and viewed from above with the forward and inboard directions indicated. The location of the intermediate hinge attaching the elevator to the horizontal stabilizer is indicated. On the right elevator trim tab, the screws attaching it to the elevator are accessible from the upper surface and an examination revealed that the center hinge screw was missing. Lateral movement of the trim tab revealed a slight sideways movement and relative motion was observed between the trim tab and the screws. The screws in the outboard and inboard hinges are indicated by the blue arrows in Figure 43. A 0.004-inch feeler gauge was found to fit between the trim tab hinge and the lugs on the elevator hinge in the inboard and outboard hinges, and a 0.0015 feeler gauge could not be inserted in the center hinge. The purple box encloses an area of the skin that had been bulged outwards and the paint was missing. The red dashed red lines indicate cutting lines for excising the hinges and the blue dashed square indicates a panel that was removed to help quantify the looseness observed between the trim tab and the elevator.

On the accident aircraft, the right elevator trim tab was not adjustable by the pilot and fixed fair with the elevator. A portion of the link assembly normally attached to the trim tab rod was found still connected to the horn on the center hinge and is illustrated later in Figure 56. The trim tab rod identified in Figure 43 was rigidly attached to a portion of the right horizontal stabilizer rear spar and is illustrated later in Figure 54.

The right portion of the elevator torque tube previously examined is also illustrated in Figure 43 and is normally riveted to the elevator at the location indicated by the white arrow. Examination of the torque tube remaining in the right elevator revealed fracture faces between rivet holes that matched with the fractures at the outboard end of the right torque tube. The rivet holes still contained rivets. A view inside the leading edge is illustrated in Figure 44 with yellow arrows indicating the rivets. The torque tube is riveted to a structural tube inside the leading edge which is riveted to the flange indicated by the red arrows. The flange has tongues, as indicated by the purple arrow, to which the elevator skin is riveted. Examination of the flange revealed that the outer edges attached to the elevator skin had been deformed outboard. The green arrows indicate the ends of a fractured fibrous washer at the inboard edge of the elevator, there was no indication of the foam observed in the left elevator and illustrated in Figure 31.

To quantify the vertical play between the trim tab and the control rod the hardware attaching the portion of the link assembly to the horn was removed and the link extracted from the elevator. During removal of the link it was noted that the locknut at the rod end was loose. The upper skin panel indicated by the blue dashed line in Figure 43 was removed. The link was reattached to the horn and clamped to the upper skin. The clamped link is illustrated in Figure 45 with the link, the c-clamp, the center hinge and the horn identified. The red dashed lines indicate cutting lines used to excise the center hinge for examination. The white arrow indicates the filler observed on the left elevator trim tab and similarly indicated in Figures 2 and 4. The trim tab was lifted upwards until it stopped, as indicated by the blue arrow in the left image in Figure 46, and an inclinometer placed on the trim tab. The inclinometer was zeroed, the trim tab pushed down until it stopped, as indicated by the blue arrow in the right image in Figure 46 and the inclinometer displayed a reading of 3-degrees. The purple arrows in both images in Figure 46 indicate the loose attaching screw and a yellow dashed line represents the up position of the trim tab. In both images, the red dashed lines indicate the cutting lines used later to excise the inboard hinge.

Right elevator trim tab outboard hinge.

The outboard trim tab hinge portion identified in Figure 43 was excised by cutting along the red dashed lines and is illustrated in Figure 47 with attached portions of the trim tab and the rear spar identified. The yellow arrow indicates the head of the screw attaching the trim tab to the trim tab hinge, about which the portion of the trim tab could be moved easily. It was noted that a 0.013-inch feeler gauge could now be inserted between the trim tab hinge and a lug of the elevator hinge.

The trim tab skin obscuring the end of the screw was removed in order to measure the protrusion of the screw, which was found to be 0.103-inch, and access the mating surface of the trim tab with the trim tab hinge. The screw was removed and found to rotate easily when turned with a screwdriver. With the trim tab portion separated from the hinge the screw was re-inserted into the locknut and found to screw in and out easily by hand and without the use of a screwdriver. An oil-like liquid was observed in the recess previously occupied by the head of the screw.

Paint on the screw head was removed to reveal a single depressed “X” on the head and three small round indentations between cross recessions. The length of the screw under the head was measured at 0.930-inch and areas displaying a gold colored surface, consistent with chromated cadmium plating, were observed. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 28 HRC.

Examination of the hinge hardware revealed that it consisted of a bolt, a nut, a cotter pin and a washer that fit on the sleeve, as illustrated in the IPC. A second washer was found installed under the head of the bolt. Manipulation of the bolt revealed that it could be rotated easily with a screwdriver. The bolt was removed and an examination revealed a gold coloration on the end, consistent with chromated cadmium plating. The head displayed yellow and grey paint and a recessed double “X”. The length of the bolt was measured at 1.09 inches. The end of the bolt was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 27 HRC.

Examination of the mating surfaces of the trim tab and trim tab hinge revealed different colored paints on the trim tab and a bare metal surface on the trim tab hinge displaying a circular imprint. The mating surfaces are illustrated and identified in Figure 48 with the trim tab, the trim tab hinge and the locknut insert identified. On the trim tab the yellow arrow indicates the green primer, the white arrow indicates a medium grey paint on the primer and the green arrow indicates a light grey paint on the medium grey paint. On the trim tab hinge the blue arrows indicate a circular imprint that would be consistent with a washer being installed in that location, at some previous time.

Right elevator trim tab center hinge.

The center trim tab hinge identified in Figure 43 consisted of two pieces and was excised by cutting along the red dashed lines. The pieces are illustrated in the left image in Figure 49 with attached portions of the trim tab and the rear spar identified. The elevator hinge, the bolt, the trim tab hinge and the horn on the trim tab are also identified. The examination revealed that the horn had been displaced outboard and upward. The yellow arrow indicates the hole normally occupied by the screw attaching the trim tab to the trim tab hinge. It was noted that a portion of the screw was retained in the trim tab hinge and displayed a fracture face illustrated later in Figure 50. A 0.014-inch feeler gauge could now be inserted between the trim tab hinge and a lug of the elevator hinge. The white arrow indicates the filler that had obscured the underlying rivet heads. The blue arrow indicated a disturbed area on the upper surface of the rear spar. The black arrow indicates a forward deformation of the sheet metal normally in contact with the forward face of the rear spar and the blue arrow indicates a disturbed area on the upper surface of the rear spar that extended from the forward edge rearwards to the approximate center of the upper surface.

Examination of the hinge hardware revealed that it consisted of a bolt, a nut, a cotter pin and a washer that fit on the sleeve, as illustrated in the IPC. Manipulation of the bolt revealed that it could be rotated easily with a screwdriver. The bolt was removed and an examination revealed a gold coloration on the end, consistent with chromated cadmium plating. The head displayed red, yellow and grey paint and a raised single “X”. The length of the bolt under the head was measured at 1.15 inches. The end of the bolt was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 25 HRC.

The fractured portion of the screw was retained in the locknut and a view of the thread protruding from the head of the locknut is illustrated in the right image in Figure 49 with the trim tab hinge identified. The protruding thread on the other side of the locknut was measured at 0.188-inch. The blue arrows indicate the two forward stakes that were oriented circumferentially around the head of the locknut. The white arrow indicates a third stake oriented tangential to the locknut head with its outer edge at the rear edge of the trim tab hinge. The yellow arrow indicates a fourth stake oriented tangential to the locknut head such that an inner corner had fractured the thin material between it and the locknut recess at the location indicated by the red arrow. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The trim tab hinge containing the portion of screw was placed on an annular spacer to protect the fracture face and a hardness test performed on the ground end of the screw. The hardness of the screw was measured at 25 HRC.

Examination of the mating surface on the trim tab hinge revealed a circular imprint and the fractured portion of the screw retained in it displayed a distinctive rearward deformation. The trim tab hinge is illustrated and identified in the left image in Figure 50 with the locknut insert identified. The blue arrows indicate a circular imprint on the mating surface of the trim tab hinge that would be consistent with a washer being installed in that location, at some previous time. The mating surface was mostly bare metal. The purple arrow indicates the screw fracture face and the yellow arrow indicates a gap between the screw threads and the locknut threads.

A closer view of the fracture face indicated by the purple arrow in the left image in Figure 50 is illustrated in the right image. Examination of the fracture face revealed an area between the root of the thread and the red dashed line displaying clean shiny scratches and surface lines on the remaining fracture face, both oriented in the direction indicated by the black arrow, consistent with a shearing action. The orange arrows indicate the root of the thread that had also been displaced in the direction indicated by the black arrow. The gap indicated by the yellow arrow indicates an initial bending of the screw, in the direction indicated by the black arrow, prior to the initiation of the shearing action.

Examination of the trim tab surface that mates with the trim tab hinge surface illustrated in the left image in Figure 50 revealed exposed primer in each corner. The blue arrows in the left image in Figure 51 indicate the corners. The examination also revealed mechanical damage to the adjacent horn tangs and the skin below the mating surface. The black arrow indicates an area where paint had been removed on the inner edge of the left tang and the yellow arrow indicates a significantly larger area of exposed primer and bare metal on the inner edge of the right tang. Closer examination of the bare metal revealed that it had been scraped repeatedly to produce what appeared to be whiskers of metal. The red line is a continuation of the skin edge to illustrate the deformation indicated by the red arrow.

The rod end of the trim tab link was re-connected to the horn and movement of the trim tab portion revealed that the body of the rod end could contact the inner edges of the horn when the trim tab was positioned perpendicular to the link. The trim tab portion and the re-connected trim tab link are illustrated and identified in the right image in Figure 51 with the rod end in contact with the edges of the horn at the yellow arrow, which is the location indicated by the yellow arrow in the left image. In that position, the rod end and its locknut are located between the horn and the lower skin so that upward movement of the trim tab forces the locknut into the skin deformation indicated by the red arrow in the left image.

Right elevator trim tab inboard hinge.

The inboard trim tab hinge portion identified in Figure 43 was excised by cutting along the red dashed lines and is illustrated in the left image in Figure 52 with the trim tab, trim tab hinge, bolt and elevator hinge identified. The yellow arrow indicates the head of the hinge screw attaching the trim tab to the trim tab hinge, about which the portion of the trim tab could be moved easily. It was noted that a 0.014-inch feeler gauge could now be inserted between the trim tab hinge and a lug of the elevator hinge.

The trim tab skin obscuring the end of the screw was removed in order to measure the protrusion of the screw, which was found to be 0.110-inch, and to access the mating surface of the trim tab with the trim tab hinge. The screw was removed and found to rotate easily when turned with a screwdriver. With the trim tab portion separated from the hinge the screw was re-inserted into the locknut and found to screw in and out easily by hand and without the use of a screwdriver.

Paint on the screw head was removed to reveal a single depressed “X” on the head and three small round indentations between cross recessions. The length of the screw under the head was measured at 0.924-inch and a gold coloration, consistent with chromated cadmium plating, was observed on the end of the screw. The end of the screw was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 31 HRC.

Examination of the hinge hardware revealed that it consisted of a bolt, a nut, a cotter pin and a washer that fit on the sleeve, as illustrated in the IPC. A second washer was found installed under the head of the bolt. Manipulation of the bolt revealed that it could be rotated easily with a screwdriver. The bolt was removed and an examination revealed a gold coloration on the end, consistent with chromated cadmium plating. The head displayed yellow and grey paint, a raised single “X” and the raised letters “RSP”. The length of the bolt under the head was measured at 1.09 inches and displayed a 1/32-inch wide groove between the thread and the plain shank. The end of the bolt was ground flat, cleaned and subjected to XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 26 HRC.

Examination of the mating surfaces of the trim tab and trim tab hinge revealed exposed bare metal predominantly located in the corners of the trim tab. The mating surface of the trim tab hinge was bare metal. The mating surfaces are illustrated and identified in the right image Figure 52 with the trim tab, the trim tab hinge and the locknut insert identified. The blue arrows indicate the bare metal areas in the left corners of the trim tab and the purple arrow indicates exposed primer between the bare metal areas. The white arrows indicate the bare metal areas in the right corners of the trim tab and the black arrow indicates a band of bare metal between them. The yellow arrow indicates a circumferentially oriented band of bare metal adjacent to the screw hole.

Although the screw could be screwed in and out easily an examination of the locknut revealed worn threads where the screw would first engage in the nut. A view of the first threads in the locknut is illustrated in Figure 53 with red arrows indicating areas where the threads had been worn away and blue arrows indicating rounded grooves on thread crests, consistent with the threads being previously cross threaded.

Right elevator trim tab control assembly.

The right elevator trim tab was not adjustable by the pilot and was fixed fair with the elevator. The actuator mechanism, some of which is illustrated in Figure 1 had been removed and the rod assembly illustrated and identified in Figure 20 had been replaced. The replacement rod fit in the existing guide and was bolted in place using an existing hole in the guide. The rear end of the fixed rod had been threaded and a rod end, suitable for the clevis end of the existing link assembly, installed. The fixed rod and the portion of the rear spar of the horizontal stabilizer identified in Figure 43 are illustrated and identified in Figure 54 with the forward and inboard directions indicated. The green arrows indicate distinct machining marks on the fixed rod consistent with it being turned and cut with a single point tool. Examination of the rod revealed that it had a wall thickness of 0.160-inch and XRF analysis of the rod identified it as alloy steel designated 4130 which, depending on the tempering temperature, can have hardness between 24HRC and 48 HRC.

Examination of the fixed rod and rear spar portion revealed forward deformation of the spar and the attachment of the guide to the horizontal stabilizer rear spar is illustrated in the left and right images in Figure 55. The left image is a view looking forward with the rear spar, guide and rod identified and purple arrows indicating inward deformation of the spar flanges. The blue arrow indicates the bolt attaching the rod to the guide and the yellow arrow indicates a threaded hole that was originally occupied by a grease fitting for lubrication of the actuator mechanism. A side view looking inboard is illustrated in the right image in Figure 55 with a blue arrow indicating the nut on the end of the bolt similarly indicated in the left image. The purple arrows indicate forward deformation of the spar web which was greatest adjacent to the hole for the rod.

The trim tab link identified in Figure 45 was mated to the link clevis identified in Figure 54 and is illustrated in Figure 56 with the forward direction indicated and the mated fracture faces indicated by the green arrow. The link and the rod end identified in the right image in Figure 51 and the clevis are identified. Although the link was bent, measurements and an examination revealed that it was similar to the link in the left elevator and illustrated in Figure 20. As in Figure 20, the blue arrows in Figure 56 indicate the welds joining the fittings to the tube. The yellow arrow indicates the rod end lock nut which was found to be loose.

A side view of the fractured rear end of the link indicated by the green arrow in Figure 56 is illustrated in the left image in Figure 57 with the fracture face indicated by the yellow arrow and the adjacent weld indicated by the blue arrow. The purple line is parallel to the link to illustrate the bending indicated by the purple arrow. The red arrow indicates the reduction of thread pitch indicative of that location being the compressive side of the bend. The blue dashed line indicates the internal construction as in the left image in Figure 21. The fracture face indicated by the yellow arrow in the left image in Figure 57 is illustrated in the right image with the fracture face similarly indicated and black arrows indicating the two fractured threads similarly indicated in the left image. Examination of the fracture face revealed a cupped profile with a rough grainy surface consistent with an overload event. The fracture face was excised by cutting the link at the forward yellow dashed line in Figure 56 and solvent cleaned for an SEM examination that revealed the ductile dimples, typical of an overload, that are illustrated in Figure 58.

To confirm that the construction of the link assembly satisfied the requirements of drawing 99-52526 the link was cut at the rear yellow dashed line in Figure 56 to remove a sample containing the weld indicated by the blue arrow. The sample was then cut longitudinally, as indicated by the red dashed line in Figure 56, and one half was metallurgically encapsulated, polished and etched[16] for detailed examination. The etched surfaces are illustrated in the left image in Figure 59 with the installed forward direction of the link indicated. The weld, the tube portion, and the fitting portion are identified and yellow arrows indicate the outer surface of the weld indicated by the blue arrow in Figure 57. A closer view of the weld in the red box is illustrated in the right image in Figure 59 with the outer surface of the weld indicated by the yellow arrow. The red line is a continuation of the outer surface of the tube and illustrates an offset between the tube and the fitting indicated by the red arrows. The black arrows indicate a plated outer surface, consistent with the chromium plating requirement in drawing 99-52526. On drawing 99-52526 an arrow indicates a weld and an attached note states “resistance weld & trim off smooth 2 places”.

The etchant revealed the three different microstructures illustrated in Figure 60 at similar magnifications and identified as “T” for the tube, “W” for the weld and “F” for the fitting. Microstructure “T” displayed a fine ferrite grain structure (the light area) with pearlite colonies at the grain boundaries and small globular carbide inclusions, typical of low carbon steel. Microstructure “W” displayed an acicular (needle like) structure typical of low carbon martensite normally produced by a welding operation. Microstructure “F” displayed pearlitic carbon colonies (the dark areas) in a ferrite matrix, typical of a low carbon steel. Microhardness testing was also performed in “T”, “W” and “F” at HK500[17] scale. Three tests in “T” resulted in an average hardness of 187 HK,

[16] Etchant was 2% Nital, a 2% solution of nitric acid in ethanol.
[17] Hardness, Knoop with a 500 gram load.

which converts[18] to a tensile strength of 84 ksi. Three tests in “W” resulted in an average hardness of 504 HK, which converts to a tensile strength of 229 ksi. Three tests in “F” resulted in an average hardness of 220 HK, which converts to a tensile strength of 98 ksi.

Chrome plating on the other half of the sample was mechanically removed sufficient for XRF analysis. The sample was cleaned and the XRF analysis of the tube portion identified it as carbon steel. The review of drawing 99-52526 revealed that the tube material was specified as 1025, which is a low carbon steel, but it did not specify the fitting material.

The bulge contained in the purple square in Figure 43 is illustrated in the left image in Figure 61 and indicated by the yellow arrow. The red arrow indicates a circular crack in the painted surface consistent with a flat headed rivet being located under the paint. As in the left elevator, the trim tab control originally passed through a hole in the elevator front spar and a view of that hole, looking aft, is illustrated in the right image in Figure 61 with the front spar, and the upper skin illustrated in the left image, identified. As in the left image, the yellow arrow indicates the bulge and the red arrow indicates the inner reaction head of the rivet. The white arrows indicate the original contours of the hole and the green arrow indicates a fracture. The blue arrow indicates a clean smeared area of spar material that had been deformed rearwards. The orange arrow indicates a clean smeared surface that did not appear to have changed the contour of the hole significantly.

The hole illustrated in the right image in Figure 61 is illustrated in Figure 62 looking forward with the front spar and adjacent ribs identified and the blue dashed line indicating the cutting lines similarly indicated in Figures 43 and 45. The white arrows indicate the original contours of the hole and the blue arrow indicates spar material that had been deformed rearwards. The orange arrow indicates the deformed and smeared area similarly indicated in the right image in Figure 61. The black arrow indicates an area where the surface had been disturbed to reveal the underlying bare metal of the front spar.

Left aileron trim tab.

The upper surface of the left aileron trim tab received for examination is illustrated in Figure 63 with its hinges and the forward and inboard directions, as installed, indicated. The outboard hinge was supplied separated from the trim tab, as illustrated, and the inboard hinge was supplied with a portion of the aileron hinge still attached and a bent control rod still connected to the horn. A view of the trim tab leading edge is illustrated in Figure 64 with yellow arrows indicating where mechanical damage had closed the gap normally in the leading edge. The inboard aileron hinge, the control rod and the horn are illustrated and identified. A review of the IPC revealed that the hinge bolts were specified as AN23-17, similar to the bolts in the elevator trim

[18] ASTM E-140. Standard hardness conversion tables for metals.

tab hinge. The hinge screws were specified as NAS221-10 for the center and outboard hinges and NAS221-12 for the inboard hinge. The review also revealed that the locknut insert is not specified with the fitting and the bearing.

Left aileron trim tab outboard hinge.

The left aileron outboard hinge identified in Figure 63 is illustrated in Figure 65 with the inboard and forward directions, as installed, indicated. The trim tab fitting, the trim tab hinge and the tip of the screw joining the two together are identified. Measurements revealed that the screw protruded 0.109-inch above the locknut insert. The trim tab hinge was found to rotate about the screw, limited by its contact with the trim tab fitting at the locations indicated by the white and yellow arrows in Figure 65. Examination of the screw revealed that the head had a diameter of 0.436-inch, larger than the 0.361–0.385-inch requirement for the screws specified in the IPC, and displayed the identifications “MAC” and “X”. The screw was extracted easily by hand using a screwdriver to reveal a gold colored surface, consistent with chromated cadmium plating. With the trim tab hinge separated from the fitting the screw was found to rotate easily in and out of the locknut insert by hand. The end of the screw was ground flat and cleaned for XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 28 HRC.

After removal of the trim tab hinge an examination of the trim tab fitting revealed that the forward lug, to which the trim tab hinge is normally attached, had been twisted approximately 5-degrees counterclockwise when looking aft. The inboard lug indicated by the blue arrow in Figure 65 had been bent forward.

The bolt in the trim tab hinge was found to be bent as illustrated in Figure 65 and still retained portions of the lugs from the aileron hinge. The head displayed a raised double “X” and displayed a gold colored surface, consistent with chromated cadmium plating. The larger portion of lug retained on the inboard side of the hinge displayed an interrupted rough grainy surface with a slight lip on its outboard edge, consistent with being overloaded in an inboard direction. Hardware in the hinge consisted of the bolt, nut, cotter pin, washer, sleeve and a needle roller bearing.

Examination of the mating surfaces of the trim tab and trim tab hinge revealed areas where paint had been removed. The mating surfaces are illustrated and identified in the left image in Figure 66 with the locknut insert also identified. The blue arrow on the trim tab indicates an area where the base metal had been exposed and the blue arrow on the trim tab hinge indicates deformation in the area that would have contacted the trim tab at the location indicated by the yellow arrow in Figure 65. The black arrows indicate the grey paint remaining on the trim tab hinge.

The head of the locknut insert is illustrated in the right image in Figure 66 with a purple arrow indicating the intact metal threads and a red arrow indicating fully formed threads in the red insert. The blue arrows indicated long arced stakes in the trim tab hinge for comparison with the shorter arced stakes illustrated later in Figure 68.

Left aileron trim tab center hinge.

The left aileron center hinge identified in Figure 63 was excised by cutting along the red dashed lines and is illustrated in Figure 67 with the forward and inboard directions indicated. The trim tab, the trim tab hinge, the hinge bolt, the end of the hinge screw and a portion of the aileron hinge are identified. Examination of the hardware in the hinge consisted of the bolt, nut, cotter pin, washer, sleeve and a needle roller bearing. Attempts were made to move the trim tab hinge about the screw attaching it to the trim tab but it was found to be firmly locked in the position illustrated.

Examination of the screw revealed head markings similar to those on the outboard hinge screw, namely “MAC” and “X”. The two thicknesses of material above the end of the screw were deformed upwards. The material above the end of the screw was removed by cutting on the yellow dashed line in Figure 67 and the end of the screw was found to protrude 0.077-inch above the head of the insert. An initial resistance to extraction was felt when extracting the screw using a screwdriver but it became easy when the end of the screw cleared the red insert. The extracted screw displayed a gold colored surface, consistent with chromated cadmium plating, and the head diameter was measured at 0.433-inch. The end of the screw was ground flat and cleaned for XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 26 HRC.

The hinge bolt was removed to separate the trim tab from the trim tab hinge and an examination of the bolt revealed areas displaying a gold colored surface, consistent with cadmium plating, and “OIDO” and “X” stamped on the head. The bolt length was measured at 1.09 inches. The end of the bolt was ground flat and cleaned for XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 27 HRC.

Examination of the mating surfaces of the trim tab and trim tab hinge revealed areas where paint had been removed. The mating surfaces are illustrated and identified in the left image in Figure 68 with the locknut insert also identified. The yellow arrows indicate surface marks that described an arc. The blue line connects the straight edges of two smeared surface marks consistent with them being produced by the edge on the trim tab hinge indicated by the blue arrow, consistent with the trim tab hinge being locked inboard as illustrated in Figure 67. The mating surface of the trim tab hinge was almost devoid of paint and primer.

The head of the locknut is illustrated in the right image in Figure 68 with a purple arrow indicating the intact metal threads and a red arrow indicating fully formed threads in the red insert. The blue arrows indicated short arced stakes retaining the insert and the yellow arrows indicate two short stakes that had been applied closer to the edge. The white arrow indicates yellow paint.

Left aileron trim tab inboard hinge.

The left aileron inboard hinge identified in Figure 63 is illustrated in the left image in Figure 69 with the trim tab hinge, bolt and aileron hinge identified. A closer view, looking aft, is illustrated in the right image with the aileron hinge, bolt, trim tab hinge horn, horn bolt and the rod end of the control rod identified. The image also illustrates the permanent outboard deflection that had been applied to the horn and the fractures at the outboard end rivets of the aileron hinge indicated by the yellow arrows.

Manipulation of the hinge revealed that the trim tab hinge was loose and could be rotated about the screw. The hinge was excised from the trim tab by cutting along the red dashed line in the left image in Figure 69 and the bolt was extracted for examination. The range of movement of the trim tab hinge was limited by its installation in the trim tab and is illustrated in the images in Figure 70. In the left image the hinge was moved inboard until it stopped and in the right image the hinge was moved outboard until it stopped. In both images in Figure 70, the trim tab hinge, the trim tab and the end of the screw that connect them are identified.

Trim tab skin above the end of the screw was removed by cutting along the yellow dashed line in Figure 70 and the protrusion of the screw above the locknut insert was measured at 0.09-inch. Extraction of the screw with a screwdriver was initially easy but resistance was felt when the screw was approximately half way out. Examination of the screw revealed that the threaded portion had been deformed. The screw is illustrated in Figure 71 with a steel rule parallel to the shank and a red arrow indicating the location of maximum deformation. The examination also revealed a single "X" stamped on the head and a gold colored surface was observed only on the end, consistent with chromated cadmium plating. The diameter of the head and the length of the screw satisfied the requirement in MS27039. The end of the screw was ground flat and cleaned for XRF analysis which displayed a composition satisfying the material requirement in MS27039. The hardness of the screw was measured at 28 HRC.

Examination of the bent control rod identified in Figure 63 revealed a construction similar to the trim tab link assemblies illustrated earlier in Figures 20 and 56 with the exception that the forward fitting consisted of a solid rod end and not a threaded fitting. The solid rod end contained a bush that displayed deformation at its inboard end. The inboard side of the rod end is illustrated in the right image in Figure 71 with a red arrow indicating thinning of the bush. The yellow arrow indicates a lip of bushing material that had been deformed outward and the yellow dashed line contains a smoother surface in the bore of the bush, consistent with being impacted by the original attaching hardware.

Examination of the mating surfaces of the trim tab and trim tab hinge revealed a distinct circular imprint and mechanical damage. The mating surfaces are illustrated and identified in the left image in Figure 72 with the locknut insert also identified. The blue arrows on the trim tab hinge indicate the edges of a circle containing primer while the area outside of the circle displayed bare metal. The purple dashed circle on the trim tab encompasses an area that was mostly devoid of the deposit observed outside the circle and the yellow arrow indicates material displacement in the direction indicated by the arrow.

The head of the locknut insert is illustrated in the right image in Figure 72 with a purple arrow indicating the intact metal threads and a red arrow indicating fully formed threads in the red nylon insert. The blue arrows indicated arced stakes retaining the insert that were longer and wider than the stakes illustrated in Figure 68.

Examination of the hinge bolt previously extracted revealed a raised double "X" on the head. Gold colored areas, consistent with chromated cadmium plating, were observed and the length was measured at 1.09 inches. The end of the bolt was ground flat and cleaned for XRF analysis which displayed a composition satisfying the material requirement in AN23. The hardness of the bolt was measured at 27 HRC.

Locknut examination.

The IPC describes the locknut in the elevator trim tab hinges and in the aileron trim tab hinges as "Nut-Spline (ELASTIC)", part number "22D8-02". The vendors list in the front of the IPC indicates that "ELASTIC" was the Elastic Stop Nut Corporation. It was reported that the original locknuts were manufactured by ESNA®[19] and had a fiber insert which was later replaced by nylon. A MACLEAN-ESNA®[20] drawing of their ND style locknut was acquired and on page 1 it displayed an issue date of January 25, 1951, and referenced MS51866, document 4 in section C. An encircled 12 (a drawing revision number) dated November 3, 2003 was adjacent to the issue date. On page 2 an encircled 12 was adjacent to "locking insert: red nylon (350º max performance)". The drawing contained a nut, part number 22ND8-02, consistent with nylon (N) replacing the insert in the original nut, part number 22D8-02. MS51866 had an approved date of June 22, 1970, displayed a temperature of 250ºF in the title and specified that the "configuration of locking feature (all metal or non-metallic insert) optional". Note 1 specified that a "non-metallic insert shall be nylon or equivalent".

An unused locknut with a fiber insert, part number 22D8-02, and an unused locknut with a nylon insert, part number 22ND8-02, were acquired for comparison with the inserts in the elevator and aileron trim tab hinge locknuts. An examination of the threads that had been formed in the inserts revealed that most of the flanks displayed a relatively smooth and partially polished surface. The insert in the locknut of the left elevator trim tab hinge is illustrated in the left image in Figure 73 for comparison with the unused fiber insert illustrated in the left image in Figure 74 and the unused nylon insert illustrated in the left image in Figure 75. Samples were removed from all three inserts and each subjected to FTIR[21] analysis. Visual comparison of the resultant FTIR spectra

[19] Elastic Stop Nut Corporation of America of Pocahontas, AR, founded in the late 1930's.
[20] Created when ESNA® became a part of MacLean-Fogg® in 1995.
[21] A Fourier Transform Infra-Red (FTIR) spectrometer collects and processes infrared wavelength absorbance/transmission of a sample.

found that all three spectra were identical, indicating that the insert materials were similar.

Removal of the samples for FTIR analysis had exposed the inside of the inserts which are illustrated in the right images in Figures 73, 74 and 75. The right image in Figure 73 illustrates the inside of the insert in the area within the red box in the left image with a red arrow indicating a thread in the metal portion of the nut. The blue arrows indicate the remaining threads in the insert which now displayed a fibrous texture. The yellow arrows indicate indentations in the crest of an insert thread and in the crest of the adjacent metal thread consistent with the screw being cross-threaded.

A closer view of the inside of the fiber insert in locknut part number 22D8-02 is illustrated in the right image in Figure 74 with a blue arrow indicating the fibrous texture exposed by the sample removal which was similar to the fibrous texture illustrated in the right image in Figure 73.

A closer view of the inside of the nylon insert in locknut part number 22ND8-02 is illustrated in the right image in Figure 75 with a blue arrow indicating the smooth surface exposed by the sample removal.

The locknut examination also revealed more of the yellow paint noted during the previous examinations. The purple arrow in the left image in Figure 73 indicates yellow paint below the grey paint indicated by the black arrow. Research revealed that the aircraft had been painted yellow when it flew at the 1985 National Champion Air Races.

Tailwheel retract lock.

The tailwheel retract lock assembly supplied for examination is illustrated in Figure 76 with the bellcrank, the shaft and the hook assembly identified. The shaft is normally straight and supported in bearings at each end, at the locations indicated by the yellow and green arrows. The shaft is mounted laterally in the tail of the aircraft with the bellcrank bearing mounted on the left longeron (the left direction is indicated in Figure 76). The retract lock assembly retains the tailwheel in the up position when retracted and is operated by a cable normally connected to an arm on the bellcrank and to the landing gear control handle in the cockpit.

Examination of the bellcrank revealed that the arm was missing. The bellcrank is illustrated in the left image in Figure 77 with the left direction indicated and the damaged part number “73-34515” displayed. The yellow arrow indicates the bearing surface, the red arrow indicates a fracture where the arm was originally located and the white arrow indicated mechanical damage adjacent to the fracture face. The fracture face on the arm is illustrated in the right image in Figure 77 with the left direction indicated. The fracture face displayed a rough grainy surface, consistent with an overload event, and the blue arrow indicates mechanical damage to the fracture face coupled with a significant deflection to the left, consistent with the arm being subjected to a sideways impact after the fracture. The white arrow indicates the lower end of the mechanical damage similarly indicated in the left image which extended onto the fracture face, also consistent with it being produced after the fracture event. The red arrow indicates more mechanical damage to the fracture face and the purple arrow indicates mechanical damage to the hub of the bellcrank.

The hook of the lock assembly was cleaned to reveal the lock assembly part number "73-34527", the hook assembly part number "73-34510" and an inspection stamp located on the left side. The right side of the hook displayed the part number "73 34510 - - 3", an inspection stamp and an assembly stamp. The left side of the hook is illustrated in the left image in Figure 78 with the up and forward directions, as installed, indicated and a blue arrow indicating the inspection stamp. The lower contact surface indicated by the red arrow in the left image in Figure 78 is illustrated in the right image with the left direction indicated and a blue arrow indicating the inspection stamp. Examination of the contact surface revealed multiple contact marks adjacent to the left side that had exposed bare metal. The yellow arrow indicates material that had been displaced to the left and is also indicated by the yellow arrow in the left image. The green arrow indicates material that had been displaced to the right and down with the primer still intact.

Examination of the upper contact face indicated by the purple arrow in the left image in Figure 78 revealed multiple contact marks adjacent to the right side that had exposed bare metal. The contact face is illustrated in the left image in Figure 79 with the left direction indicated. The yellow arrow indicates material that had been displaced to the right and up. The examination also revealed contact marks on the forward corner of the upper surface indicated by the white arrows in the left image and in the left image in Figure 78. The corner is illustrated in the right image in Figure 79 with the left direction indicated. The red arrow indicates the exposed bare metal of the contact mark at the corner and the green arrow indicates a continuation of the mark up the left side as indicated by the green arrow in the left image in Figure 78.

Derek Nash
Mechanical Engineer

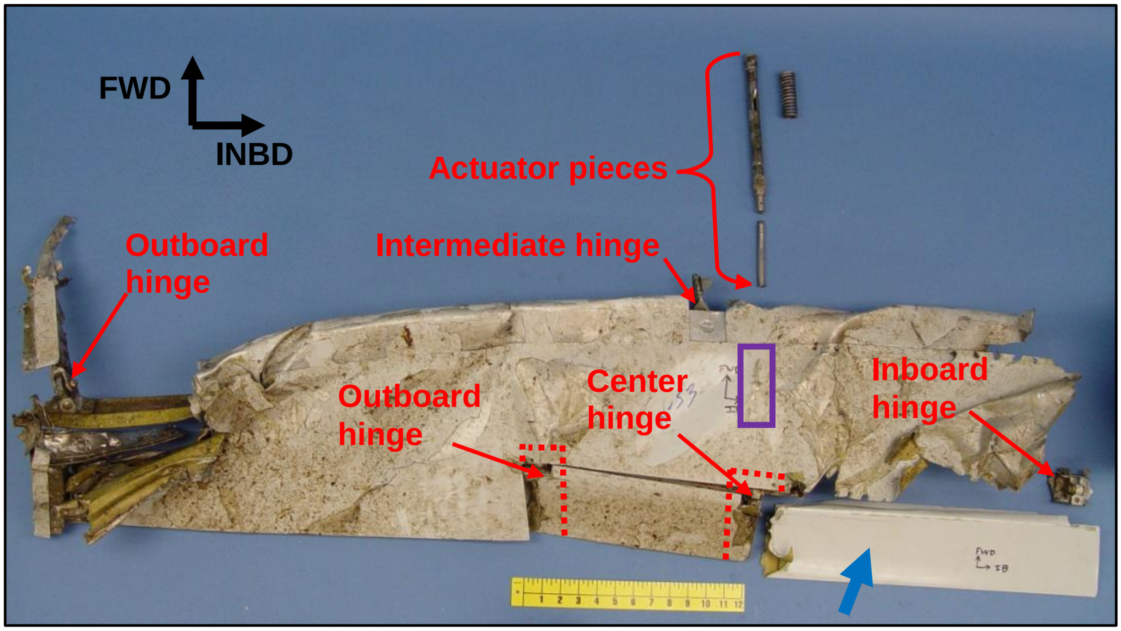


Figure 1. The left elevator, trim tab pieces and actuator pieces received for examination.

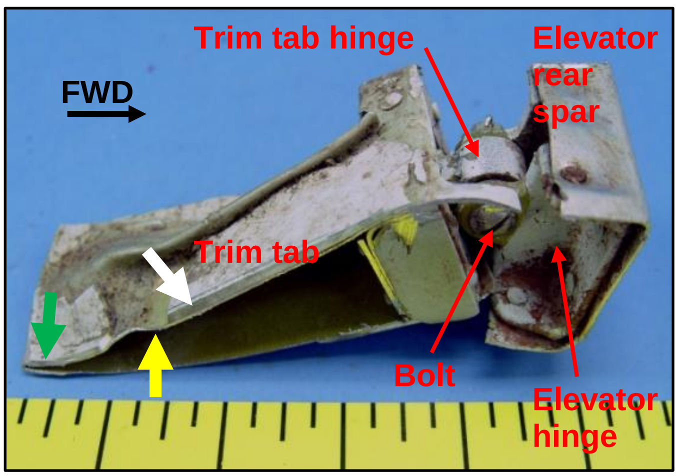


Figure 2. The outboard trim tab hinge excised from the left elevator.

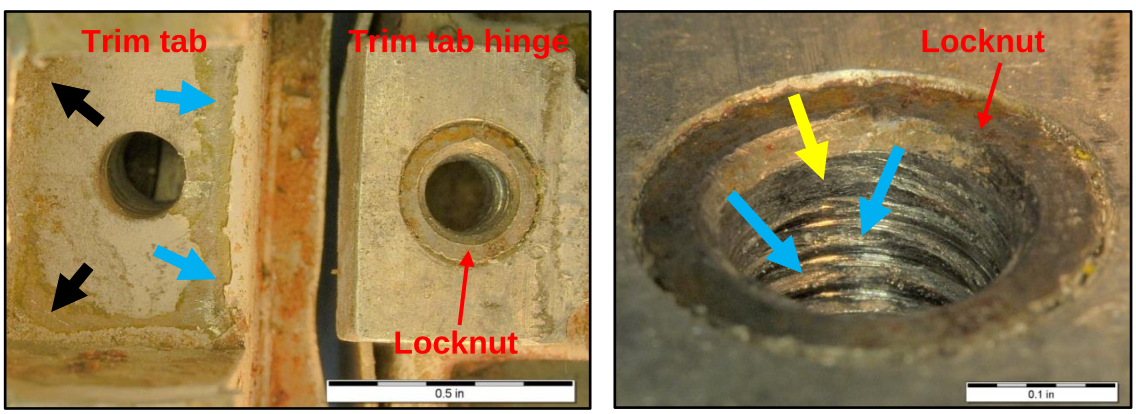


Figure 3. The mating surfaces of the outboard trim tab hinge with the trim tab (left) and the thread in the trim tab hinge locknut (right).

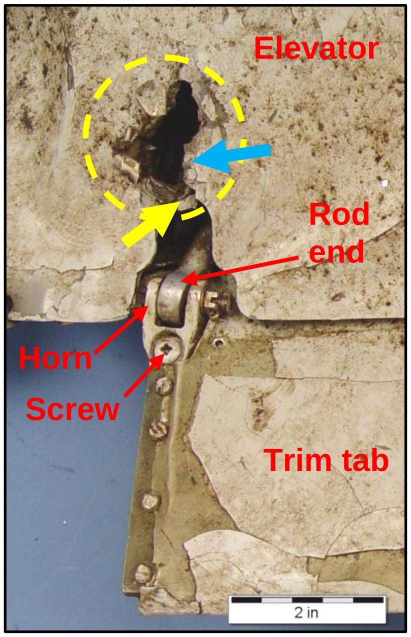
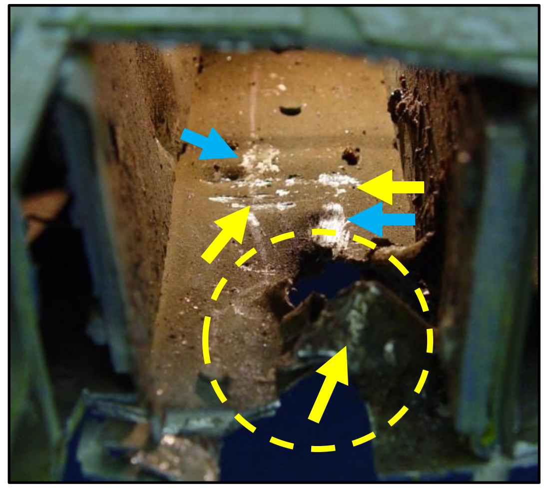


Figure 4. Damage to the lower skin forward of the center hinge (left) and to the adjacent inner surface (below).



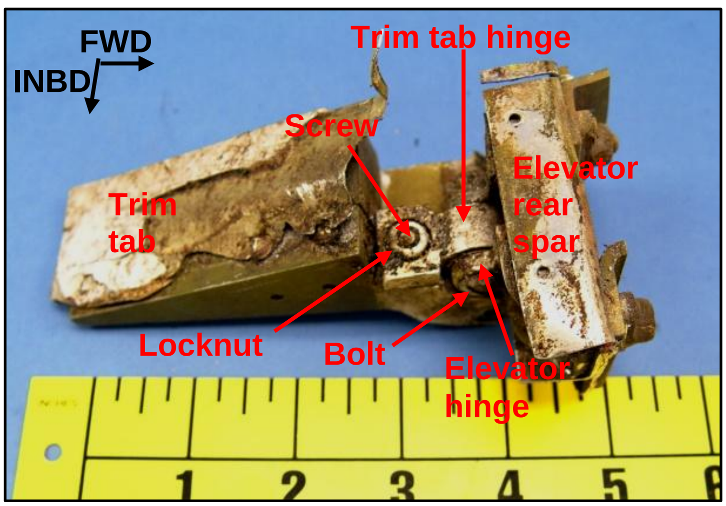


Figure 5. The upper side of the center trim tab hinge excised from the left elevator.

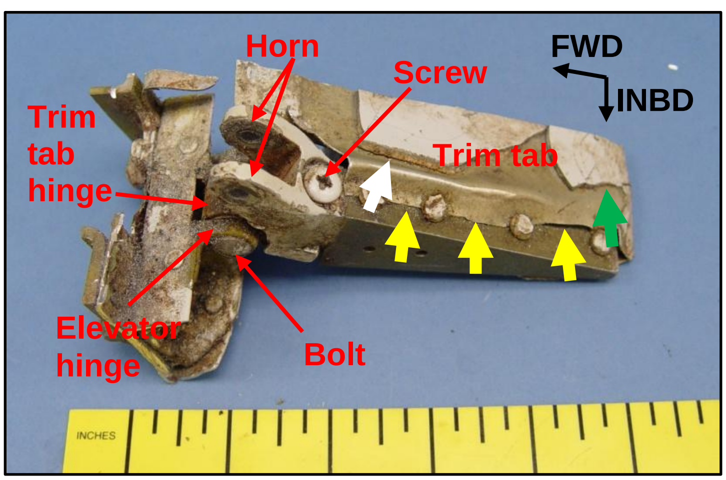


Figure 6. The lower side of the center trim tab hinge excised from the left elevator.

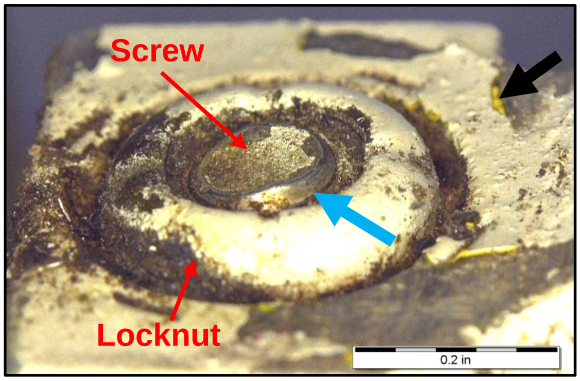
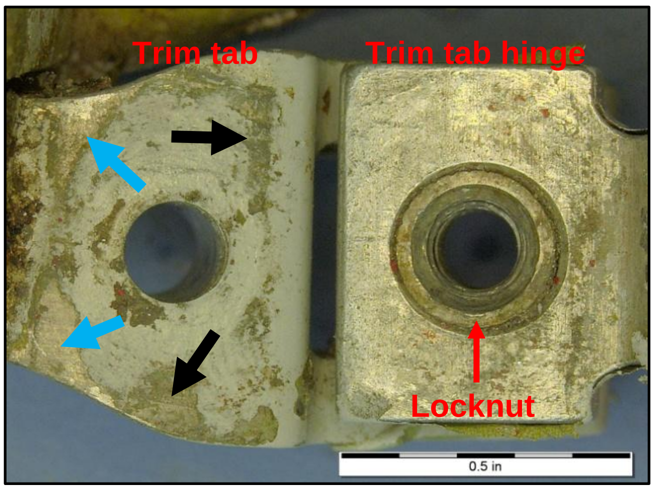


Figure 7. Protrusion of the center trim tab screw.



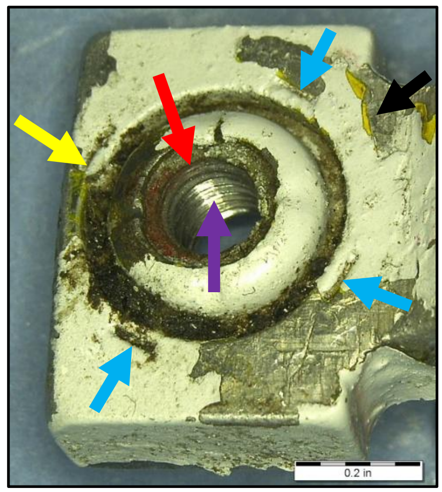
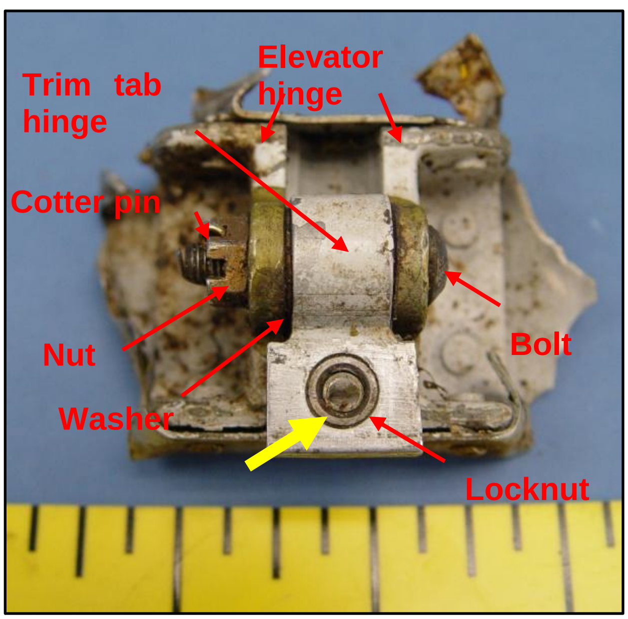


Figure 8. The mating surfaces of the center trim tab hinge and trim tab (left) and the head of the locknut (right).



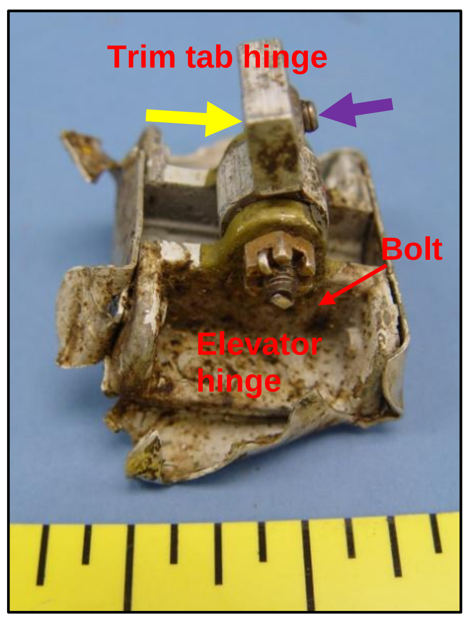


Figure 9. The inboard hinge identified in Figure 1 (left) and a side view (right).

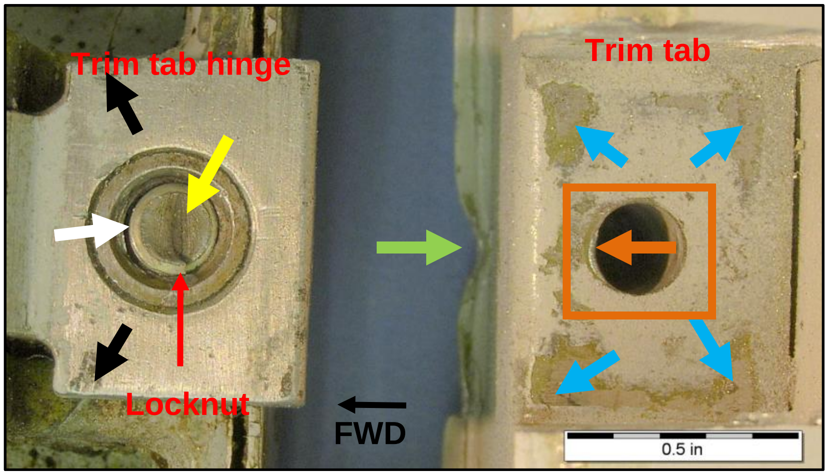


Figure 10. The mating surfaces of the inboard trim tab hinge and the trim tab.

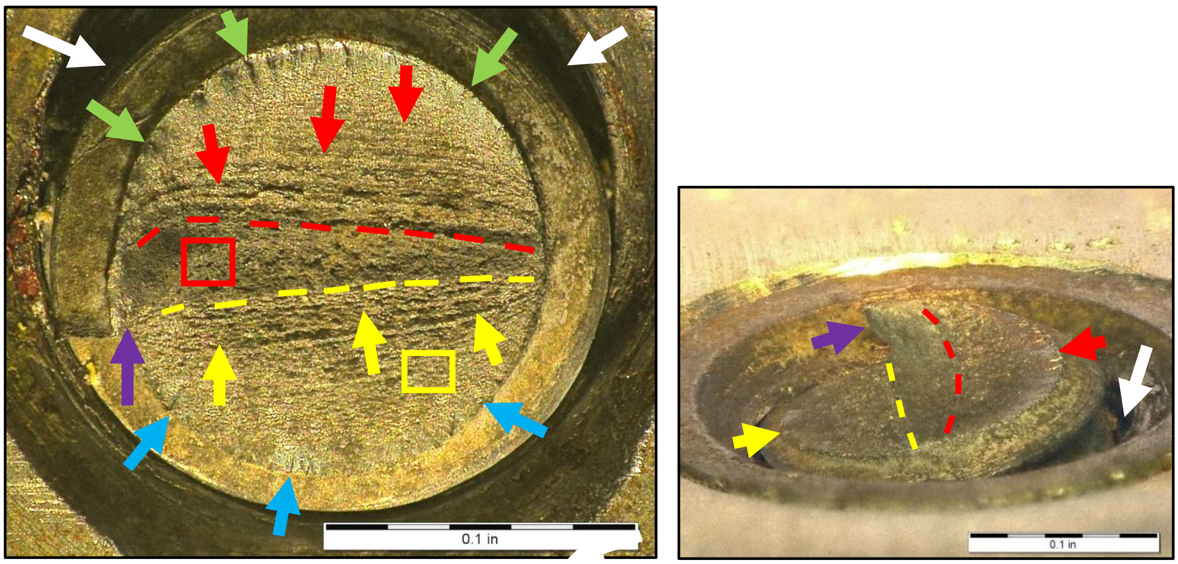


Figure 11. The fracture face on the left elevator inboard trim tab hinge screw indicated by the yellow arrow in Figure 10 (left) and a side view of the fracture face (right).

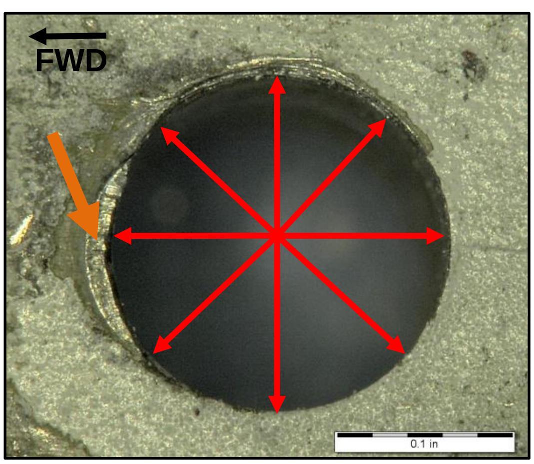


Figure 12. The inboard trim tab attachment hole located in the brown square in Figure 10.

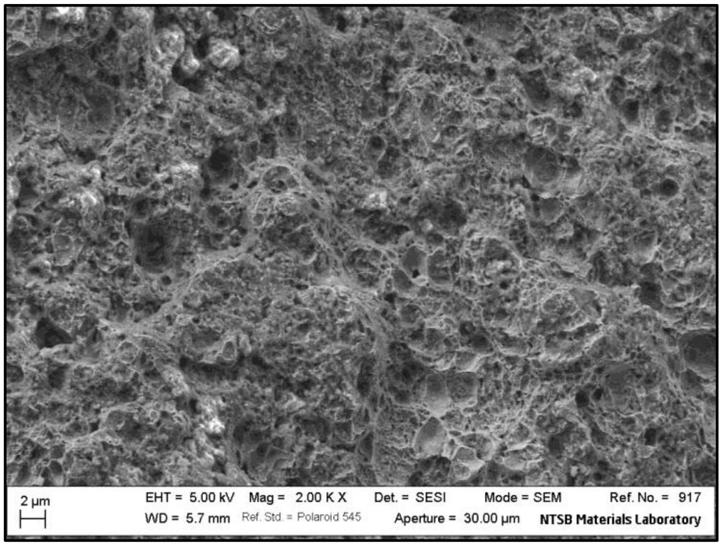


Figure 13. Typical fracture features located in the red box in Figure 11.

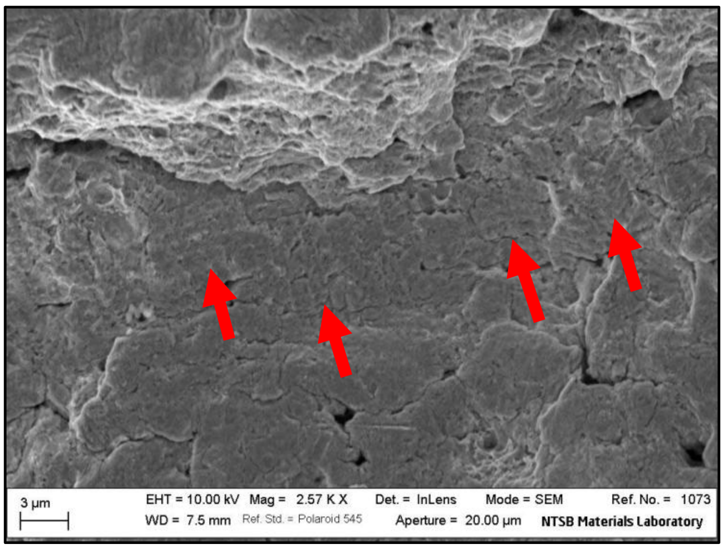


Figure 14. Fatigue striations located within the yellow box in Figure 11.

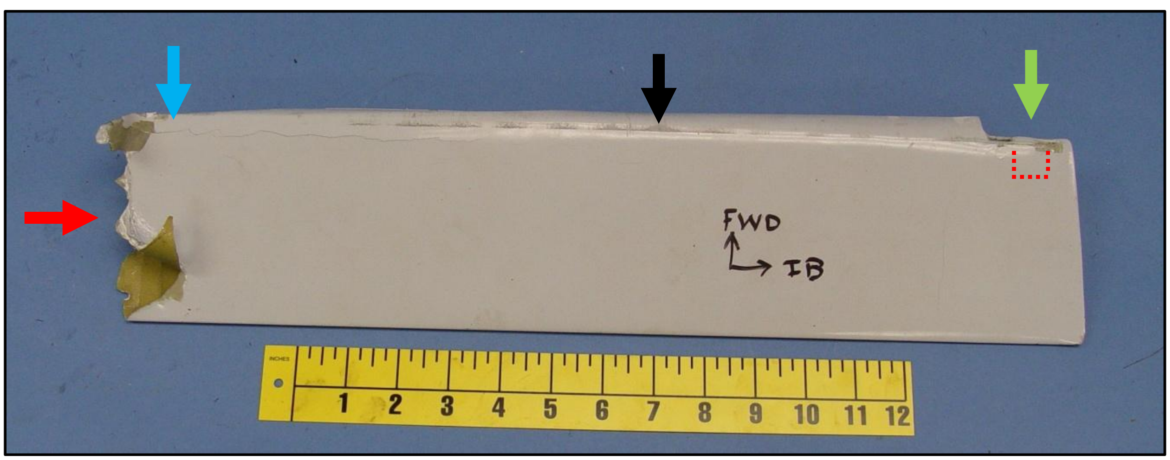


Figure 15. The upper surface of the inboard portion of the left elevator trim tab indicated by the blue arrow in Figure 1.

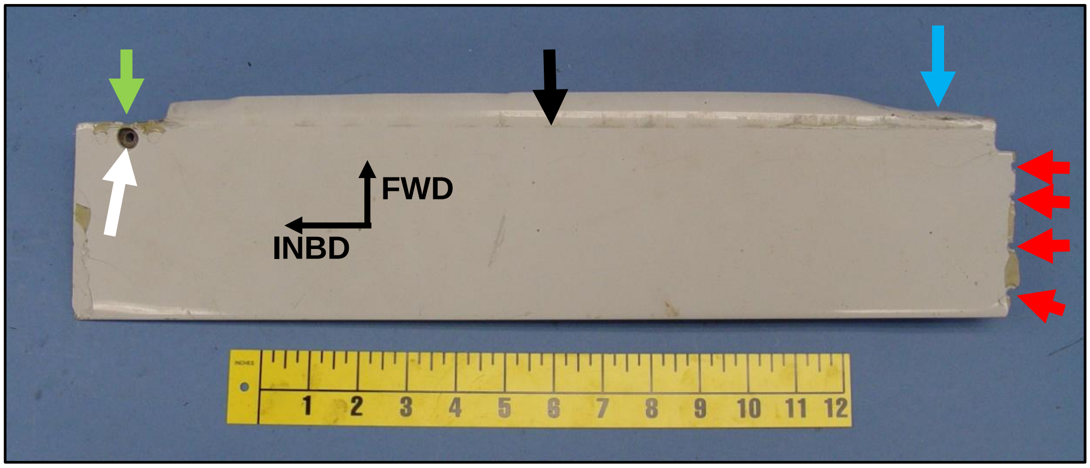


Figure 16. The lower surface of the inboard portion of the left elevator trim tab indicated by the blue arrow in Figure 1.

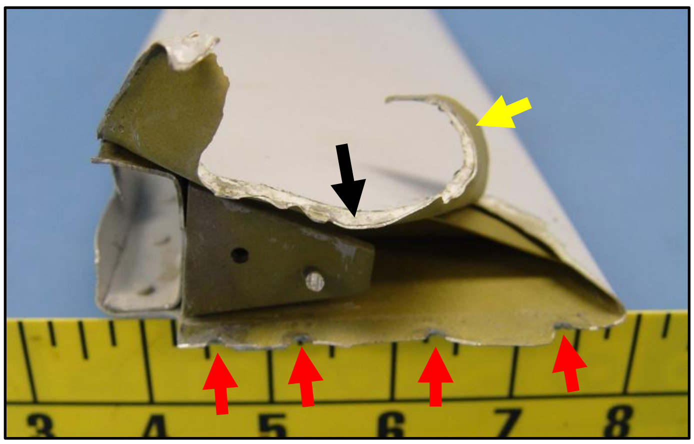


Figure 17. The outboard edge of the left elevator trim tab indicated by the red arrow in Figure 15.

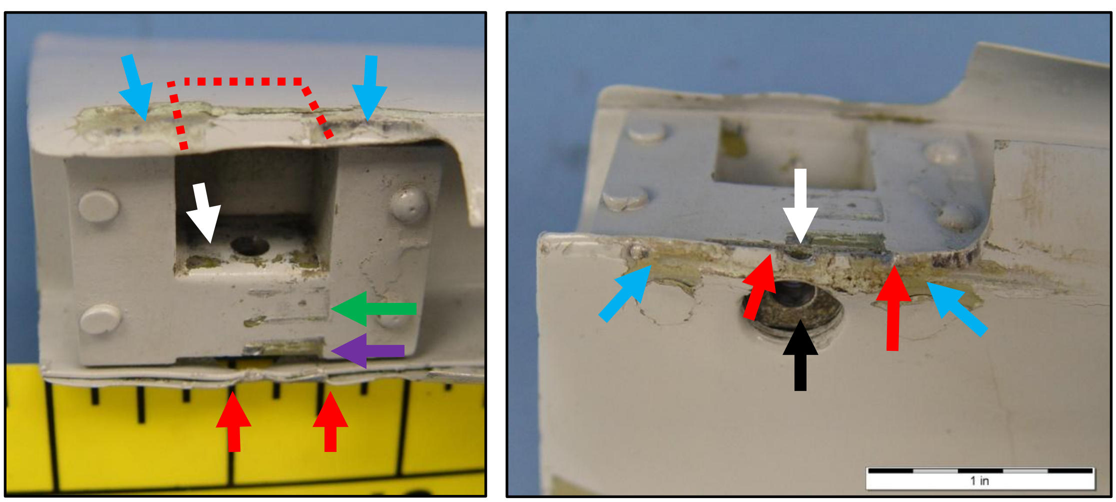


Figure 18. A rearward view of the inboard trim tab indicated by the green arrow in Figure 15 (left) and a view from below (right).

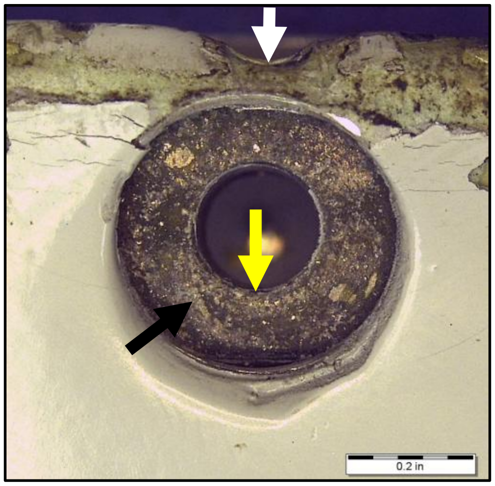


Figure 19. The original location for the head of the inboard trim tab screw.

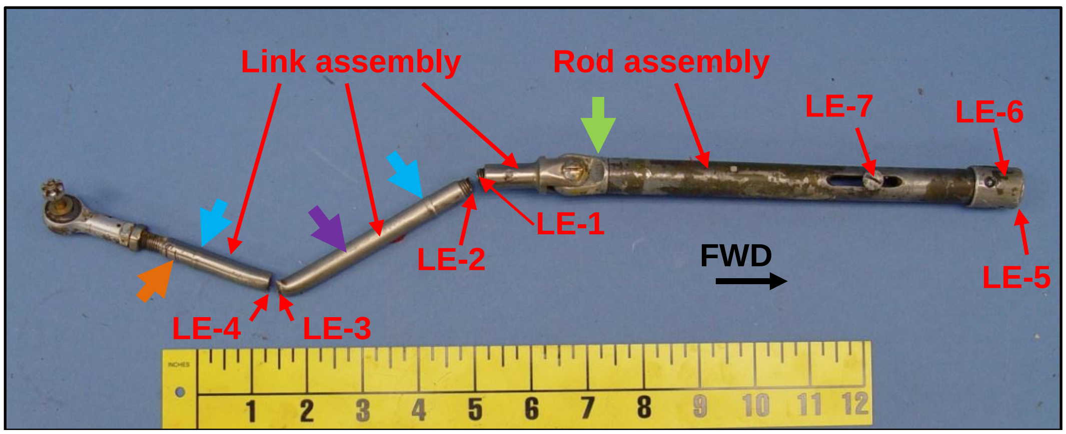
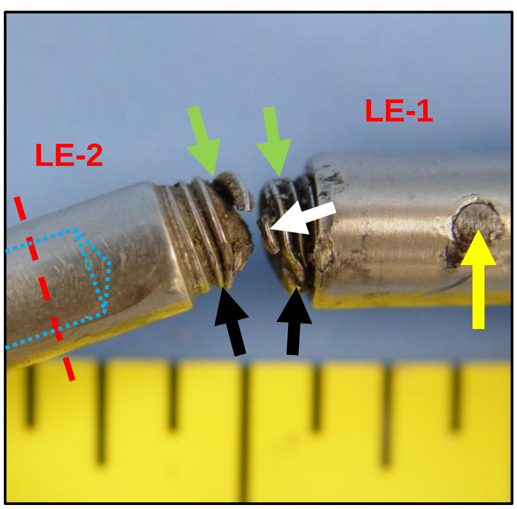


Figure 20. The left elevator trim tab actuator pieces identified in Figure 1 with the rod end and portion of the link assembly removed from the center hinge horn.



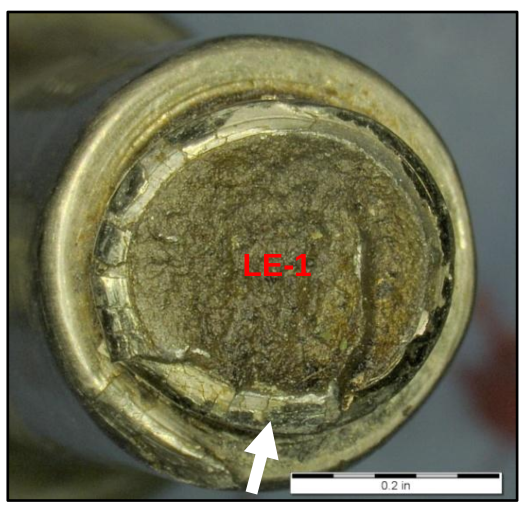


Figure 21. The link fractures identified as LE-1 and LE-2 in Figure 20 (left) and the fracture face on LE-1 (right).

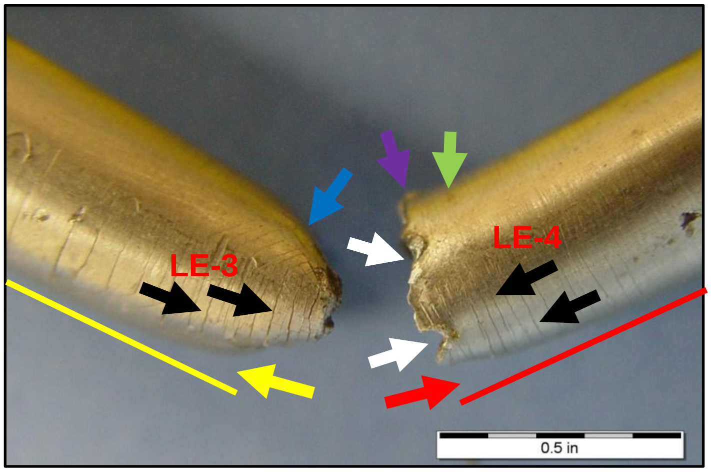


Figure 22. The link fractures identified as LE-3 and LE-4 in Figure 20.

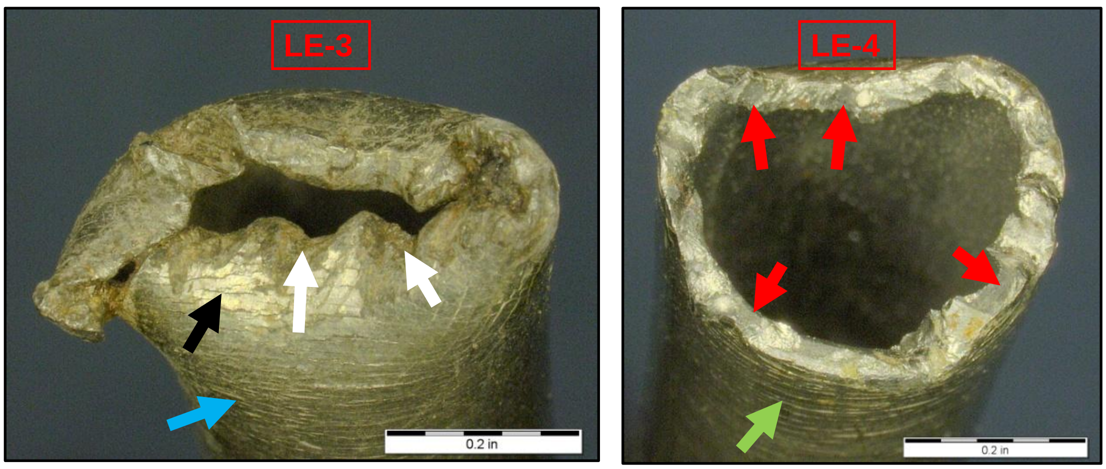


Figure 23. The fracture faces identified as LE-3 (left) and LE-4 (right) in Figure 22.

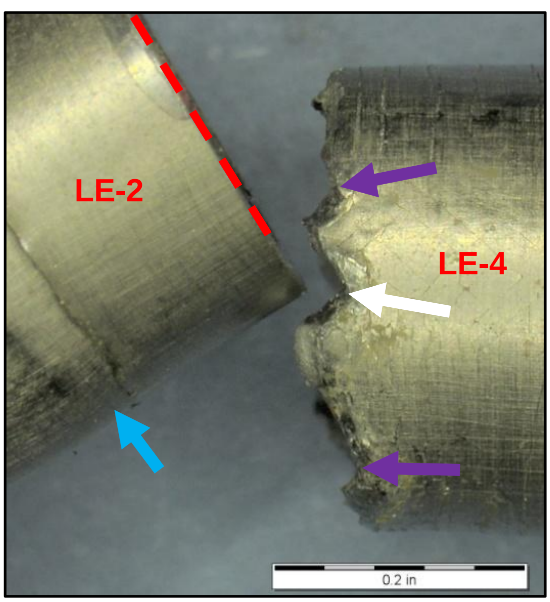


Figure 24. Fracture face LE-4 with the cut end of the link indicated by the red dashed line in Figure 21.

Figure 25. The left elevator actuator piece indicated by the purple arrow in Figure 20 positioned alongside the feature in the purple box in Figure 1.

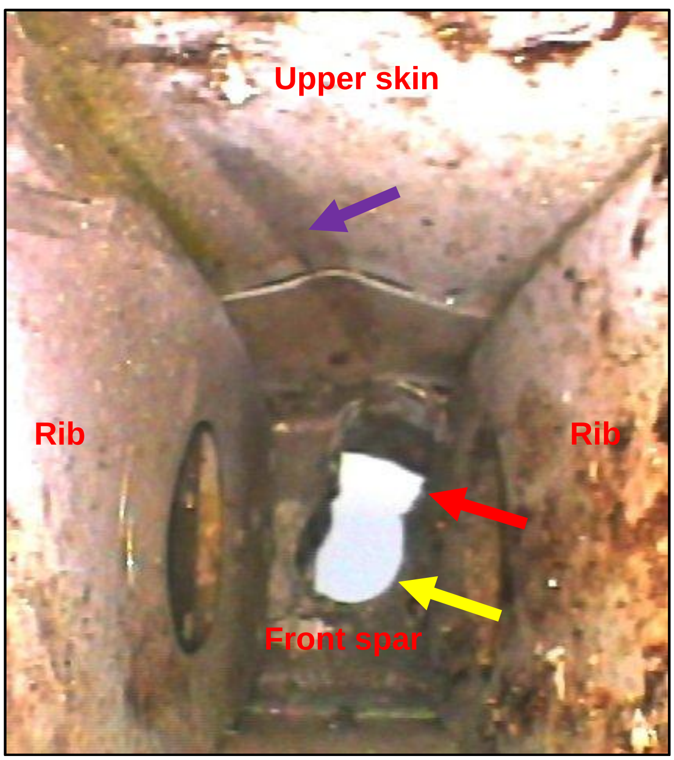


Figure 26. A view inside the actuator compartment of the left elevator, looking toward the front spar

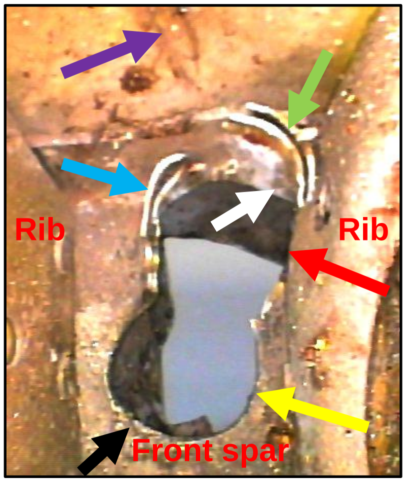
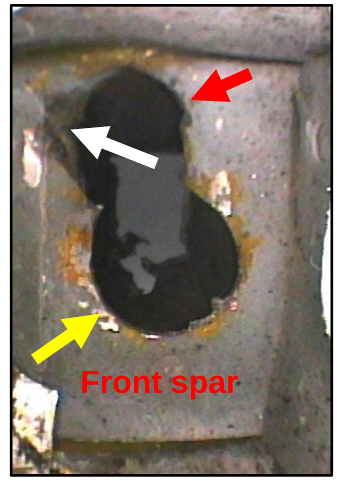


Figure 27. A closer view of the actuator hole in Figure 26 (left) and a view of the hole looking aft (right).



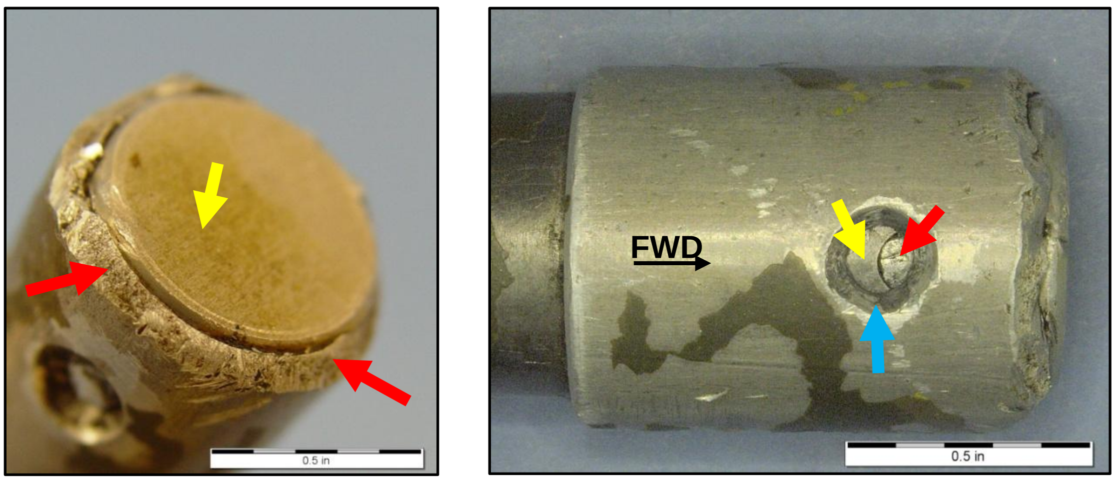


Figure 28. The fracture- at the forward end of the rod identified as LE-5 (left) and as LE-6 (right) in Figure 20.

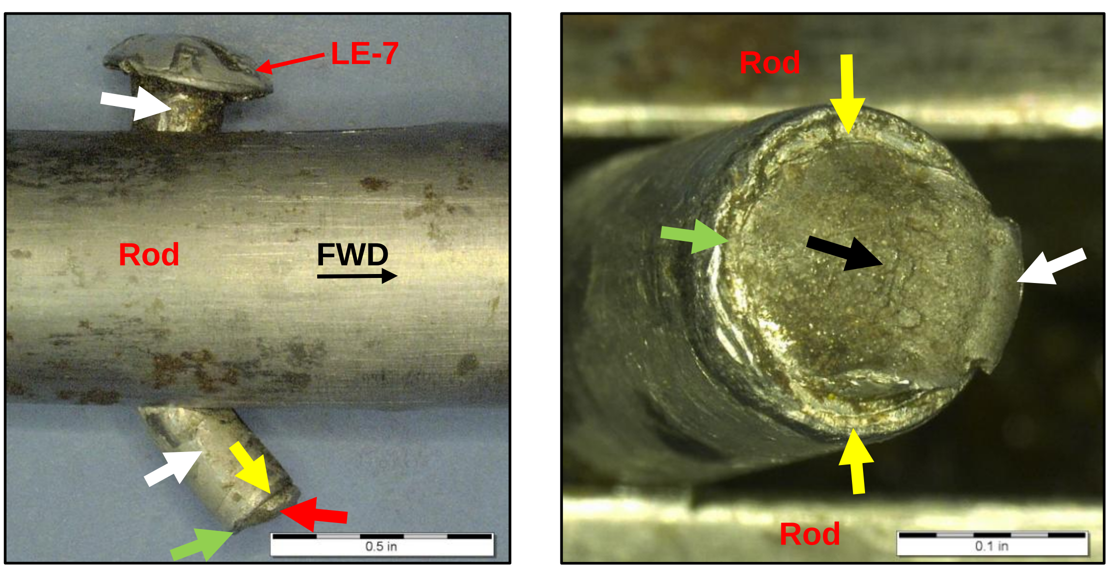


Figure 29. Side view of the bolt identified as LE-7 in Figure 20 (left) and a view of the fracture face indicated by the red arrow (right).

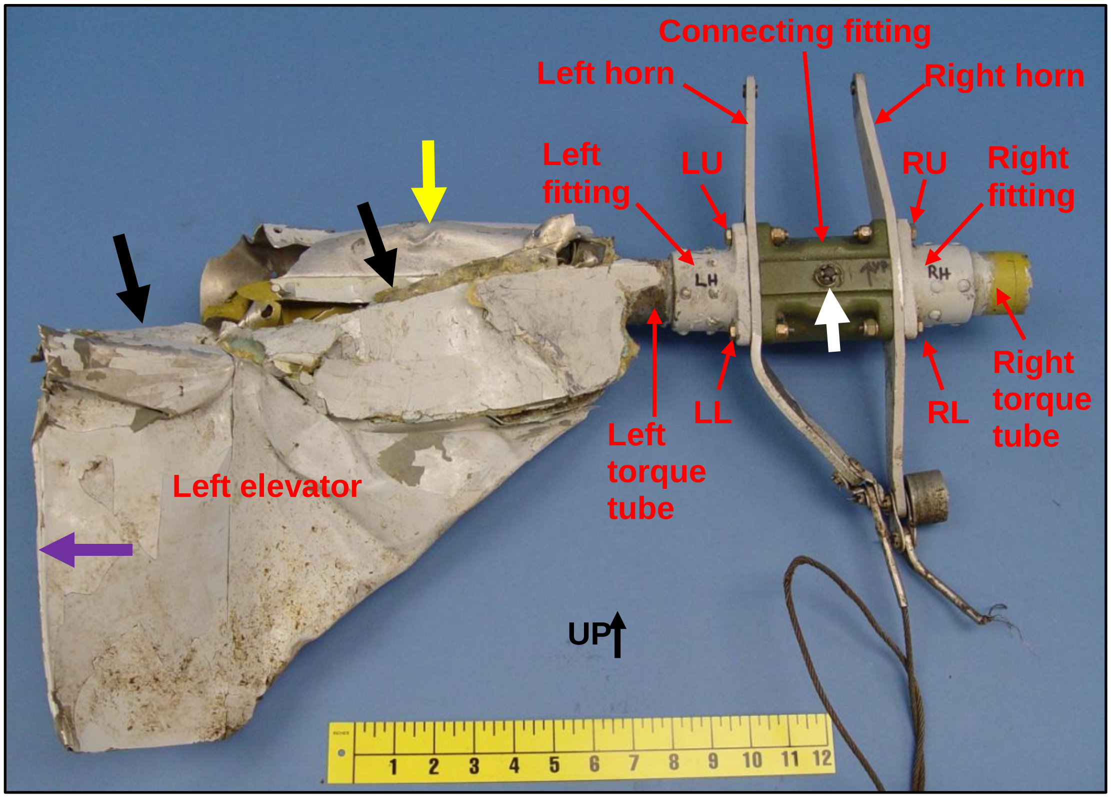


Figure 30. The elevator torque tube assembly and inboard portion of the left elevator received for examination, looking forward.

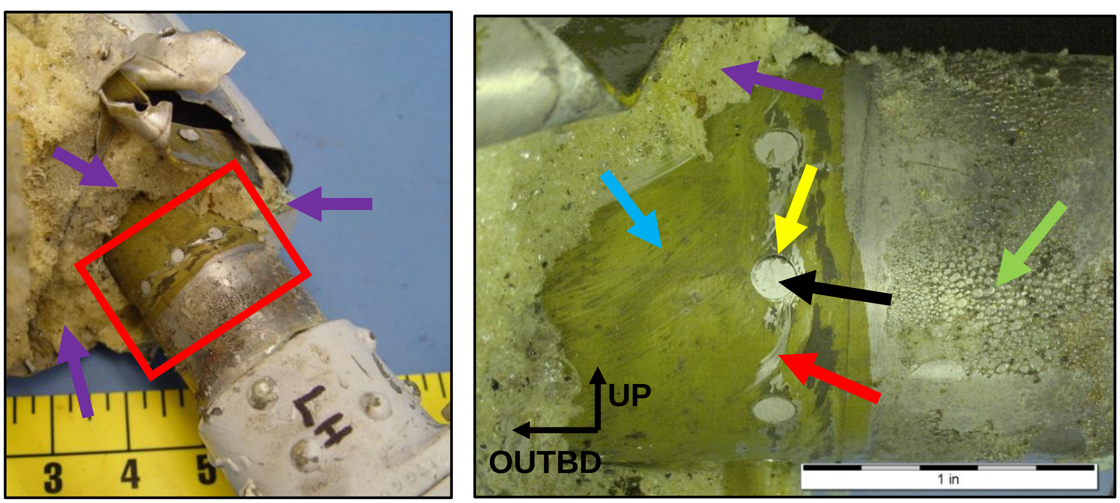


Figure 31. The left elevator inboard connection to the torque tube (left) and a closer view of the area in the red box (right).

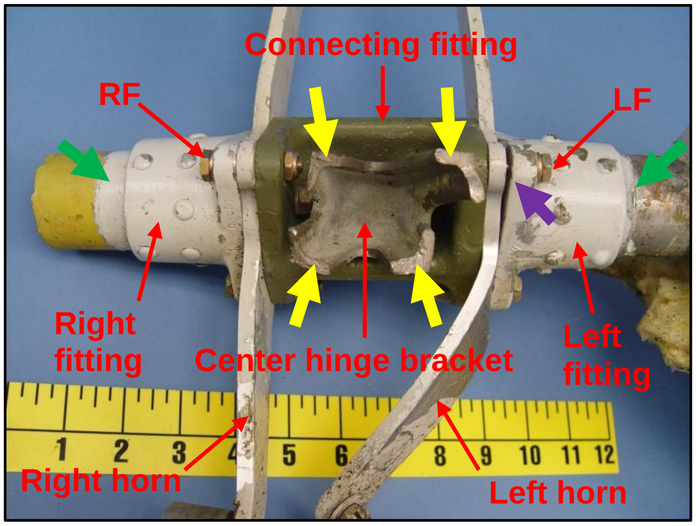


Figure 32. The elevator torque tube assembly looking aft.

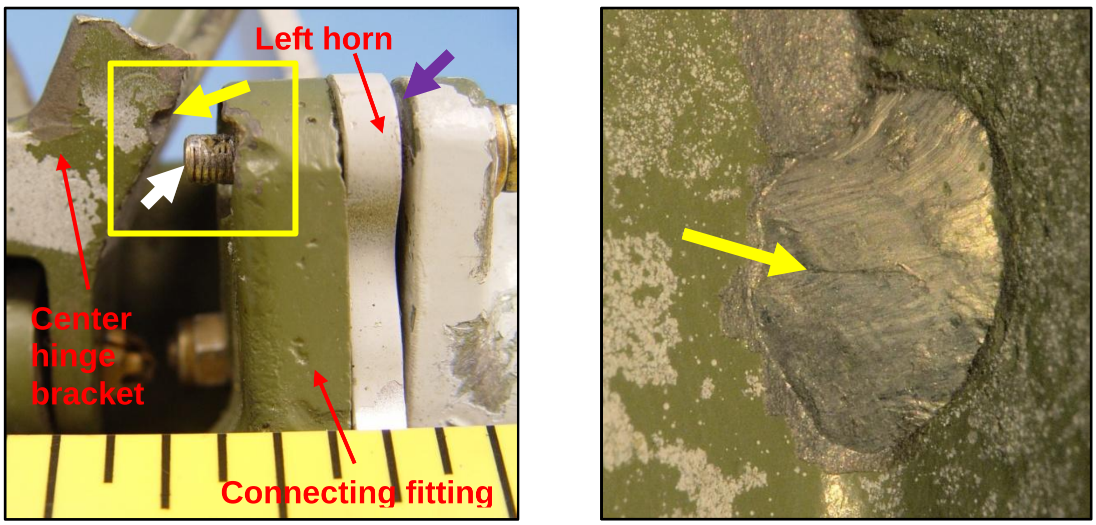


Figure 33. The area in the vicinity of the purple arrow in Figure 32 (left) and the indentation indicated by the yellow arrow (right).

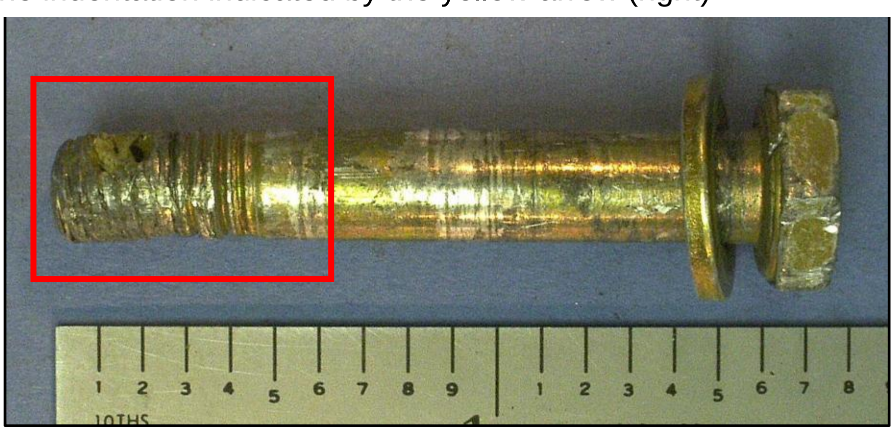


Figure 34. The left forward bolt identified as LF in Figure 32 extracted from the fittings.

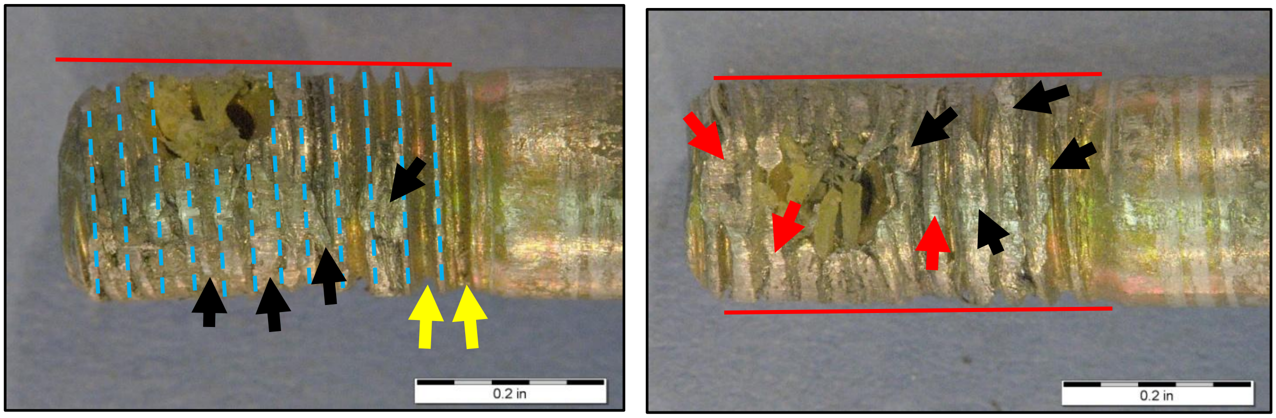


Figure 35. Two views of the threaded end of the bolt in the red box in Figure 34.

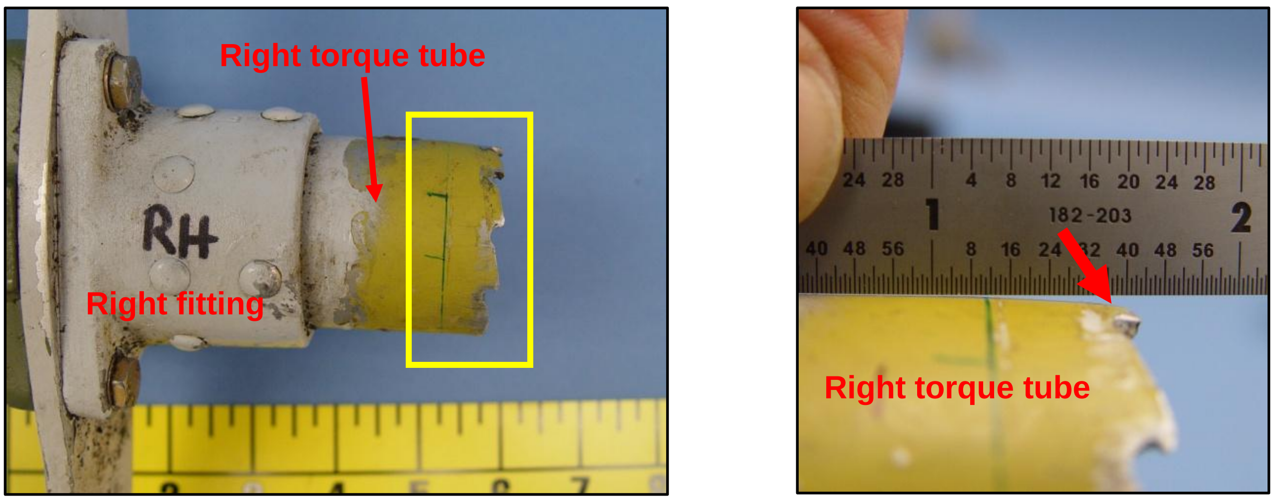
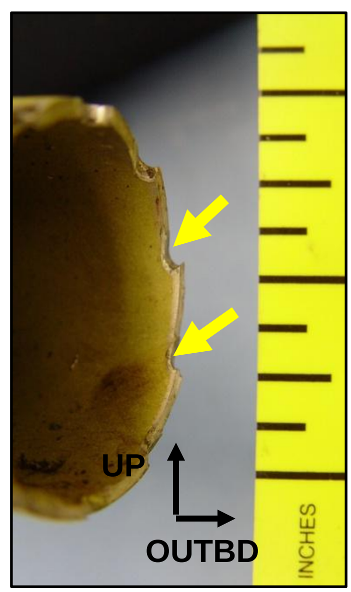


Figure 36. The right elevator torque tube and fitting looking forward (left) and a closer view of the area in the yellow box (right).

Figure 37. The rear edge of the torque tube within the yellow box in Figure 36 (left) and the forward inside edge (right).



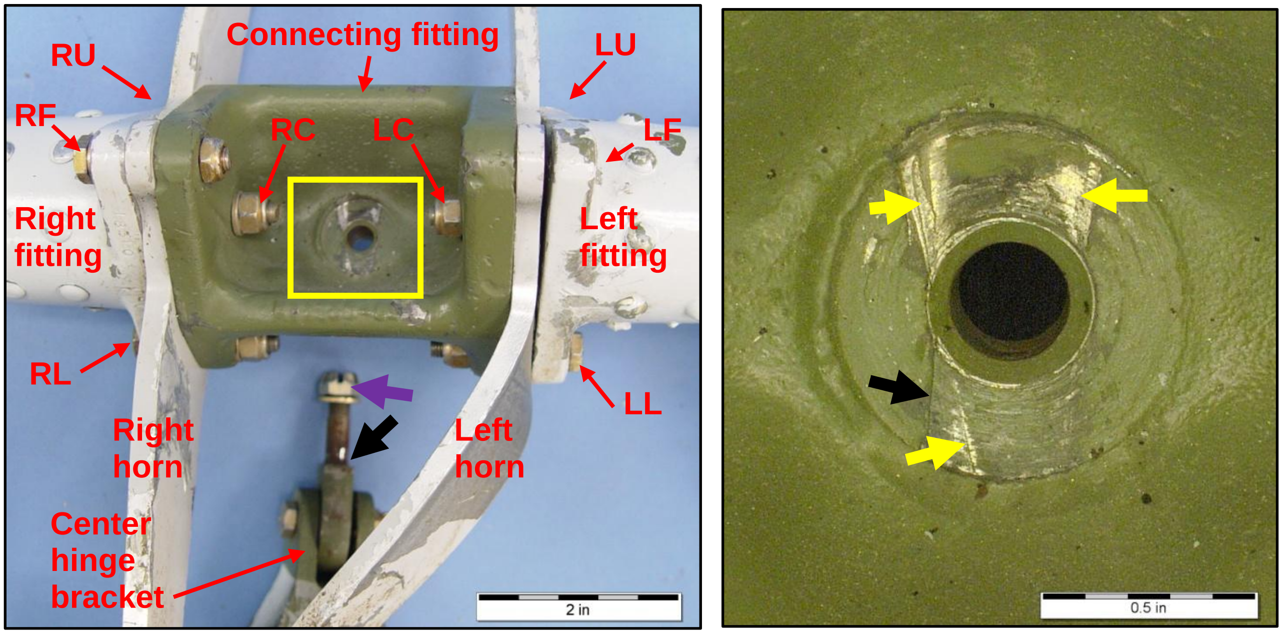


Figure 38. The elevator torque tube assembly looking aft with the center hinge bracket removed (left) and a close up of the area within the yellow box (right).

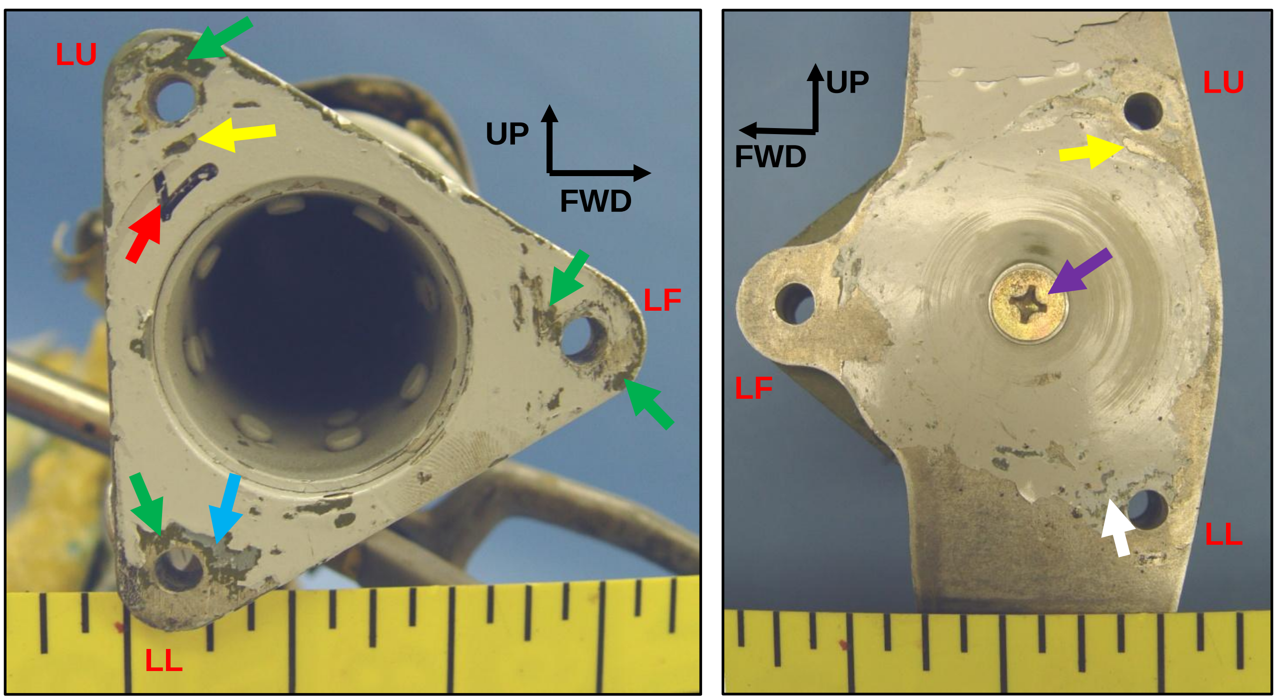


Figure 39. The mounting face of the left fitting (left) and it's mating face on the left horn (right).

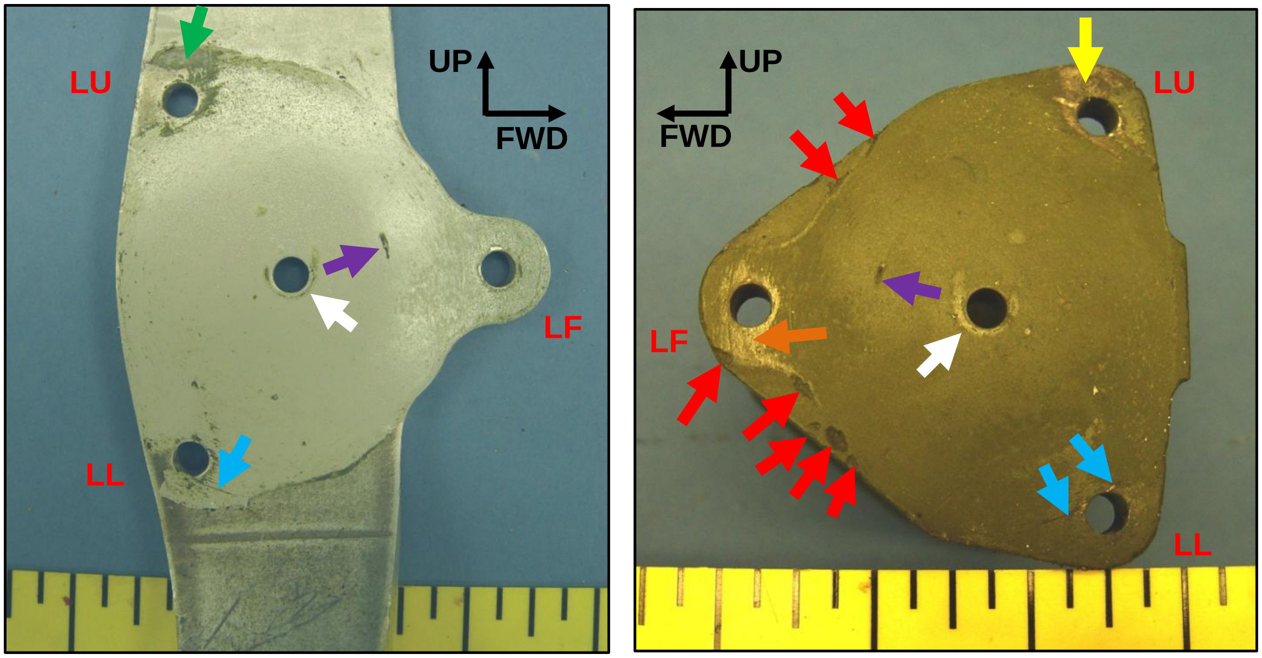


Figure 40. The inner face of the left horn (left) and it's mating face on the connecting fitting (right).

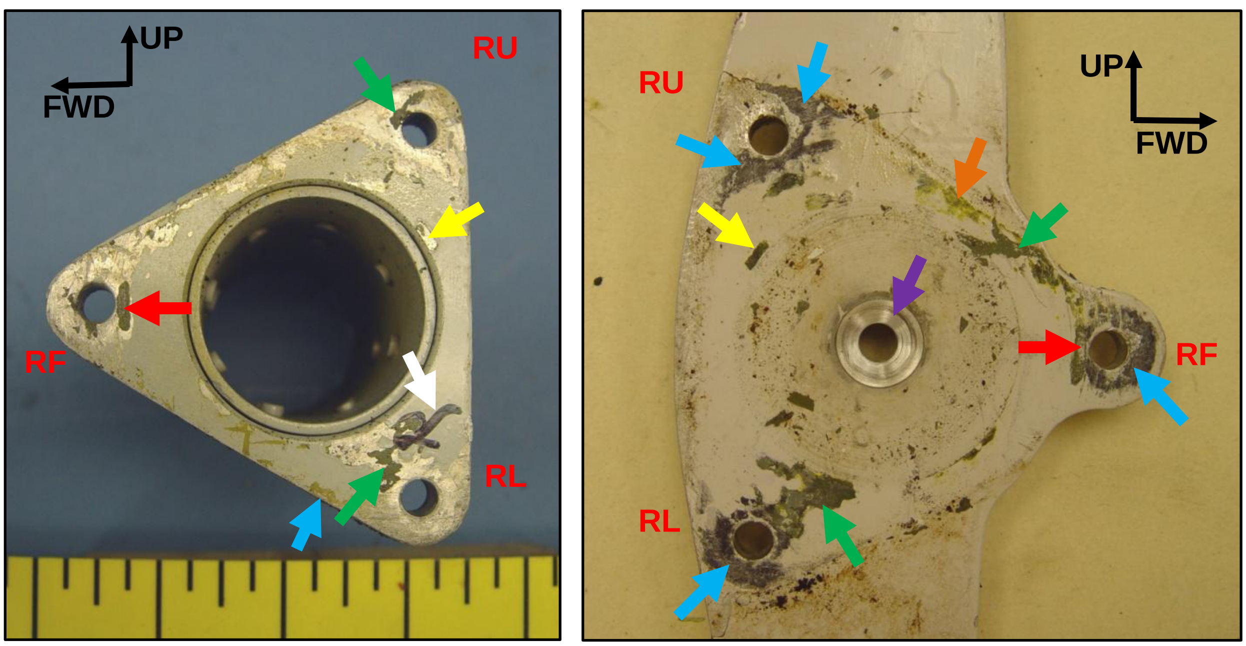


Figure 41. The mounting face of the right fitting (left) and it's mating face on the right horn (right).

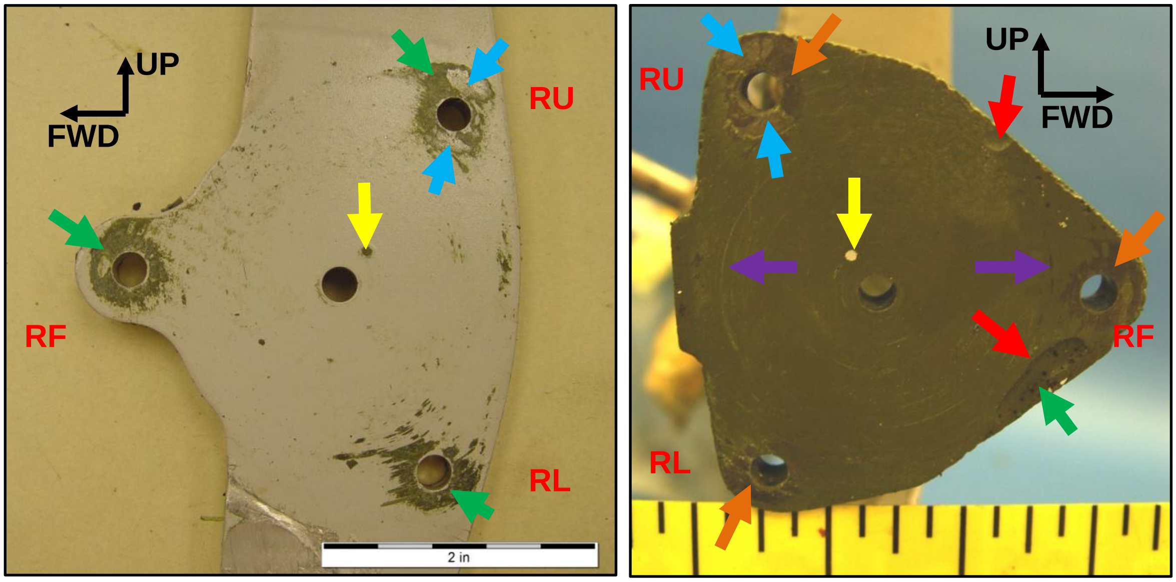


Figure 42. The inner face of the right horn (left) and it's mating face on the connecting fitting (right).

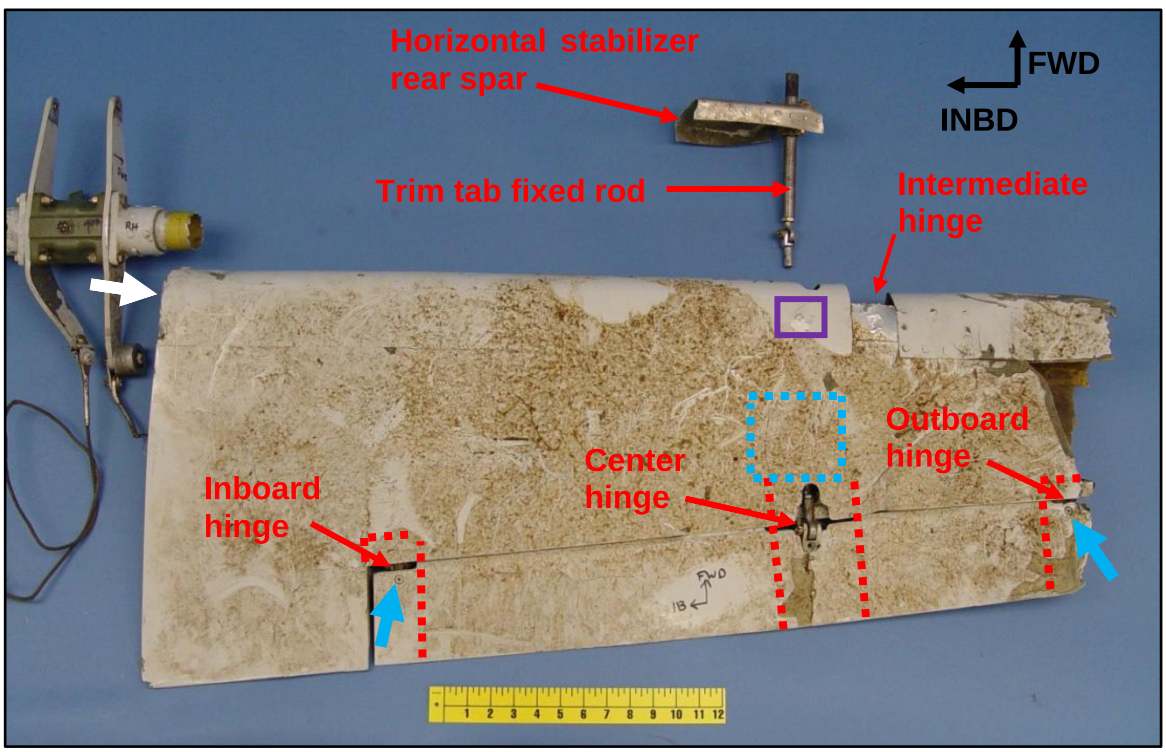


Figure 43. The right elevator with trim tab and a portion of the trim tab rod contained in a portion of the horizontal stabilizer rear spar.

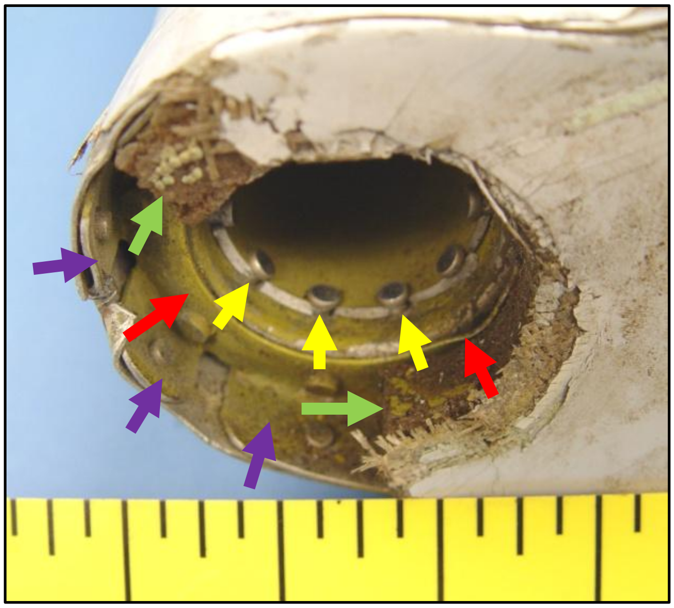


Figure 44. The inboard end of the right elevator indicated at the location indicated by the white arrow in Figure 43.

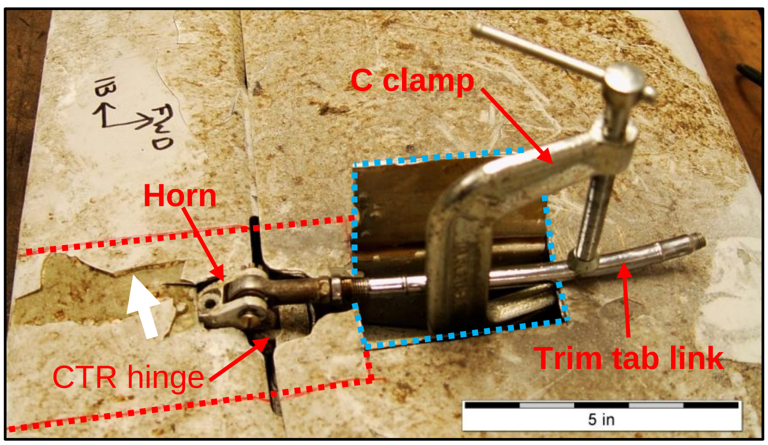


Figure 45. The right elevator with the trim tab link clamped to the upper skin.

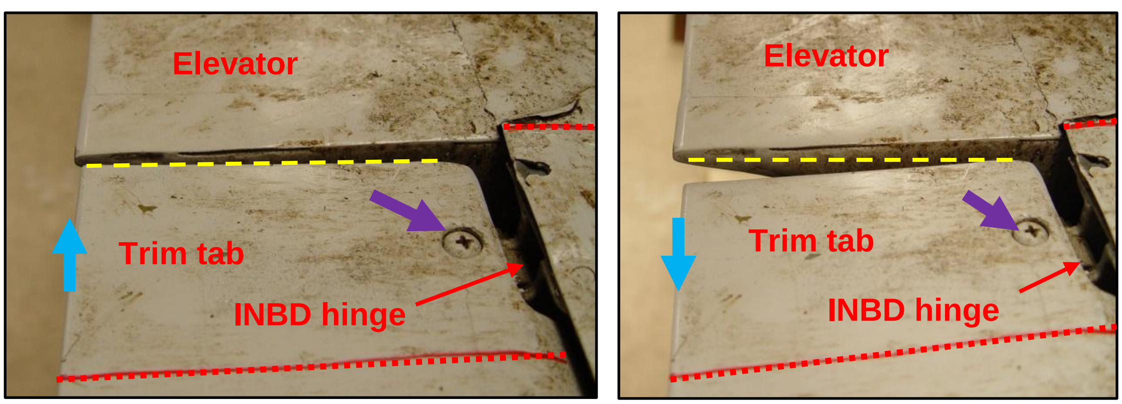


Figure 46. The right elevator trim tab raised up (left) and pushed down (right) with the link clamped as in Figure 45.

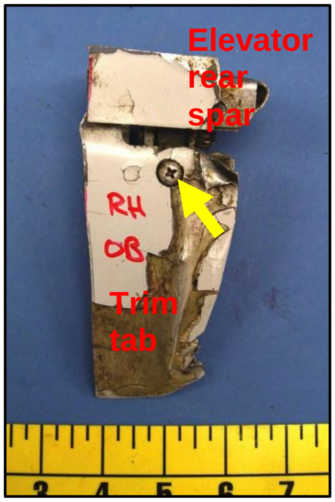


Figure 47. The outboard hinge in Figure 43 excised from the right elevator.

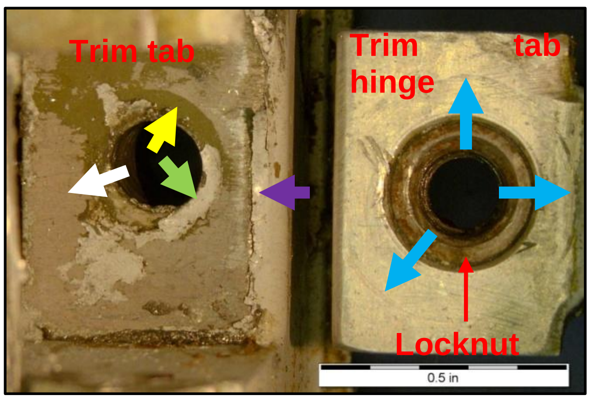


Figure 48. The mating surfaces of the outboard trim tab hinge with the trim tab.

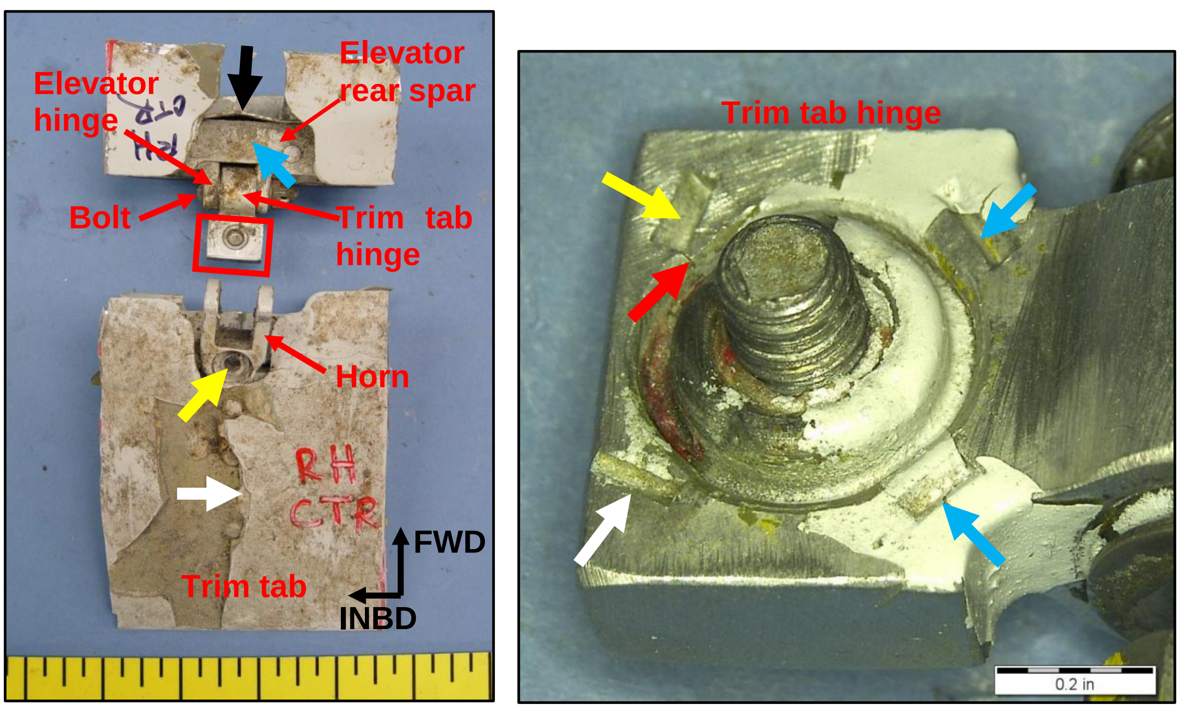


Figure 49. The center hinge in Figure 43 excised from the right elevator (left) and the head of the locknut in the trim tab hinge (right).

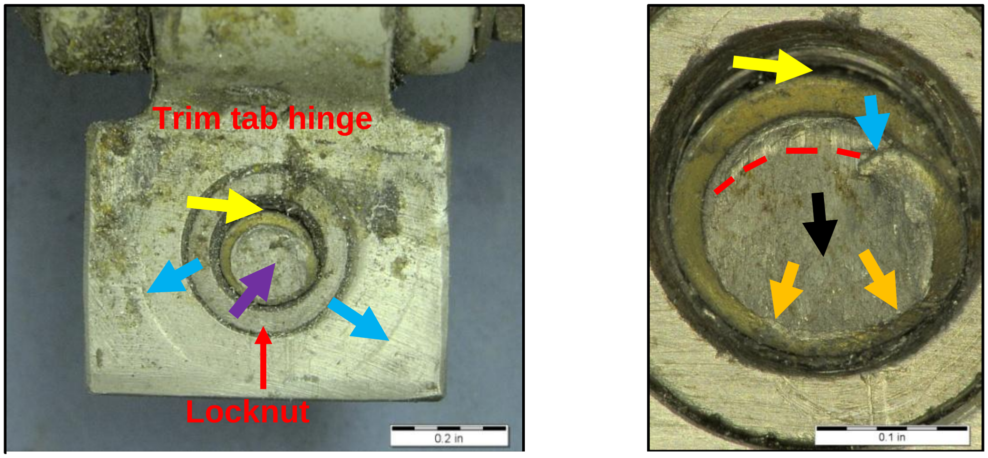


Figure 50. The trim tab hinge in the red box in Figure 49 (left) and a closer view of the cleaned screw remnant indicated by the red arrow (right).

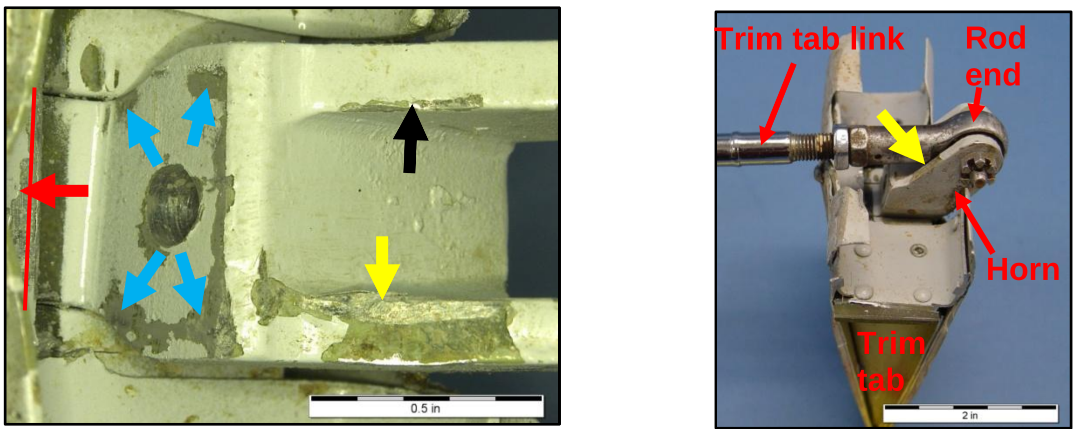


Figure 51. The mating surface of the trim tab hinge in Figure 50 with the trim tab (left) and the trim tab link reconnected to the horn (right).

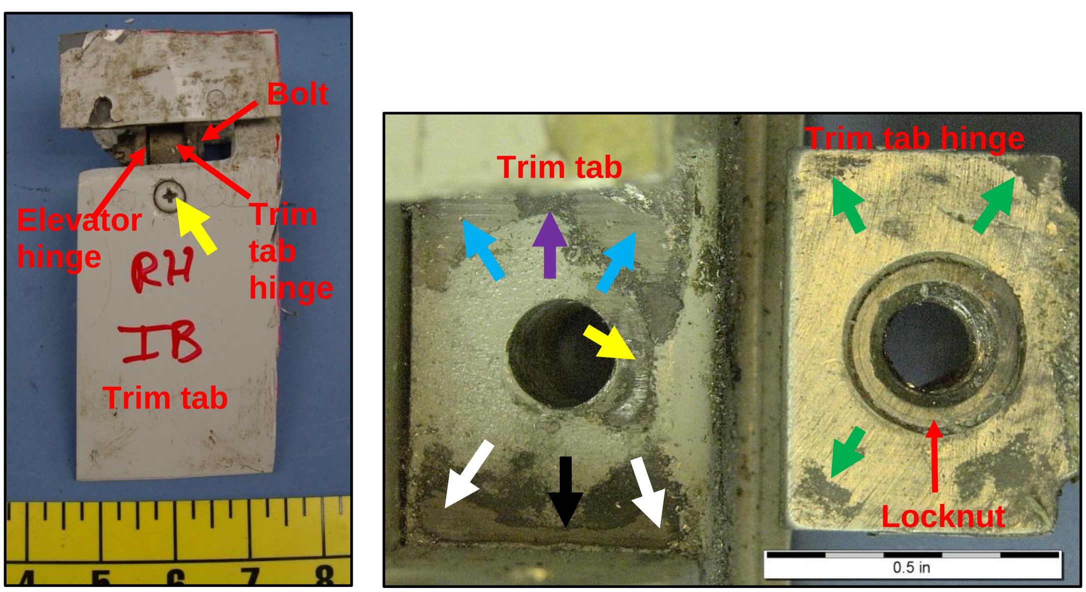


Figure 52. The inboard hinge in Figure 43 excised from the right elevator (left) and the mating hinge surfaces (right).

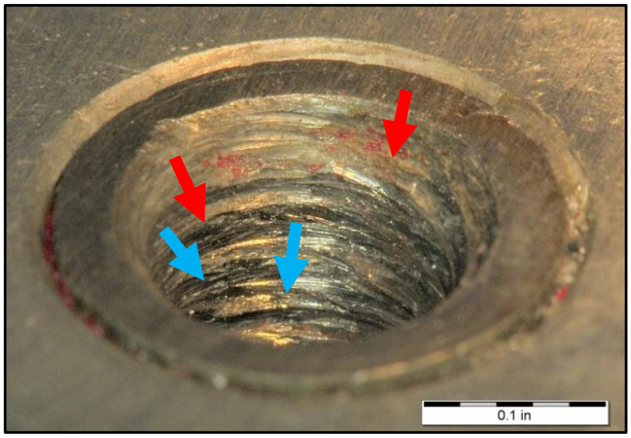


Figure 53. The threads in the locknut in Figure 52 after cleaning.

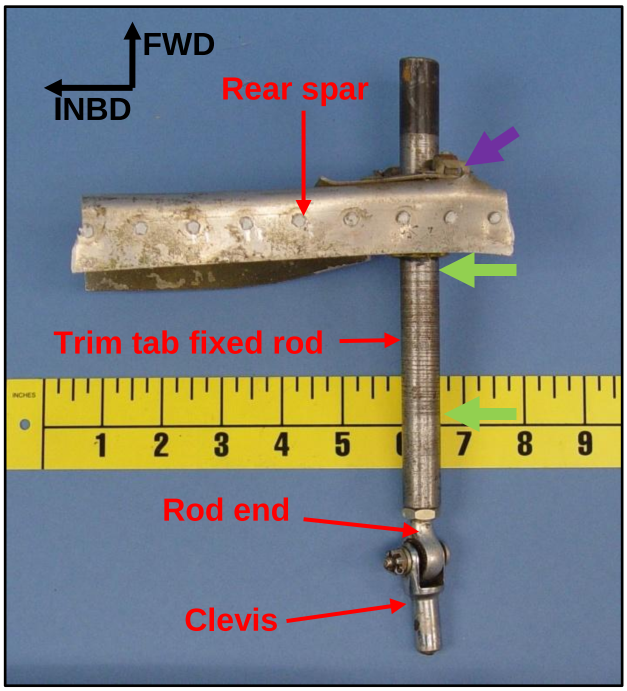


Figure 54. The trim tab fixed rod with the clevis portion of the link and a portion of the horizontal stabilizer rear spar as identified in Figure 43.

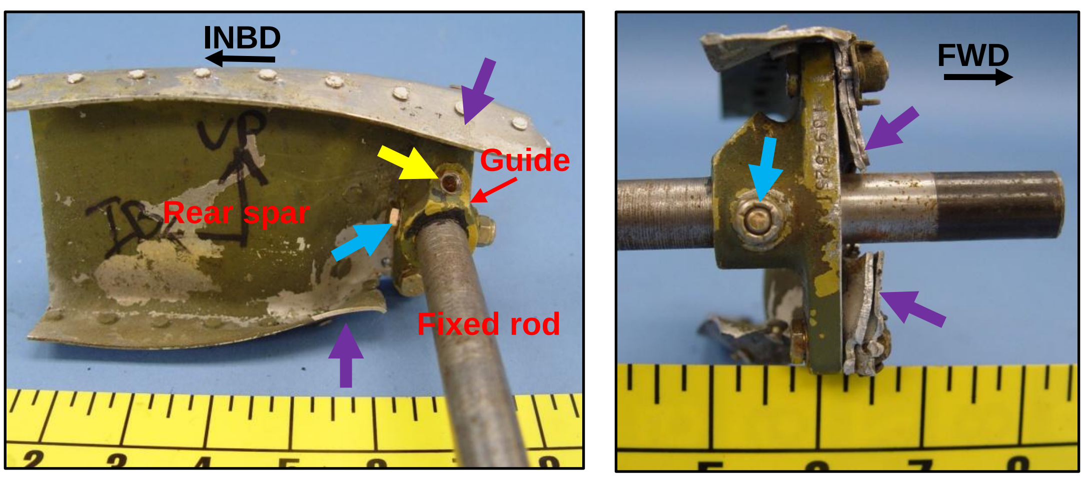


Figure 55. A view of the trim tab fixed rod and horizontal stabilizer rear spar looking forward (left) and looking inboard (right).

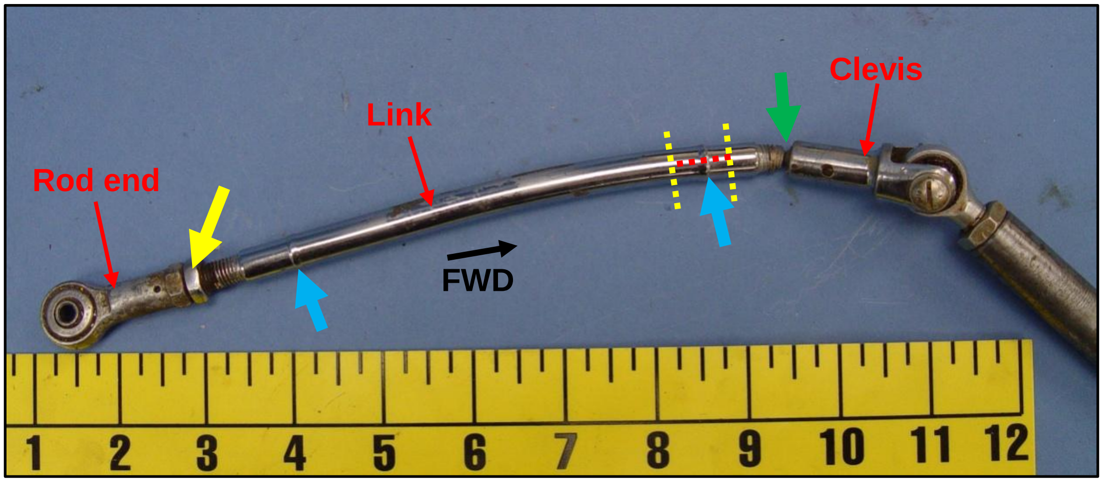
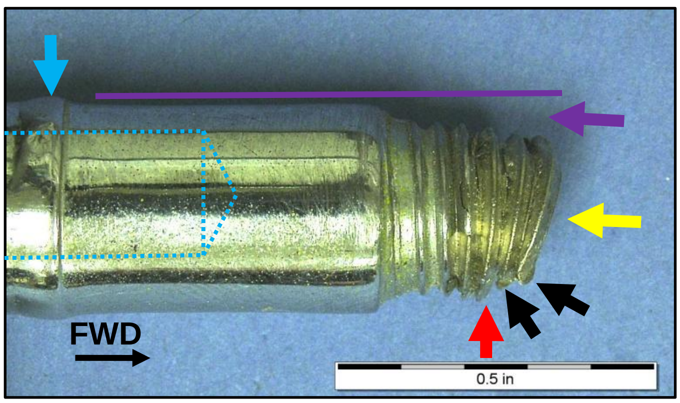


Figure 56. The right elevator trim tab link identified in Figure 45 mated with its clevis identified in Figure 54.



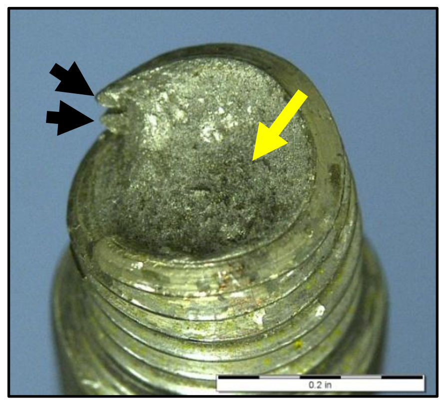


Figure 57. The forward end of the link identified in Figure 56 (left) and the fracture face indicated by the yellow arrow (right).

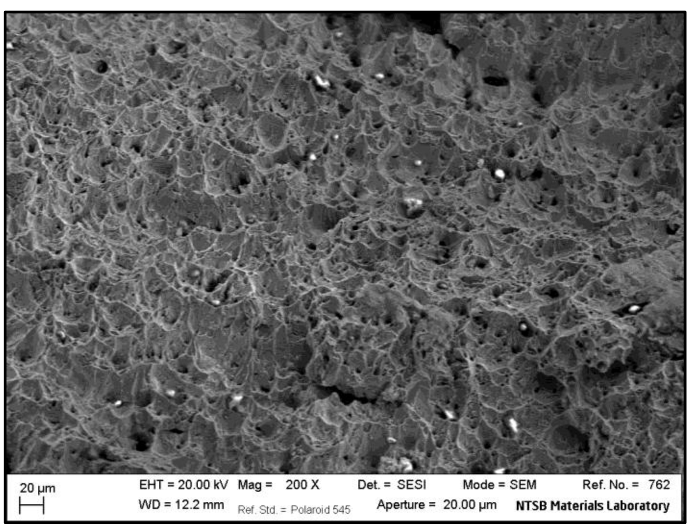


Figure 58. SEM micrograph of the fracture surface indicated by the yellow arrow in Figure 57.

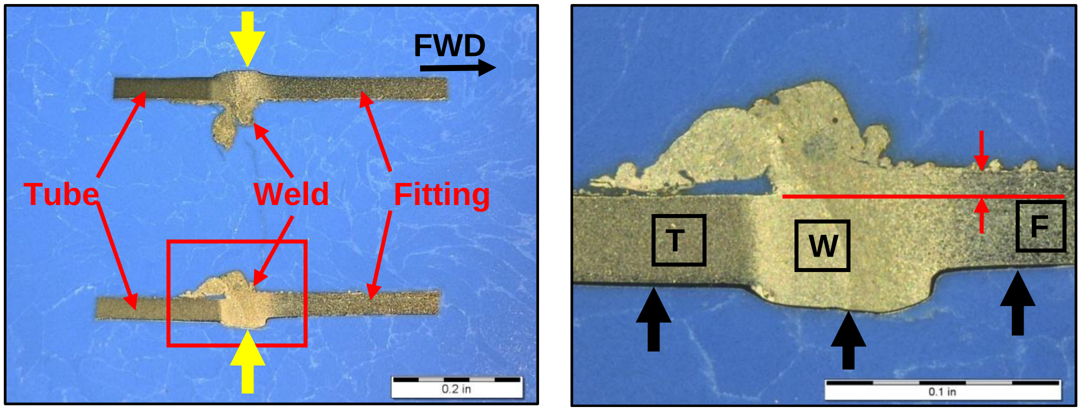


Figure 59. Sectional view of the link along the red dashed line in Figure 56 (left) and a closer view of the weld in the red box (right).

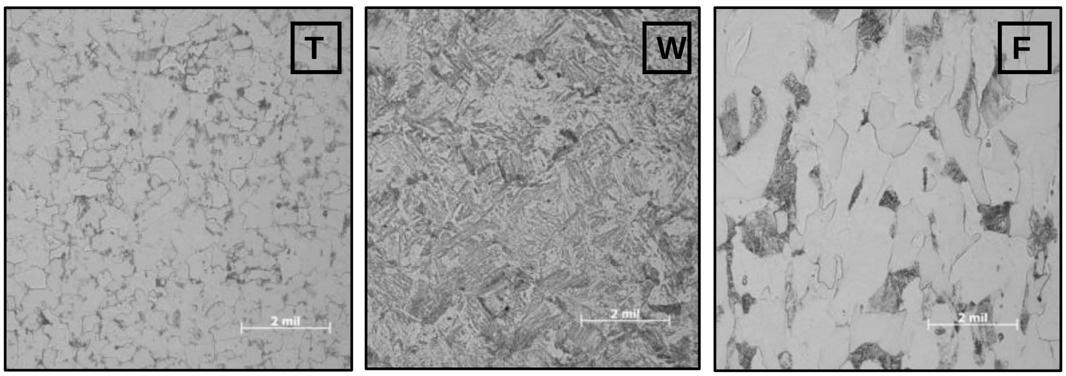


Figure 60. The microstructures in areas T, W and F in the right image in Figure 59 at similar magnifications. Etchant 2% Nital.

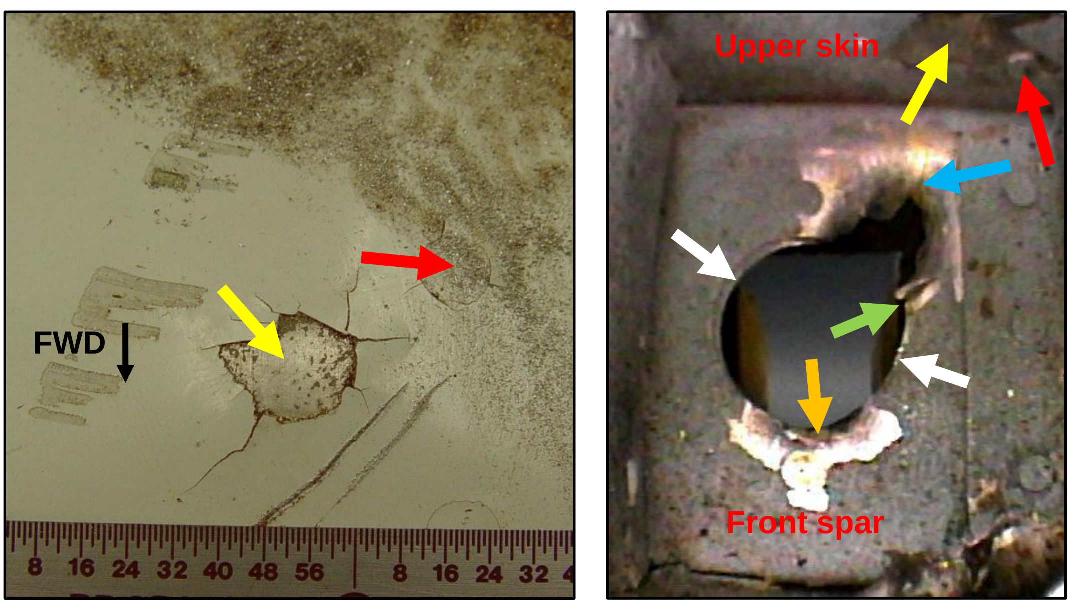


Figure 61. The bulged area in the purple square in Figure 43 (left) and a view of the trim tab rod hole in the elevator front spar, looking aft (right).

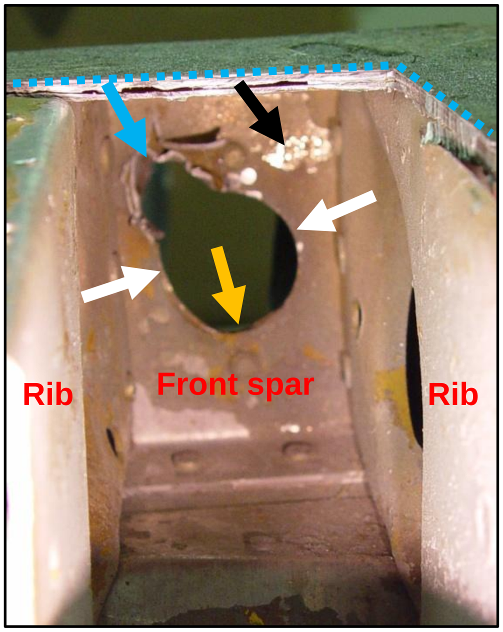


Figure 62. The trim tab rod hole in the elevator front spar, looking forward.

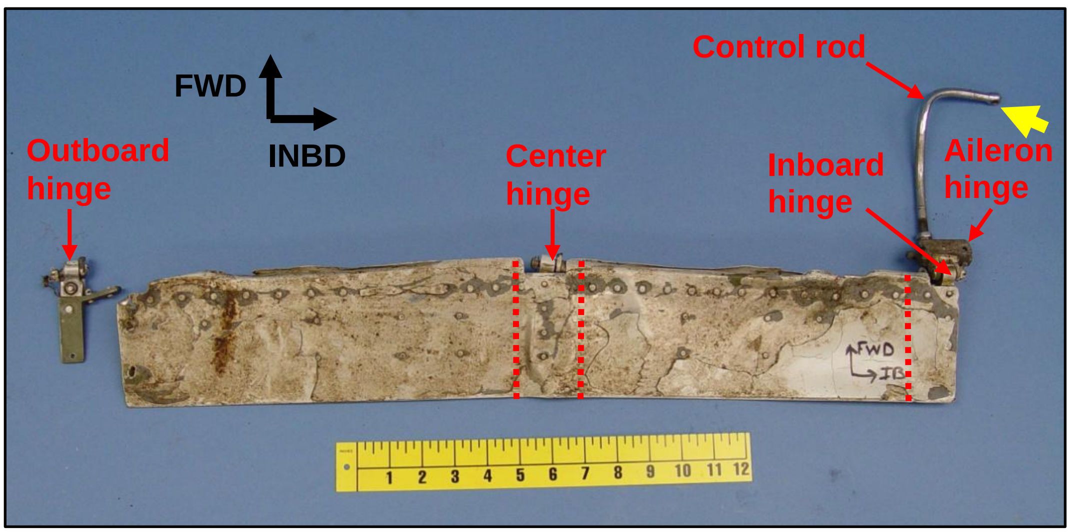


Figure 63. The upper surface of the left aileron trim tab submitted for examination.

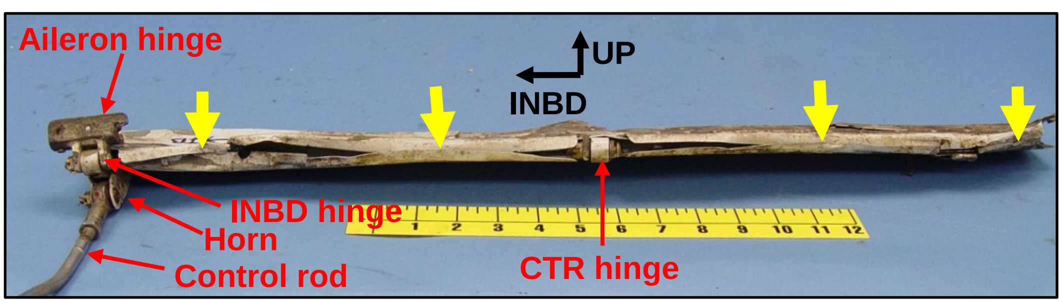


Figure 64. The forward edge of the left aileron trim tab submitted for examination.

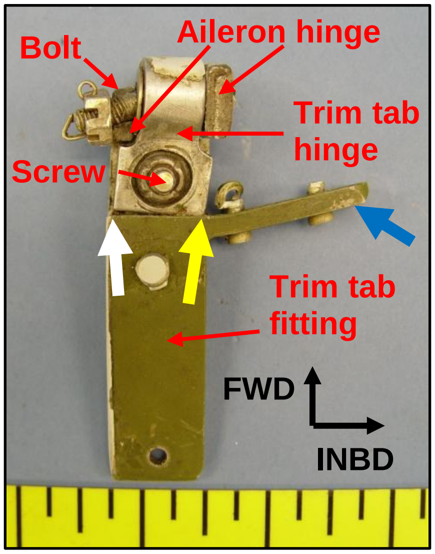


Figure 65. The left aileron trim tab outboard hinge identified in Figure 63.

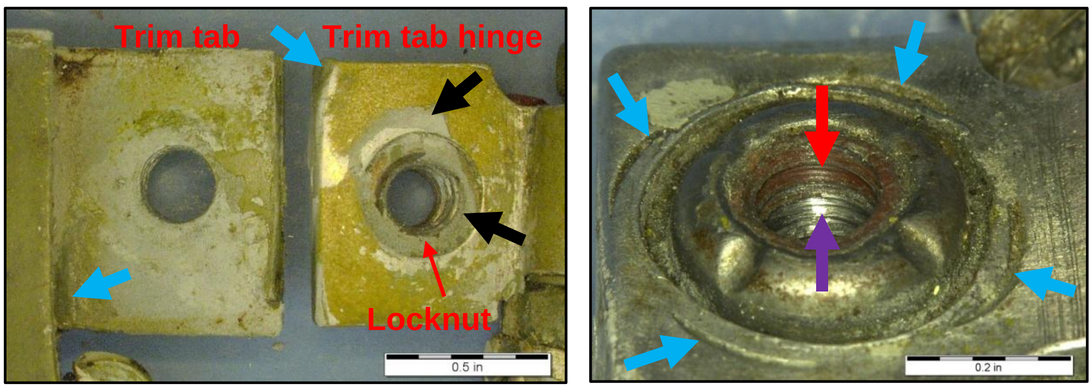


Figure 66. The mating surfaces of the left aileron trim tab outboard hinge and the trim tab (left) with the head of the locknut (right).

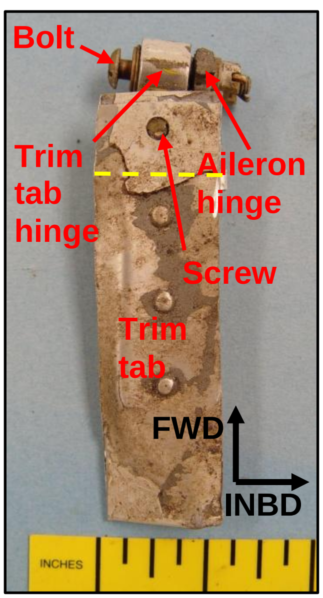


Figure 67. The left aileron trim tab center hinge excised from the trim tab illustrated in Figure 63.

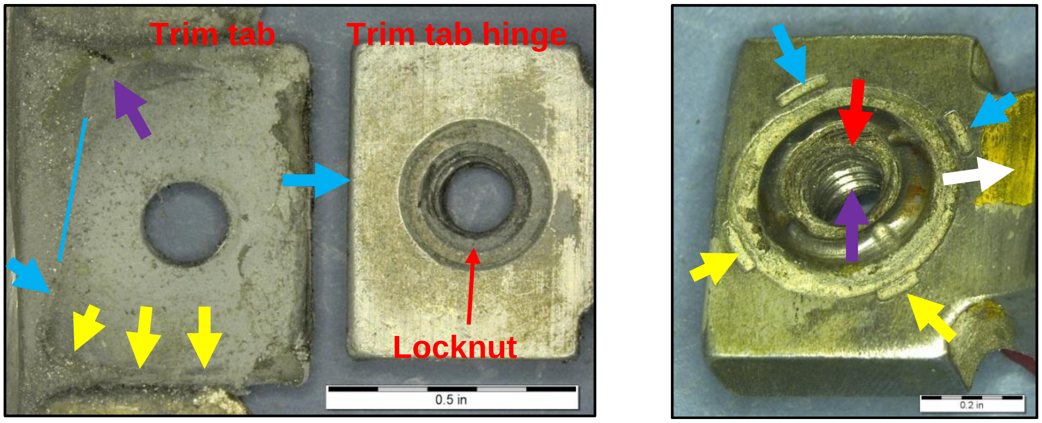


Figure 68. The mating surfaces of the left aileron trim tab center hinge and the trim tab (left) with the head of the locknut (right).

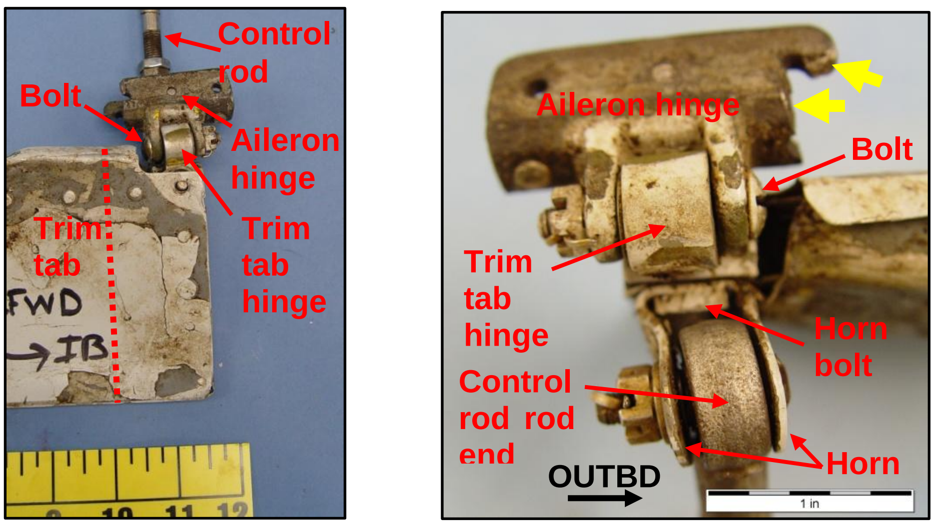


Figure 69. The left aileron trim tab inboard hinge illustrated in Figure 63 (left) and a view of the hinge looking aft (right).

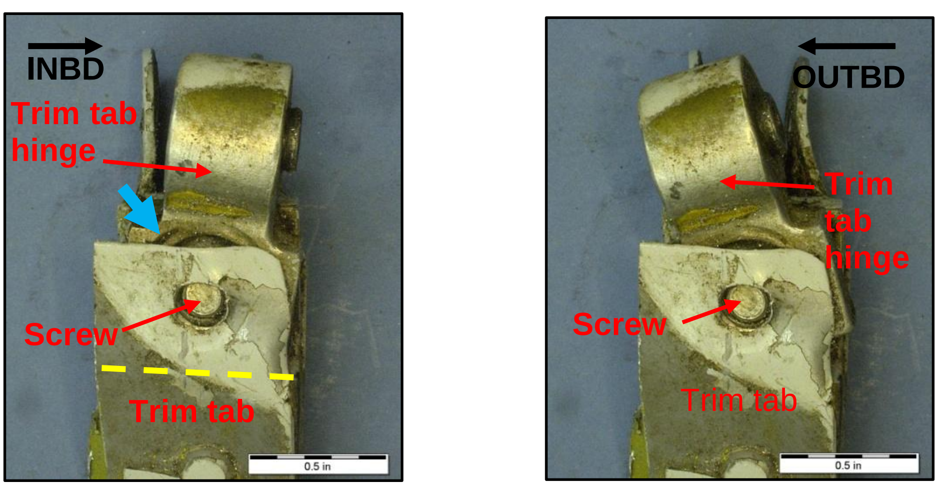


Figure 70. The left aileron trim tab inboard hinge illustrating its inboard movement (left) and outboard movement (right).

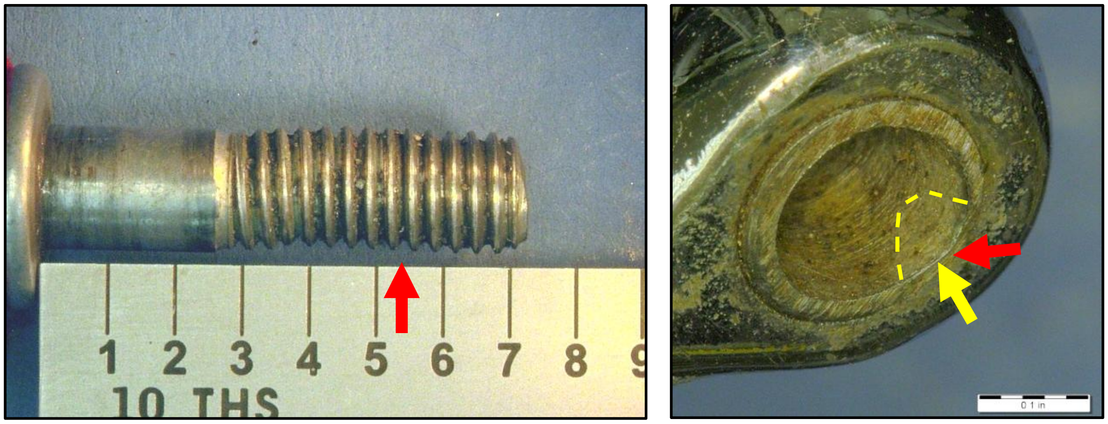


Figure 71. The screw extracted from the left aileron trim tab inboard hinge (left) and the hole in the forward end of the control rod (right).

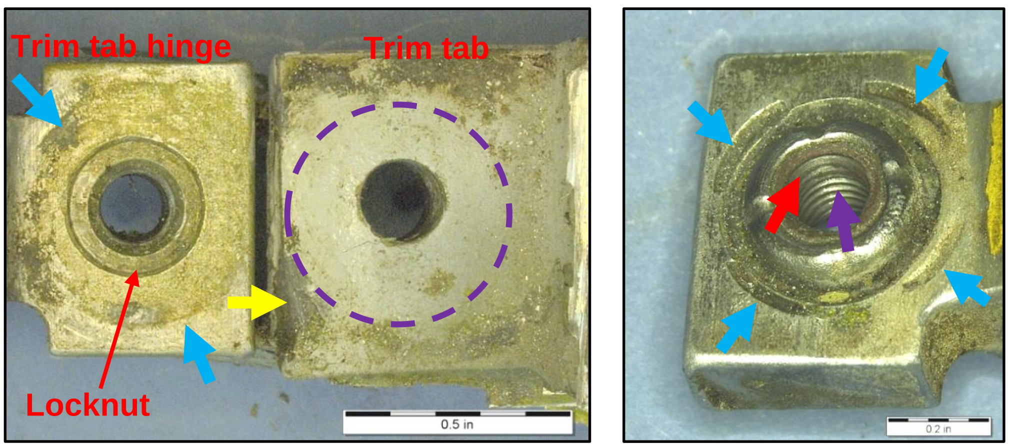


Figure 72. The mating surfaces of the left aileron trim tab inboard hinge and the trim tab (left) with the head of the locknut (right).

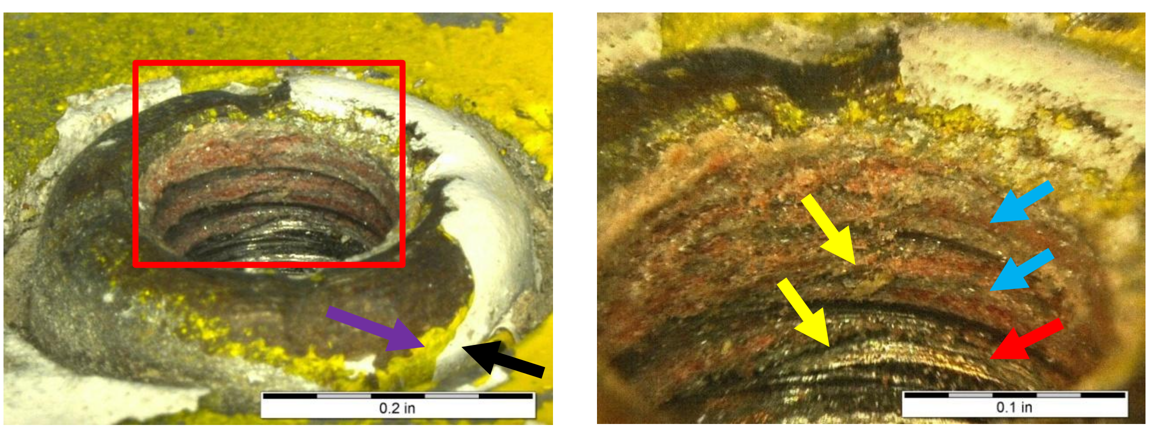


Figure 73. The head of the locknut in the left elevator trim tab outboard hinge, (left) and a closer view of the insert within the red box (right).

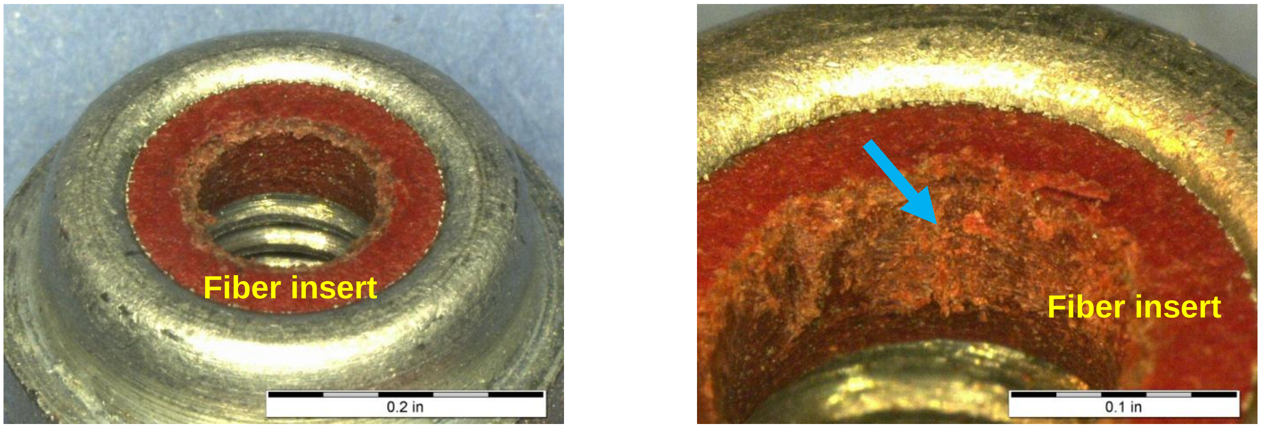


Figure 74. The head of an unused locknut with a fiber insert, part number 22D8-02, (left) and a closer view of the insert after removal of material for FTIR analysis (right).

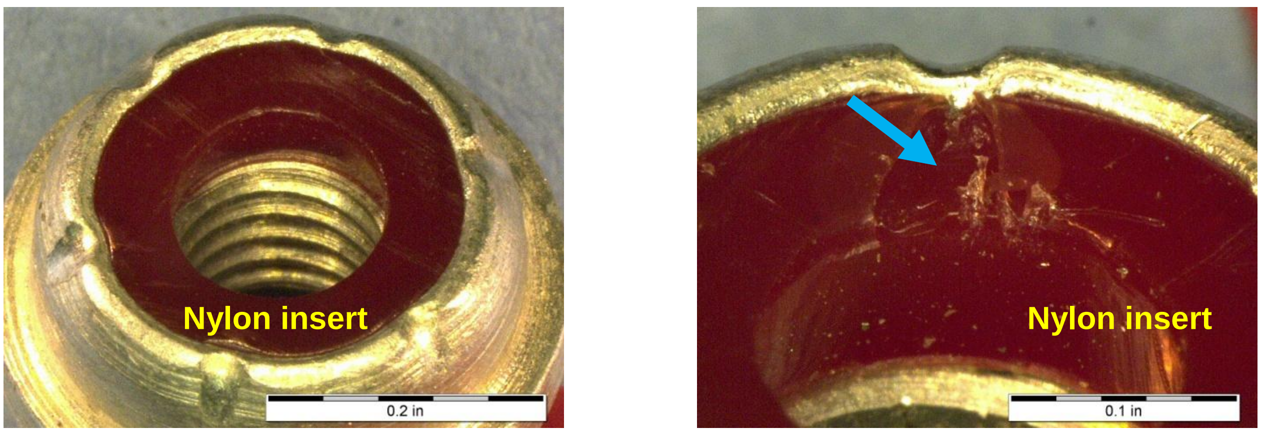


Figure 75. The head of an unused locknut with a nylon insert, part number 22ND8-02, (left) and a closer view of the insert after removal of material for FTIR analysis (right).

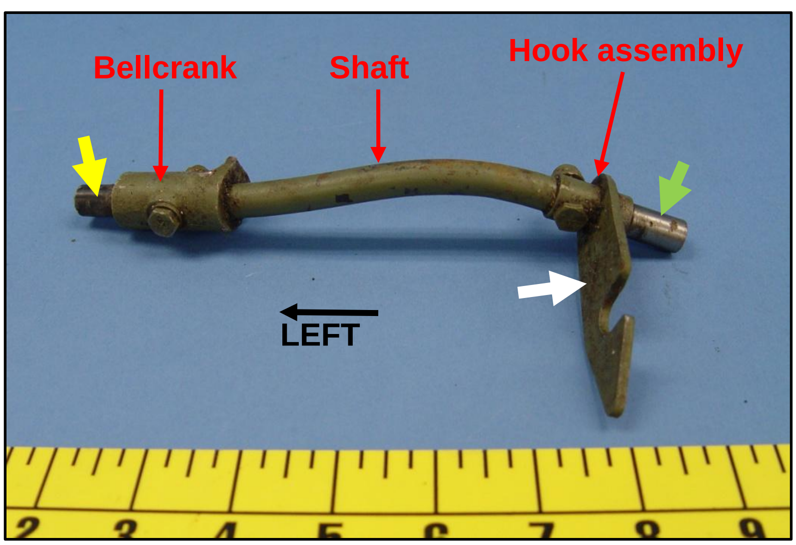
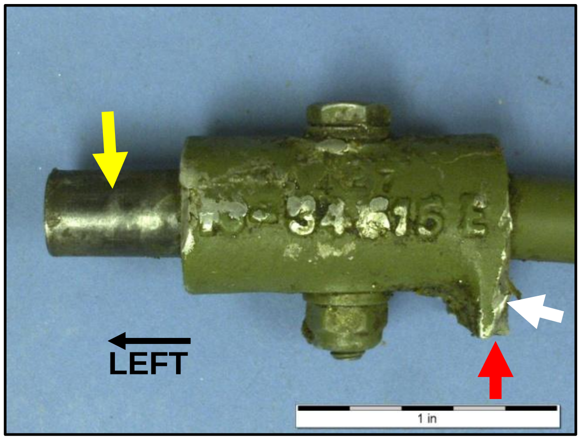


Figure 76. The tailwheel retract lock assembly supplied for examination.



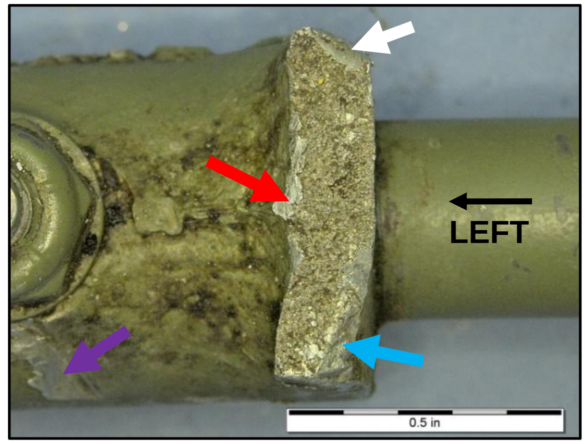
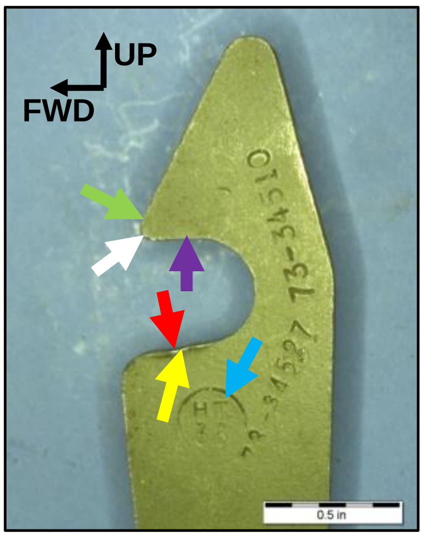


Figure 77. The bellcrank identified in Figure 76 (left) and the fracture indicated by the red arrow (right).



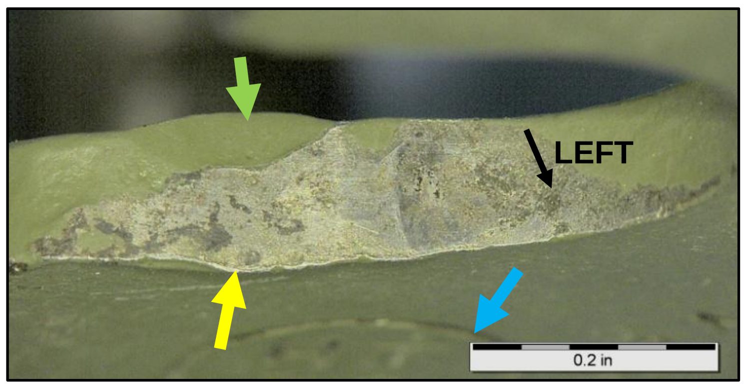
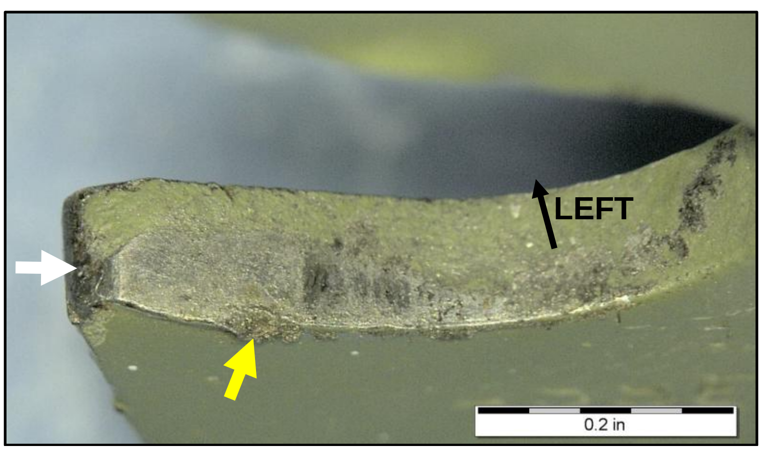


Figure 78. The left side of the hook indicated by the white arrow in Figure 76 (left) and the multiple contact marks on the lower edge indicated by the red arrow (right).



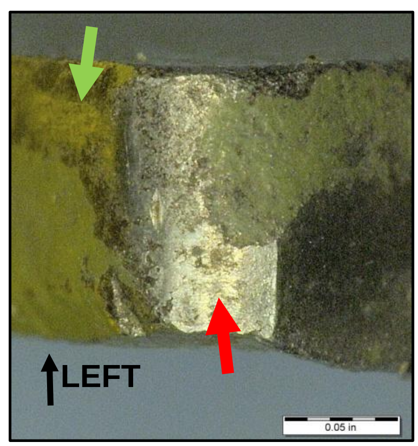


Figure 79. Multiple contact marks on the upper edge indicated by the purple arrow in Figure 78 (left) and the corner indicated by the white arrow in the left image and in Figure 78 (right).