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. 02-077

A. ACCIDENT

Place	:	Belle Harbor, New York
Date	:	November 12, 2001
Vehicle	:	Airbus A300-600, N14053
NTSB No.	:	DCA02MA001
Investigator	:	Brian Murphy, AS-40

B. COMPONENTS EXAMINED

Vertical stabilizer and adjacent fuselage, rudder hinge fittings, and rudder.

C. ACCIDENT SUMMARY

On November 12, 2001, at approximately 0917 EST, American Airlines flight 587, an Airbus A-300-600, N14053, crashed into a neighborhood in Belle Harbor, New York, several minutes after taking off from Kennedy International Airport. The airplane was on a scheduled flight to Santo Domingo, Dominican Republic. All 260 persons aboard the airplane were fatally injured, as were 5 on the ground.

D. DETAILS OF THE EXAMINATION

This report documents results of the visual examination of the vertical stabilizer and adjacent fuselage, the rudder hinge fittings, and the rudder. Additional materials laboratory reports will document other aspects of the structural examination of these components. The nondestructive inspections using ultrasonic imaging, Lamb wave, x-ray radiography, and thermal imaging will be documented in Materials Laboratory Factual Report 02-078. The results from materials testing and microstructural examination will be documented in Materials Laboratory Factual Report 02-082. The detailed fractographic examination of the attachment fittings at the lower end of the vertical stabilizer will be documented in Materials Laboratory Factual Report 02-083.

The initial examination of the vertical stabilizer, rudder hinge fittings, and rudder occurred in a hangar at Floyd Bennett Field, Brooklyn, New York, where the components were located after recovery from Jamaica Bay. The fuselage and attached pieces of the vertical stabilizer were first examined at the crash site in Belle Harbor, New York and then at the hangar at Floyd Bennett Field. Following these initial examinations, the leading edge

fairings were removed from the vertical stabilizer, and all subject components were moved by truck to the National Aeronautics and Space Administration's Langley Research Center (NASA Langley) in Hampton, Virginia.

Parties to the examination were the Federal Aviation Administration (FAA), the Bureau Enquetes – Accidents (BEA), Airbus Industrie, American Airlines (AA), and the Airline Pilots Association (APA). Participants in the visual examination included:

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1. Construction and Assembly

The vertical stabilizer and rudder for the Airbus A300-600 has a symmetric airfoil shape. The vertical stabilizer and rudder are 27 feet 3 inches tall. From leading edge (LE) to trailing edge (TE) with a neutral (zero degree) rudder position, the width of the vertical stabilizer and rudder is 25 feet at the base and 10 feet 2 inches at the tip.

1.1. Vertical Stabilizer

The vertical stabilizer design is a stiffened box with removable LE fairings and TE panels. The stiffened box consists of two integrally stiffened skin panels for the left and right sides, spars for the forward and aft sides, and closure ribs at the upper and lower ends. The integral stiffeners in the skin panels consist of 24 "I"-shaped stringers that extend spanwise parallel to the aft spar, numbered from the aft to forward. Internal stiffeners for the box consist of a center spar at the lower end of the span and 16 ribs, not including the two closure ribs. The ribs are numbered from the lower end upward starting with the lower closure rib. The components of the box are riveted together, and the LE fairings and TE panels are attached with threaded fasteners.

Except for the fasteners, lightning protection strips, and TE panel support frames, the vertical stabilizer is made entirely of composite materials. The stiffened box of the vertical stabilizer is a solid carbon-fiber reinforced polymer (CFRP) laminate composed of T300 carbon fibers in a Hexcel 913[1] epoxy matrix. The laminate includes both unidirectional tape and eight-harness satin fabric layers in the construction. The zero-degree fibers of the fabric and tape layers in the composite are oriented parallel to the stringers and aft spar, which is at an angle of 33.3 degrees relative to vertical. The LE fairings and the TE panels for the vertical stabilizer are sandwich composites having a nomex honeycomb core and glass-fiber reinforced polymer (GFRP) facesheets on the LE fairings and both GFRP and CFRP facesheets for the TE panels.

1.2. Vertical Stabilizer to Fuselage Attachment

The primary attachment locations for the vertical stabilizer are six CFRP lugs (longitudinal lugs) that connect by bolts to six metal clevis fittings on the fuselage. Three longitudinal lugs extend from the lower end of each of the two vertical stabilizer skin panels. At the thickest point, the longitudinal lugs are approximately 1.62 inches, 2.48 inches, and 2.17 inches thick for the forward, center, and aft lugs, respectively. The thickness of each lug decreases as plies are dropped in the lug-to-skin transition area.

The vertical stabilizer also is attached to the fuselage by six smaller composite lugs (transverse lugs) that attach to the fuselage by lateral yokes. Two of these transverse lugs extend from the lower end of each of the three spars. These lugs are approximately 0.47 inch thick.

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[1] At the time the accident airplane was manufactured, the epoxy used in the vertical stabilizer was CIBA 913C, made by Ciba-Geigy Ltd., of Switzerland. Ciba-Geigy sold their composites business to Hexcel Corporation in 1996.

1.3. Rudder

The rudder is a single-segment wedge-shaped design with removable LE fairings. The wedge consists of left and right skin panels with a single spar at the forward side. The skin panels are fastened together at the trailing edge by rivets with a metallic strip on each side. Threaded through-bolts near the trailing edge also help fasten the two skin panels. At the lower end, a metal strap, which retains the rubber lower sealing strip, is attached by threaded fasteners that also connect the skin panels to the lower rib. The spar is riveted to the skin panels. Pieces of the LE fairings are attached to the skin panels with threaded fasteners and to each other with threaded fasteners through metal support flanges. There are no internal stiffeners in the wedge. Closure ribs cap the upper and lower ends of the rudder.

The rudder skin panels and spar are sandwich composite panels. Each panel has a nomex honeycomb core and GFRP and CFRP face sheets. The LE fairings are sandwich composites with GFRP facesheets.

1.4. Rudder Hinge Fittings

The rudder is attached to the vertical stabilizer by seven hinges, numbered from the lower end upward. There are three rudder position actuators that control the rotation of hinges 2, 3, and 4. The rudder position sensor is located at hinge 1. Each hinge is composed of a forward fitting that is attached to the vertical stabilizer aft spar and an aft fitting that is attached to the rudder spar. The forward fittings are attached to the vertical stabilizer through bolts that fasten to CFRP flanges on the vertical stabilizer aft spar. The aft fittings are attached to the rudder using bolts that thread into barrel nuts located in fiberglass blocks embedded in the rudder skin panels aft of the rudder spar. Each pair of hinge fittings is pinned together at the hinge line. Spherical bearings are located at each attach point for the forward fitting.

The hinge fittings are made of an aluminum alloy. The bolts that attach the aft fitting to the rudder spar are specified as ABS 0232 series (made from a titanium alloy with 6 percent aluminum and 4 percent vanadium) or NAS 670 series (made from A286 CRES, corrosion resistant steel, alloy) bolts. At the time the accident airplane was assembled, only the ABS 0232 series bolts were specified.

2. Visual Examination

Overall views of the vertical stabilizer and adjacent fuselage are shown in figures 1 to 5. Figures 1 and 2 show the fuselage and attached pieces of the vertical stabilizer and fairings as they were examined at Floyd Bennett Field. These pieces generally showed damage consistent with exposure to extreme heat and fire. Figures 3 and 4 show recovery of the vertical stabilizer as it was raised from Jamaica Bay. The lower end and leading edge of the vertical stabilizer are shown in figure 5 as it was received at Floyd Bennett Field. Visible damage to the vertical stabilizer was generally limited to the lower end and

the trailing edge with no evidence of exposure to heat or fire. Nearly the entire vertical stabilizer was recovered. The lower ends of the fractured right aft and right forward lugs, portions of rib 1, and a portion of the forward spar were not recovered.

All but one of the 14 rudder-to-stabilizer hinge fittings were recovered, either attached to the vertical stabilizer or to the rudder. The hinge 1 aft fitting was not recovered. Also, three of the four attach bolts for the hinge 1 aft fitting were fractured, and the forward pieces of these bolts were not recovered. One of the attach bolts for the aft fitting from hinge 3 fractured just aft of the head, and the head was not recovered. Also, seven of the bolts for the aft fitting from hinge 4 fractured, and the forward piece of one was not recovered.

Approximately 95% of the rudder was recovered in numerous pieces. Two pieces of the rudder LE fairing and one piece of the rudder right skin panel were recovered on land. The remaining pieces of the rudder were recovered from Jamaica Bay.

2.1 Fuselage

The attachment points for the vertical stabilizer were located on two pieces of the fuselage as shown in figures 1, 2, and 6. The forward clevis fittings and lateral yokes were located on the forward piece and the center and aft clevis fittings and lateral yokes were located on the aft piece. The structure between the two pieces of the fuselage appeared to have been melted.

All bolts, bushings, and sleeves for the vertical stabilizer attachment points at both the clevis fittings and the transverse yokes were in place and intact on the fuselage pieces. The sleeve for the aft left transverse yoke had some deformation. Pieces of the vertical stabilizer lugs were observed in each of the clevis fittings except for the right aft fitting and the right forward fitting[2], and in each of the transverse yokes except for the center two. The aft transverse yokes were free to rotate through a limited range on the lower attach bolts. The center transverse yokes were free to rotate through their entire range on the lower attach bolts. The forward right transverse yoke was trapped in a nearly horizontal position by previously molten aluminum. The forward left transverse yoke was free to rotate on the lower attach bolt.

Each side of the vertical stabilizer has a fairing between the vertical stabilizer and the fuselage. The upper sides of these fairings are attached to clips that are fastened to the stabilizer just above rib 1. The lower sides of these fairings are attached to clips that are fastened to the fuselage. Pieces of the fairings are shown in the overall views of the fuselage in figures 1 and 2. The fuselage is shown with the fairing pieces removed in the remainder of the fuselage pictures. The clips that fasten the lower side of the fairing to the fuselage are shown in figures 7 and 8 for the right and left sides, respectively. There were 10 clips on each side of the aft fuselage piece. The nine aft-most clips on the right side were deformed upward (except for one) with the outboard end deflected upward as shown

[2] A few pieces of composite material from the right forward lug were found in the right forward clevis fitting.

in figure 7. The tenth clip from the rear was broken. On the left side, the nine aft-most clips from the rear were approximately in their normal position. The tenth clip from the aft was bent upward and aft. Figure 8 shows the first through seventh clips as viewed looking aft.

Aft of the aft vertical stabilizer attachment points, two hydraulic tube fittings were pulled upward and bent to the left. Between the aft vertical stabilizer longitudinal attachment points, two longitudinal rows of fasteners were pulled downward through the skin, resulting in dimples around the holes.

Impact marks on the fuselage were observed in several locations in the vertical stabilizer attachment area. Deformation from a severe mechanical impact was observed on the forward face of the right center clevis fitting inboard lug. An impact mark was observed on a stiffener just outboard of the right center clevis fitting.

2.2 Vertical Stabilizer

The vertical stabilizer was largely intact with no significant areas of skin buckling. An overall view of the right side of the vertical stabilizer is shown in figure 9 as it was examined at NASA Langley Research Center. The LE fairings were removed for shipping from Floyd Bennett Field. There were some localized areas of damage on the vertical stabilizer, which will be described below. At the lower end, shown in figures 10 and 11, each of the six attachment locations were separated either by fractures that intersected the lug attach hole or by fractures through the structure above the hole. Portions of rib 1, the rib 1 rib-to-skin attach angle, and the lower end of the forward spar also were fractured. Along the trailing edge, the TE panels were damaged in several locations.

2.2.1. Lower End: Longitudinal Lugs

Two views of the right aft longitudinal lug are shown in figures 12 and 13. Figure 13 shows the lug fracture after a piece of rib 1 was removed. As shown in figure 10, the piece of rib 1 covered the inboard side of the translaminar fracture in the forward leg of the lug. The fracture surfaces intersected the lug attach hole. The lower portion of the lug was missing and was not recovered. The translaminar fracture surfaces appeared to have a rough appearance consistent with fracture under primarily tensile loads. Fractures on each leg of the lug were on different translaminar planes, and the change in planes occurred near the center of the lug thickness. On the aft leg, the outboard side of the fracture was in a plane nearly perpendicular to the zero-degree fiber direction, and the inboard side of the fracture was in a plane approximately 45 degrees from the zero-degree fiber direction. On the forward leg, the outboard side of the fracture was in a plane approximately parallel to the zero-degree fiber direction, and the inboard side of the fracture was in a nearly horizontal plane. Some ply separation was observed above the fracture, with the largest separations intersecting the translaminar fracture where the fracture plane changed. The ply separations visible as cracks on the surface were limited to the lug region below rib 1.

The bore of the right rear lug was in good condition, showing bearing contact over a large portion of the bore surface. A few lines of partially circumferential white powdery deposits were noted on the bore surface.

Views of the right center lug area fracture are shown in figures 14 and 15. The fracture occurred in the vertical stabilizer structure above the lug bore, and the lower piece remained attached to the fuselage as shown in figure 15. Translaminar fractures occurred in the skin and the lug build-up layers (precured halves) primarily in a slightly curved plane perpendicular to the zero-degree fiber direction at a location up to approximately 12 inches above the lug attach bolt centerline. The translaminar fracture appeared rough, consistent with fracture from tensile loading. The stringer module layers[3], as can be seen in figure 14, remained with the main portion of the vertical stabilizer, and tape layers (stringer outer flange layers) between the stringer module layers and the lug build-up layers (precured halves) also remained with the vertical stabilizer. Rib 1 fastener holes near the lower end of the stringer module layers were torn out in a downward direction for the fasteners that remained with the lower piece. A piece of the upper leg of the rib 1 attach angle also remained with the lower piece. Some layers of tape pulled out from the lower piece near the forward side and remained with the upper piece. There was a ply separation on the forward edge of the lower piece in a fire-damaged area.

For the right center lug area, the space between the vertical stabilizer lug and each lug of the fuselage clevis fitting was greater on the outboard side than the inboard side. The vertical stabilizer lug piece was free to rotate on the attach bolt.

Views of the right forward lug are shown in figures 16 and 17. The fracture surfaces intersected the lug attach hole. Most of the lower portion of the lug was missing and was not recovered, but a small amount of composite material was left in the circumferential groove between the two hat bushings that remained attached to the fuselage. The translaminar fracture surfaces appeared to have a rough appearance consistent with fracture primarily under tensile loading. On the aft leg of the lug, fracture occurred on different planes. On the inboard and outboard sides of the aft leg, the fracture was on planes perpendicular to the length of the front spar, and near the center of the aft leg (with a width of approximately 50 percent of the thickness), the fracture was on a plane at a 45-degree angle to the zero-degree fiber direction. On the forward leg of the lug, the fracture surface was almost entirely on a plane that was perpendicular to the length direction of the front spar.

The bore of the right forward lug was in good condition, showing bearing contact over a large portion of the bore surface. A few lines of partially circumferential white powdery deposits were noted on the bore surface.

Views of the left aft lug area fracture are shown in figures 18 and 19. The fracture occurred in the vertical stabilizer structure above the lug bore, and the lower piece

[3] The stringer module layers are fabric layers associated with the building up of the stringers. At their lower end, the fabric layers are assembled inside the upper leg of the rib 1 attach angle.

remained attached to the fuselage as shown in figure 19. A translaminar fracture occurred near the center of the lug (about four inches above the lug bore), fracturing primarily at the rib 1 fastener row as shown in figure 18. The fracture intersected most of the fastener holes except for an area near the forward end, where the fracture was above the holes. The fracture surfaces were generally rough on the inboard side of the fracture, but appeared smoother on the outboard side of the fracture, consistent with either a bending fracture or a tensile fracture with post-fracture damage. Interlaminar fractures occurred at either side of the middle piece that fractured from the middle of the lug and between the stringer module layers and the lug build-up layers. Some of the tape layers between the stringer module layers and the lug build-up layers also remained with the upper piece and some remained with the lower piece. Fractures at the upper end of the lower piece generally appeared to correspond with the upper ends of the lug build-up layers.

The left stringers 1, 2, and 3 were cracked or fractured at the stringer runout area near the bottom end of the stringers. A small part at the runout of stringers 1, 2, and 3 had web and flange damage consistent with outboard bending. Rib 1 fasteners were pulled out of the stringer module layers and the fasteners remained attached to the lower piece of the lug.

The left lightning strap at the aft spar was buckled at a position about 7.5 inches above rib 1. Interlaminar fracture was observed intersecting the aft surface of the left skin in this area, visible from 5.5 inches to 10.5 inches above rib 1.

Views of the left center lug area fracture are shown in figures 20 and 21. The translaminar fracture occurred in the vertical stabilizer structure above the lug bore, and the lower piece remained attached to the fuselage as shown in figure 21. There were multiple fasteners through the lug and adjacent structure both above and below the fracture associated with a factory repair (concession number TH-9802). There was no visible sign of distress or fracture associated with the repair fasteners. None of the other fittings had similar fasteners. The translaminar fracture occurred primarily at the rib 1 fastener row as shown in figure 20, intersecting most of the rib 1 fastener holes. The fracture was horizontal and perpendicular to the skin surface. The fracture surfaces were generally rough, consistent with fracture under primarily tensile loading.

Views of the left forward lug are shown in figures 22 to 24. The fracture surfaces intersected the lug attach hole. The lower portion of the lug remained with the fuselage and had a darkened appearance consistent with severe exposure to heat and fire as shown in figure 24. The upper side of the fracture is shown in figures 22 and 23. On the aft leg of the lug, the translaminar fracture was primarily on a horizontal plane and appeared rough, consistent with fracture under tensile loading. On the forward leg of the lug, the translaminar fracture intersected the bore nearly tangentially and was primarily on a plane parallel to the zero-degree fiber direction. The fracture surfaces on the forward leg of the lug were rough with multiple ply separations in the leg above the fracture surface, consistent with tensile fracture with transverse shear. On the outboard side of the hole above the bore, a bearing indentation was observed as shown in figure 23. The indentation was approximately 1/8 inch deep and the shape corresponded to the profile of the upper

end of the outboard lug on the fuselage clevis attach fitting. Ply separation also was observed in the fire damaged lower portion of the lug that remained with the fuselage.

Above the lug fracture, an interlaminar fracture was observed where the stringer module layers were separated from the lug build-up layers. Rib 1 fasteners at the lower end of the stringer module layers were pulled through the layers. The interlaminar fracture intersected the lower surface of the vertical stabilizer from the front spar aft to approximately 1.5 inches aft of stringer 21. The interlaminar fracture intersected the forward surface of the vertical stabilizer from rib 1 to above rib 2. Between ribs 2 and 3, the interlaminar fracture was observed intersecting the interior surface of the left skin panel at the stringer 24 flanges and at the front spar flange.

2.2.2 Lower End: Transverse Lugs

A view of the upper portion of the aft transverse lugs is shown in figure 25. The translaminar fractures of the lugs intersected the yoke attach holes. On the right lug, the outboard leg was fractured in a vertical plane and intersected the yoke attach hole approximately at a 90 degree angle. The inboard leg was fractured at an approximately 45-degree angle to the vertical direction and intersected the yoke attach hole tangentially. On the left lug, the inboard leg was fractured in a near vertical plane, and the outboard leg was fractured at an approximately 45-degree angle to the vertical direction. All fracture surfaces except for the left outboard leg appeared rough, consistent with a tensile fracture. The left outboard leg had a smoother appearance consistent with compression fracture. A bearing failure was observed on the forward face of the left lug with characteristic bearing cracks. The most prominent bearing crack extended approximately one inch upward and outboard from the lug attach hole. The lower pieces of the lugs remained with the fuselage transverse yokes. The lower pieces were darkened and had ply separations, consistent with exposure to heat and fire.

A view of the upper portion of the center transverse lugs is shown in figure 26. The translaminar fractures of the lugs intersected the lug attach holes. On the right lug, the outboard leg was fractured in a vertical plane, intersecting the bore approximately at a 90-degree angle. The inboard leg was fractured at an approximately 45-degree angle to the vertical direction, intersecting the bore approximately tangentially. On the left lug, the inboard leg was fractured in a near vertical plane, intersecting the bore approximately at a 90-degree angle. The outboard leg was fractured at an approximately 45-degree angle to the vertical direction, intersecting the bore approximately tangentially. All fracture surfaces were rough, consistent with fracture under tensile loading. The lower pieces of the lugs were not recovered.

As shown in figure 11, the forward spar was fractured above the forward transverse lug attachment area at a position approximately 14 inches above rib 1, just below two racks for electronic equipment. A piece of the spar remained attached to the fuselage left transverse yoke, as shown in figure 27. This remnant piece had an edge of an access hole at the upper end. The lower piece of the right attach lug also remained in the right transverse yoke. The pieces that remained with the attach yokes had heavy fire damage.

2.2.3. Lower End: Rib 1

Overall views of the lower end as shown in figures 10 and 11 show the rib 1 damage. The portion of rib 1 between the aft spar and center spar was missing except for two areas: (1) An area adjacent to the right side of the aft spar (about 21 inches by 14 inches). The forward end of this area was deflected downward and was held in position by the fracture surface on the right aft lug. (2) A triangular area at the left center fitting (about 9 inches by 8 inches). Portions of the lower leg of the rib 1-to-skin attach angle remained, and fasteners were pulled downward through those remaining areas. At the forward end, the center portion of rib 1 was missing from the front spar back to the forward end of an access hole, and the left side of rib 1 was missing from the front spar back to the aft end of that access hole.

2.2.4. Lower End: Other Damage

Rudder actuator control tubes (two acting in parallel) extend vertically through the fuselage and vertical stabilizer between the forward and center lug attachment locations, then horizontally aft from the bell crank at the upper end of the vertical tubes. The lower ends of the vertical tubes were fractured in tension adjacent to the lower rod ends. The upper rod ends of the vertical tubes were bent aft. The following sets of witness marks were observed on these rudder actuator control rods and adjacent structure. The second, third, and fourth marks listed could be created only with the vertical tubes pulled downward and the horizontal tubes moved forward an amount greater than could be accomplished by hand forces.

(1) Witness marks were observed on the lower aft edge of the center spar of the vertical stabilizer between the lateral yokes. The vertical tubes contacted the center spar witness marks when they were rotated aft to a near horizontal position.
(2) The lower side of the horizontal tubes had a set of witness marks 7.25 inches aft of their forward attach point on the bellcrank. The lower side of a cutout in the center spar had corresponding contact marks. At the time of the examination at Floyd Bennett Field, the witness marks on the horizontal tube were about 3.5 inches aft of the edge of the center spar cutout.
(3) The lower side of the right horizontal tube had a witness mark 24 to 25 inches aft of their forward attach point on the bellcrank. A corresponding contact mark was observed on a rib 3 cross brace. At the time of the examination at Floyd Bennett Field, the witness mark on the horizontal tube was about 3.5 inches aft of the cross brace.
(4) The lower side of the horizontal tubes had a set of witness marks 87.5 inches aft of their forward attach point on the bellcrank. The lower side of a cutout in the aft spar had corresponding contact marks. At the time of the examination at Floyd Bennett Field, the witness marks on the horizontal tube were about 3.5 inches aft of the edge of the aft spar cutout.

The upper rod end bearings of the vertical rudder control tubes had extensive damage. All of the balls were missing from the bearing for the right rod end, and the inner

race was fractured. The right rod could move vertically up and down on the rod end. The left rod end bearing had less damage, and the rod could not move vertically. Other bearings in the rudder control rod linkage did not show similar damage. During recovery, as shown in figure 3, the lower ends of the vertical rudder control tubes were bent to the aft by a hoisting strap.

The rib 3 forward section left hand diagonal channel was fractured at the front spar/skin panel junction as shown in figure 28.

2.2.5. Trailing Edge

Overall views of the vertical stabilizer trailing edge are shown in figure 29. A metal cover plate was present on the vertical stabilizer at the lower end of the hingeline. A closer view of this plate is shown in figure 30. The aft end of the plate was bent upward. Several marks were present in the black surface residue, the paint, or as scratches in the metal. The marks appeared to correspond to contact with the lower end of the rudder LE fairing and portions of the lower cover plate for the rudder LE fairing. One mark was continuous across the bend at the aft end and appeared to correspond to off-axis contact with the lower end of the rudder LE fairing before the plate was bent.

The TE panels on the vertical stabilizer were damaged in several locations. The left TE panel near hinge 1 was damaged. This area was not contacted by hoisting straps as the vertical stabilizer was recovered from the water, as shown in figure 3, but a strap was placed at this damaged location when the vertical stabilizer was hoisted onto a truck for shipping to Floyd Bennett Field.

Hydraulic lines aft of the aft spar of the vertical stabilizer were separated from their support brackets from hinge 2 downward. The three aluminum hydraulic lines were mostly missing.

The right TE panel at hinge 4 was fractured 13 inches forward from the aft edge of the panel. The support bracket for the right TE panel was bent inboard, 3 inches below the fracture. The left TE panel was fractured 10 inches below hinge 2, and the upper piece was deformed inboard. The two lateral support arms that attach to hinge fittings for hinges 2 and 3 for the hinged left TE panel were buckled, consistent with the left panel being pushed inboard. As shown in figures 3 and 4, a hoisting line was located in this area during recovery.

The right TE panel was fractured at the trailing edge both above and below hinge 5. The cross brace below hinge 5 had deformation and contact damage consistent with contact with the hinge 5 forward fitting arms after fracture of the arms. As shown in figures 3 and 4, a strap was placed in this area during recovery.

At hinge 6, the inboard side of the right TE panel had scuff marks and carbon fibers embedded in the surface.

At a location approximately 18 inches below hinge 7, the left TE panel was fractured through both skins within an approximate 3-inch diameter. The location of this fracture corresponded to the lower end of the rudder piece that remained attached to the hinge 7 aft fitting.

The aft edge of the left TE panel and support frame at hinge 7 was deformed inboard and forward along approximately 30 inches of the panel. The upper end was deformed more. The deformation corresponded to contact with the hinge 7 remnants that remained attached to the vertical stabilizer described in more detail below.

The aft end of the tip fairing was pushed forward, consistent with contact with the upper end of the rudder.

2.3. Rudder Hinge Fittings

All of the fractures of the metallic rudder hinge fittings and fitting attach bolts were overstress fractures. Hinges 1 and 5 fractured at two locations. The aft fitting for hinge 1 fractured from the rudder spar as well as at the hinge point. The aft fitting for hinge 5 fractured from the rudder spar, and the forward fitting for hinge 5 fractured through the hinge arms adjacent to the aft spar of the vertical stabilizer. The CFRP forward attach flange for the forward fitting from hinge 6 separated from aft spar of the vertical stabilizer, and all portions of hinge 6 remained intact and attached to the rudder. The rudder spar fractured around the aft attach fitting at hinge 7, and all portions of hinge 7 remained intact and attached to the vertical stabilizer.

2.3.1. Hinge 1

Overall views of the hinge 1 aft fitting attach area are shown in figure 31. Three of the four aft fitting attach bolts fractured at hinge 1. The fitting fractured around the right lower attach bolt (see lower left photograph, figure 31), and the forward (head) end of the bolt was bent downward. The upper right attach bolt was fractured at the forward surface of the rudder spar and had a smeared fracture appearance, consistent with a shear fracture. The direction of shear for the upper right bolt was consistent with the forward (missing) piece of the bolt moving downward and to the left relative to the remaining piece. The bolts on the left side of the rudder fractured in the threaded area approximately one inch aft of the rudder spar forward surface. The fracture surfaces had features consistent with overstress fracture. Some small shiny smeared areas were present on the fracture surfaces consistent with post fracture damage. Bearing failures were observed on the upper left sides of the left side bolt holes in the rudder spar. The shear fracture, bending, and bearing failures are consistent with the rudder spar moving to the right and twisting counterclockwise (as viewed looking forward) relative to the aft fitting attachment flange as the fractures and damage were produced.

The hinge 1 forward fitting remained attached to the vertical stabilizer as shown in figure 29. The two-piece forward fitting consisted of upper and lower halves. The forward fitting fractured just forward of the rudder hinge point with deformation consistent with the

aft hinge piece rotating clockwise (as viewed looking forward) relative to the forward piece, as shown in figure 32. The portion of the hinge 1 forward fitting that was aft of the fracture was not recovered.

The rudder position sensor remained attached to the upper side of the hinge 1 forward fitting. The sensor arm was fractured in the threads near the jam nut on the rod end bearing and had features consistent with overstress fracture in tension.

2.3.2. Hinges 2, 3, and 4

The rudder position actuators control the rotational position of these three hinges. All three hinges fractured in the flanges of the aft fittings or in the aft fitting attach bolts, leaving most of the aft fittings and some of the adjacent rudder spar material remaining with the vertical stabilizer, as shown in figure 29. In general, the majority of the adjacent rudder spar material that remained with the vertical stabilizer was from the left side of the rudder spar. Also, the overstress fracture features and associated deformation of hinges 2, 3, and 4 aft fitting attachment flanges and flange attachment bolts were consistent with the rudder moving in a trailing edge left (TEL) direction with the hinges held stationary by the actuators. Hinge 4 was restrained in the vertical direction by the vertical support strut (see figure 29). The position of the aft fittings of hinges 2 and 3 was slightly lower than their position with an intact rudder, and they were rotated slightly to a trailing edge right (TER) position relative to hinge 4.

Relatively small pieces of the hinges 2 to 4 aft fittings remained with the rudder, and views of these pieces are shown in figures 33 to 35 (right side) and 36 (left side). On the right side, attach bolts for the aft fittings of hinges 2 and 3 remained in place, as shown in figures 33 and 34, and each fitting fractured around the bolt heads. The only fracture on the right side of the aft fitting of hinge 4 was around the lowermost bolt head (barely visible at the bottom of the photograph in figure 35). The remainder of the right side of this fitting was intact but separated from the rudder spar by fracture of the five upper attachment bolts. The fracture surfaces of the right side of the aft fittings from hinges 2, 3, and 4 were similar to each other. They had a matte gray appearance over most of the fracture surfaces, and at the aft side of the fracture, the mating fracture surfaces appeared shiny and smooth, consistent with compression and shear in these areas. The hinge 4 attach bolts on the right side were fractured in the threaded region and had fracture features consistent with tensile overstress failure. The recovered forward ends of the right side attach bolts were bent slightly (approximately 3 degrees) with the head bent inboard relative to the threaded end.

The left side pieces of the aft fittings of hinges 2 to 4 that remained attached to the rudder are shown in figure 36. These pieces of the fittings showed more deformation than the right side pieces, with the inboard side of these pieces bent forward at the fracture. The fracture surface for the left side of the hinge 2 aft fitting intersected the bolt holes. The hinge 3 aft fitting left side fracture intersected the lowermost attach bolt hole and went around the head of the center attach bolt. The uppermost bolt fractured just aft of the head with deformation consistent with a bending fracture. The lower two attach bolts were bent

outboard at the head, and the inboard piece of the fitting had witness marks corresponding to contact with the bolt heads. On hinge 4, the aft fitting fracture surfaces intersected the bolt holes of all but the lowermost attach bolt. The fitting fracture surfaces on the left side were similar to each other. They had a matte gray appearance over most of the fracture surfaces, and at the forward side of the fracture, the mating fracture surfaces appeared shiny and smooth, consistent with compression and shear. The lowermost two left attach bolts for the hinge 4 aft fitting fractured in the threaded region and had fracture surfaces consistent with overstress fracture. The forward ends of these bolts were bent approximately 13 degrees, with the head end bent outboard relative to the threaded end.

A view of the aft side of the hinge 2 to 4 aft fitting pieces that remained attached to the vertical stabilizer is shown in figure 37. Portions of the rudder spar were attached to the fittings. Edges of the hinge fitting backing plates on the aft side of the spar were bent to the aft, including the two right corners on hinges 2 and 4 and the upper left corner and the entire right side on hinge 3.

2.3.3. Vertical Support Strut

A vertical support strut, shown in figure 38 and identified in figure 29, attaches at an angle between the hinge 4 forward fitting arms and the vertical stabilizer aft spar structure. The strut maintains the vertical position of the rudder hingeline. Two sets of markings were observed on the strut at locations on the upper and the left sides near the middle of the length of the strut. An arrow in figure 38 indicates the damage on the upper side. Closer views of these marks are shown in figures 39 and 40.

2.3.4. Hinge 5

An overall view of the forward and aft fittings of hinge 5 is shown in figure 41. The aft fitting was fractured on the right and left sides. On the right side, the fracture surfaces intersected the attach bolt holes and had a matte gray appearance consistent with overstress fracture. The inboard piece adjacent to the right fractures was bent slightly forward consistent with the left side moving forward relative to the right side. On the left side of the aft fitting, the fracture was inboard of the attach bolt holes and had a matte gray appearance consistent with overstress fracture.

An interface plate (shim) was present between the aft fitting and the rudder spar. On the right side, the plate was fractured through the attach bolt holes, and the right upper half was bent to the aft. On the left side, the plate also was fractured through the attach bolt holes, and the entire left side was deformed to the aft.

A portion of the rudder spar remained attached to the aft hinge fitting. A view of the piece is shown in figure 42 adjacent to the attachment location on the rudder. The rudder spar section attached to the fitting was damaged on its lower side, as indicated by arrows in figure 42. The damage corresponded to contact with the lower side of the hinge cutout in the rudder LE panel.

Both arms of the hinge 5 forward fitting were fractured at the forward end near the fitting attach points. The major portion hinge 5 remained attached to the vertical stabilizer only by two copper wires that made an electrical connection between the forward fitting arms and the lightning strips at the aft sides of the vertical stabilizer skin panels. The fractures at the forward end of the forward fitting were consistent with overstress fracture by bending, with the aft end of the forward fitting moving downward relative to the vertical stabilizer aft spar.

2.3.5. Hinge 6

All portions of hinge 6 remained intact and attached to the rudder, as shown in figure 43. The upper flanges of the forward fitting arms were deformed, consistent with contact with the upper edge of the rudder LE fairing cutout for hinge 6, and friction marks were observed on the lower flanges, consistent with contact with the lower edge of the rudder LE fairing cutout.

The forward fitting remained attached to portions of the two vertical stabilizer aft spar-to-hinge fitting attach angles. The vertical legs of the attach angles had mostly interlaminar fractures from the aft spar with holes where fasteners pulled through and associated tear-outs to the edge of the flange. The attach angles had translaminar fractures near the right attach point for the hinge arm.

2.3.6. Hinge 7

An overall view of hinge 7 is shown in figure 44. The hinge fitting remained intact and attached to the vertical stabilizer along with some adjacent pieces of the rudder skin panels and spar. The two-piece forward and aft fittings consisted of upper and lower halves. In overall deformation, the hinge fittings were twisted clockwise (as viewed looking forward). On the upper half of the forward fitting, the inboard flange of the right leg was locally bent forward in a location consistent with contact with the upper side of the cutout in the rudder LE fairing.

On the aft fitting, the mating faces of the upper and lower halves were deformed apart at the outboard edges near the aft flange of the fitting. At the right side of the aft hinge fitting, the right fitting-to-rudder attach block was deformed inboard.

On the right side of the aft fitting, two brackets connect the aft hinge fitting to the lightning strap at the inner surface of the skin to spar attach flange. On the lower bracket, the outboard fastener heads on the outboard leg of the bracket fractured off. On the upper bracket, the outboard leg of the bracket was fractured through the fastener holes. Two marks were observed on the aft edge of the right TE panel of the vertical stabilizer, as shown in figure 45. The marks had features and spacing consistent with contact with these fractured rudder fairing brackets. However, when examined with the overall twisting deformation in the hinge, the brackets contacted the aft edge of the panel at a location below the marks.

2.4. Rudder

Overall views of the right and left sides of the rudder are shown in figure 46, where the pieces of the rudder were placed in their respective positions. The perspective of the views shown (photographs taken with the upper ends closer to the camera) make the upper and lower ends appear relatively larger and smaller, respectively. Drawings of the right and left sides of the rudder are shown in figure 47, where the approximate fracture locations and missing pieces are shown. The larger skin panel pieces were labeled for reference in the figure. The first letter of the label represents the approximate location of the piece, lettered from top to bottom, and the remaining letters indicate right hand skin (RHS) or left hand skin (LHS).

The rudder's lower rib and spar are each attached to the skin panels through "Z" shaped CFRP flanges bonded to the skin panels. The outer leg of the "Z" flange is bonded to the inner surface of the skin panel external facesheet that extends forward past the spar or downward past the lower rib. The center leg extends perpendicularly inboard, and is attached to the end of the skin panels with blind rivets. The inner leg is bonded to the inner surface of the skin panel internal facesheet.

2.4.1. Rudder Leading Edge

Overall views of the damage at hinge 1 are shown in figures 31, 48, and 49, showing the damage from the forward, left, and right perspectives. A portion of the rudder spar was missing from the hinge attach area. On the LE fairing, there was no evidence of hinge arm contact with the right side of the hinge cutout as shown in figure 49. On the left side of the hinge cutout, pieces of the LE fairing were missing from above, below, and aft of the hinge cutout, as shown in figure 48. The lower side of the cutout was deformed consistent with contact with an object moving forward and to the left relative to the LE fairing.

The metal lightning strip[4] on the right side was buckled at a location approximately five inches below the hinge 1 LE fairing cutout.

The LE fairing was fractured nearly spanwise on the right side from below the hinge 1 cutout to just below the hinge 2 cutout. Most of this fracture can be seen in figure 49. At its lower end the fracture was located 8.5 inches forward of the spar and approximately 3.75 inches above the lower end of the LE fairing. At its upper end the fracture was located 9 inches forward of the spar and 7 inches below the hinge 2 cutout. Scuffing damage was observed adjacent to this fracture and appeared most extensive approximately 6.5 to 9 inches forward of the spar and approximately 22.5 to 33.5 inches above the hinge 1 cutout, where indicated by arrows in figure 49. The LE fairing also contained a nearly spanwise crack between the hinge 1 and 2 cutouts just right of the LE fairing centerline. This crack was only in the external face sheet and honeycomb, consistent with inward bending loads. The upper ends of the nearly spanwise fracture and crack are shown in figure 50.

[4] Metal lightning strips were located on the inner surface of the inner leg of the spar to skin flanges.

A view of the rudder spar at hinge 1 with some of the LE fairing removed is shown in figure 51. On the right side, the rudder spar "Z" shaped attachment flange had translaminar fractures just below the hinge 1 attach location. Above hinge 1 on the right side, the flange fracture was located in the outer leg at a location 5 inches above the hinge 1 attach location and was in the radius between the center and outer flanges up to the fracture in the center and inner legs at 16 inches above hinge 1. On the left side, the rudder spar had a translaminar fracture and interlaminar fractures at the hinge 1 attachment location. The lower attach hole on the external facesheet was torn out on the upper left side and the upper hole was missing, but the holes in the rudder spar flange remained intact with bearing failures on the upper left sides as shown in the lower right photograph of figure 31.

The rudder spar web above hinge 1 was fractured along the left side and remained attached to the right skin panel in that area. The fracture appeared consistent with transverse tension, i.e. the right and left skin panels moving outward relative to each other.

The internal face sheet of the spar web was fractured from the core in an area above hinge 1, as shown in figure 51. Blind rivets at the left side of the spar pulled through the external facesheet in this area. This fracture was consistent with a tensile or peeling force perpendicular to the plane of the spar web.

Below hinge 1, an area of the spar web was fractured from the right flange with a forward motion. The blind rivets on the right side of the spar pulled through the external facesheet in this area. This fracture was consistent with a tensile or peeling force perpendicular to the plane of the spar web.

An overall view of the LE fairing in the area of hinges 2 to 4 is shown in figure 52. The LE fairing in this area had numerous fractures. Many pieces in this area, mostly from the left side, were not recovered. One piece of the fairing in this area, the piece between hinges 2 and 3 on the left side, was found on land. The internal and external facesheets of the LE fairing on the right side were fractured spanwise adjacent to the spar, but the fairing piece remained attached to the skin panel. None of the ends of the LE cutouts showed evidence of contact with the hinge arms.

The left metal lightning strip was deformed at the fractures above and below hinge 4. Below hinge 4, the lightning strip below the fracture was locally bent forward. At the fracture above hinge 4, the left lightning strip was buckled and twisted, consistent with compression loading and with the piece below the fracture rotating clockwise relative to the upper piece as viewed from below.

On the right side of the LE fairing near hinge 3, four puncture holes were observed approximately 0.2 inches in diameter. An impact mark with a similar diameter that did not completely penetrate the outer facesheet was noted also in the area.

Most of the rudder spar web had translaminar fractures in this area, and the shape of the fractured area corresponded to the shape of the pieces remaining attached to the hinge fittings shown in figure 37. The pieces of the spar web between the hinges that

remained attached to the rudder had fractures between the facesheets and the honeycomb, consistent with a tension or peeling force perpendicular to the plane of the front spar web.

The spar web had a translaminar fracture that went between the center two attach bolt holes on the right side of the hinge 4 aft fitting attach area shown in figure 35. The spar web above this fracture, including the upper three attach bolt holes, remained attached to the large upper piece of the rudder that included skin panel pieces BRHS and CLHS. All of the hinge 4 attach bolt holes were intact with no tearout.

An overall view of the LE fairing at hinge 5 is shown in figure 53. Pieces of the upper forward and left side and the lower left side of the cutout were not recovered. The LE fairing was fractured at the right and left ends of the cutout, but there was no evidence of contact with the forward hinge fitting arms. On the internal surface on the right side, scrape marks were present leading up to the fracture area at the right end of the cutout. The upper left side of the metal flange on the lower side of the cutout was deformed forward. The shape of the deformation and witness marks were consistent with contact with the threaded end of the hinge point bolt after the aft hinge fitting fractured from the rudder spar.

The spar web was fractured around the hinge 5 aft fitting, and the piece that fractured remained attached to the aft fitting and vertical stabilizer. The forward facesheet of the rudder spar web was separated from the honeycomb below the fracture, consistent with a tensile or peeling force perpendicular to the plane of the spar web.

Several cracks were observed in the spar web above hinge 5. The cracks were near the center of the web and were at approximately 45-degree angles to the spanwise direction.

Views of the right and left sides of the LE fairing around the hinge 6 cutout are shown in figures 54 and 55, respectively. The ends of the cutouts on both sides were damaged, and material was missing. The width of the damaged area corresponded to the width of the forward hinge fitting arms with breakouts above and below.

The upper left side of the hinge 6 cutout had rubbing damage corresponding to contact with the upper sides of the forward hinge fitting arms as shown in figure 56. This contact area corresponded to rudder positions greater than 10 degrees TEL. Other areas of both the upper and lower sides of the hinge 6 cutout also had damage corresponding to contact with the forward hinge fitting arms, but the damage in those areas was not as continuous or heavy.

Two holes were present near the centerline of the LE fairing approximately 43 inches and 50 inches below the hinge 7 attachment location with deformation to the aft. Red paint was observed near the edges of the fracture. Except for the stripes of the American flag on the vertical stabilizer skin panels, no red paint was present on the vertical stabilizer or rudder above hinge 5.

An overall view of the LE fairing at hinge 7 is shown in figure 57. The LE fairing had multiple fractures below the hinge 7 cutout. One of the pieces below the cutout was recovered on land. Material was missing from both the right and left ends of the cutout, and the width of the missing material appeared to correspond to the width of the forward fitting arms.

The upper left side of the LE fairing cutout at hinge 7 was damaged as shown in figure 58. Two distinct regions of damage on the hinge 7 rudder LE fairing cutout correspond to contact with each arm of the hinge 7 forward fitting at rudder angles of 10 to 24 degrees TEL. Other areas of the upper and lower sides of the cutout, including the upper radius of the left cutout end, did not appear to have damage corresponding to contact with the forward fitting arms.

The rudder spar web was fractured at the hinge 7 attachment location and remained attached to the aft hinge fitting as shown in figure 44. The right spar "Z" shaped attachment flange was fractured just above and below the aft hinge fitting. The left spar flange was fractured just above the aft hinge fitting and 19 inches below the hinge fitting.

2.4.2. Skin Panels, Trailing Edge, and Lower Rib

Drawings showing the approximate fracture locations for the rudder skin panels are shown in figure 47. In describing the damage, the skin panel labels shown in figure 47 will be used for reference.

Closer views of the fractures at the lower end for the right and left sides of the rudder are shown in figures 59 and 60, respectively. Piece GRHS was fractured entirely within the right skin panel. Piece GRHS was one of the three rudder pieces and the only skin panel piece recovered on land. Piece FRHS was attached to piece FLHS at the trailing edge and by a portion of the lower rib aft of the through bolts near the trailing edge.

A metal strip for retaining the rubber lower seal was attached at the lower end of the skin panel pieces. The metal retaining strip was fractured in several locations on the right and left sides. The right metal retaining strip was fractured 7.5 inches aft of the spar, and the aft side of the fracture was deflected downward approximately ¼ inch. The rubber sealing strip was partially fractured at this location.

The right metal retaining strip was fractured again at a location 37 inches aft of the rudder spar. Local deformation of the strip was consistent with the aft side of the fracture twisting clockwise as viewed looking forward. The rubber sealing strip was partially fractured at this location and completely fractured 34.5 inches aft of the rudder spar.

A third fracture of the right metal retaining strip was located 70.5 inches aft of the rudder spar. Local deformation of the strip was consistent with the forward side of the fracture bending outboard and twisting clockwise relative to the aft side. The relative

positions of the mating pieces at the time of fracture are shown in figure 61. The mating piece GRHS is also shown in this relative position.

The nutplate assemblies (for the threaded fasteners attaching the metal retaining strip, the skin panel, and the lower leg of the lower rib attach flange) were fractured from the lower leg of the lower rib attach flange on the right side aft of a location 38 inches aft of the rudder spar. The attach flange material below each nutplate was locally torn out, consistent with the nutplates moving downward and outboard relative to the attach flange.

The left metal retaining strip and rubber seal were fractured at a location 16.5 inches from the rudder spar. The local deformation was consistent with the aft fracture surface moving downward with some counterclockwise twist as viewed looking forward. Other areas of the left metal retaining strip were crippled between the fasteners, at locations 15.5, 27.5, and 42.5 inches aft of the rudder spar.

The lower end of the left skin panel FLHS was fractured above the lower rib attach flange from 12.5 inches to 41 inches aft of the rudder spar. The left lower rib attach flange was fractured at the radius between the upper and horizontal legs from 41 inches to 73 inches aft of the rudder spar. At the aft end of this fractured section, the lower rib was fractured at the inboard edge of the flange, and the horizontal leg of the flange was deflected upward.

The nutplate assemblies were fractured from the lower leg of the lower rib attach flange on the left side aft of a location 12.5 inches aft of the aft spar. The attach flange material below each nutplate was locally torn out, consistent with the nutplates moving downward and outboard relative to the attach flange.

Piece ERHS was located just above piece GRHS. The fracture at the upper end of piece ERHS was below hinge 2 and nearly chordwise. The fracture at the lower end was near hinge 1 and with some deviation, was nearly parallel to the lower rib. The external facesheet from the lower end of ERHS was attached to GRHS. Portions of the LE fairing and most of the rudder spar web remained attached to ERHS between the upper and lower ends.

Pieces HRHS and piece ELHS were attached to each other at the trailing edge. Piece HRHS was a relatively small piece of the right skin having mating fractures with FRHS, ERHS, and CRHS. Piece ELHS was a relatively large panel with the fracture at the lower end just above hinge 1 and nearly parallel to the lower rib. The fracture at the upper end was a chordwise fracture at hinge 4. The external facesheet from this panel was mostly separated from the honeycomb. The through bolts near the upper end remained attached to piece CRHS, and deformation around the holes was inward (to the right). Most of the LE fairing between hinge 1 and 2 remained attached to ELHS.

Piece CRHS was located just above ERHS. The upper and lower fractures were nearly chordwise, located just below hinge 2 at the lower end and just above hinge 4 at the upper end.

Pieces DRHS and DLHS were relatively small pieces of the skin panels that were attached to each other at the trailing edge.

The largest continuous spanwise length of the rudder included pieces BRHS and CLHS. This section of the rudder was largely intact, extending from just above hinge 4 to just below hinge 7. Both pieces were attached to the rudder spar and the LE fairings in that span, and the pieces were attached to each other at the trailing edge. At the lower end of piece CLHS, the through bolts near the trailing edge appear pulled inward (toward the right) relative to the external facesheet.

A piece of the external facesheet was missing from the upper side of CRHS and the lower side of BRHS. A closer view of the damage is shown in figure 62. Most of the fracture was a cohesive fracture in the facesheet epoxy inside of the fibers of the inner ply, leaving the honeycomb intact with fractured epoxy on the outer edges. At the lower end, the fracture was between the facesheet layers. Some areas were fractured in the honeycomb (areas of the honeycomb that appear darker in the photo), mainly near the aft side.

On BRHS at hinge 5, the rudder spar attach angle and adjacent skin were fractured. Local deformation of the attach angle corresponded to a compressive loading with a local displacement of 0.75 inches.

Piece BLHS was a relatively small piece of the left skin panel that remained attached to the hinge 7 aft fitting. A small piece of the LE fairing was attached at the lower end of the piece. The piece mated with CLHS at the lower end and ALHS at the upper end. The lower end of piece BLHS had twisting deformation such that the lower end was twisted counterclockwise relative to the upper end. With this twist, the piece of LE fairing contacted a damaged location on the left surface of the TE panel when the hinge was rotated into the heavy damage on the aft side of the TE panel.

The upper piece of the rudder included pieces ARHS and ALHS. Both pieces were attached to the rudder spar and LE fairing above hinge 7 and to the upper spar and upper fairing. The pieces were attached to each other at the trailing edge.

Pieces ALHS and BLHS had damage corresponding to heavy contact between the rudder left side and the vertical stabilizer left TE panel. A view of the damage on the rudder is shown in figure 63 with pieces ALHS and BLHS shown in their respective positions. Above hinge 7 on piece ALHS, the line of contact damage was nearly parallel to the rudder spar. Below hinge 7 on piece BLSH, the damage was not parallel to the rudder spar.

The metal trailing edge strips were fractured at many locations along the length of the rudder. The lowest fracture, shown in figure 64, was 36 inches above the lower rib,[5]

[5] Fracture locations at the trailing edge will be reported in lengths parallel to the length of the trailing edge rather than in terms of vertical height.

corresponding to the upper end of FRHS and FLHS. Both the left and right metal strips were fractured at this location, and the local deformation was consistent with bending, where the upper pieces HRHS and ELHS both bent to the right relative to the lower pieces FRHS and FLHS.

On the right side moving upward, the next two fractures in the metal trailing edge strips were at 75 inches and 99 inches above the lower rib, locations corresponding to the lower and upper sides of CRHS at the trailing edge. The metal piece between these fractures was missing. The fractures, shown in figures 65 and 66, had local twisting deformation that appeared symmetric, consistent with piece CRHS rotating counterclockwise relative to the upper and lower pieces as viewed looking up.

On the left side moving upward from the lowest fracture, the next two fractures in the metal trailing edge strips were at 76 inches and 100 inches above the lower rib, locations corresponding to the lower and upper sides of the missing piece aft of piece ELHS. The fractures had local twisting deformation that appeared symmetric, consistent with the missing piece rotating clockwise relative to the upper and lower pieces as viewed looking up. In addition, the lower fracture had bending deformation consistent with the missing piece bending to the left and downward, and the upper fracture had bending deformation consistent with the missing piece bending to the left.

Moving upward, the next trailing edge metal strip fracture was on the left at 135 inches above the lower rib, a location corresponding to the upper end of piece DLHS. Local deformation at the fracture was consistent with piece DLHS bending to the right relative to piece CLHS.

On the right side, the metal strip was separated at 159 inches above the lower rib, a location corresponding to a junction between the manufactured ends of two metal strip pieces. The upper portion of the metal strip had a general bend and twist as shown in figure 67 consistent with piece DRHS rotating upward and twisting counterclockwise (as viewed looking up) relative to piece BRHS.

The uppermost fractures of the trailing edge metal strips were aft and below hinge 7 between pieces BRHS and ARHS on the right and between pieces CLHS and ALHS on the left. An overall view of the right side is shown in figure 68. The local deformation on both sides of the fracture was consistent with pieces ARHS and ALHS bending to the right and aft relative to pieces BRHS and CRHS.

An overall view of the lower rib is shown in figure 69. The lower rib was fractured near the trailing edge at a location 61 inches aft of the rudder spar. Deformation in the area of the fracture was consistent with the aft piece rotating clockwise relative to the forward piece as viewed looking forward.

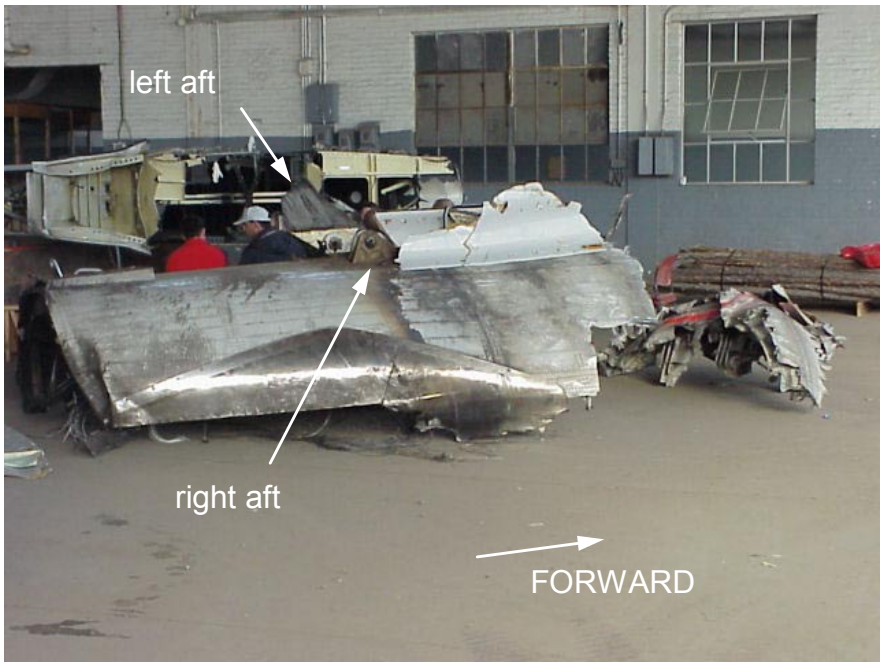
The external facesheet of the lower rib was fractured near the forward spar as shown in figure 69. The fracture was at an angle, intersecting the right skin attach flange at a location 5.5 inches aft or the spar and the left skin attach flange at a location 13 inches aft

of the spar. The fracture had a rough appearance, consistent with a compression fracture. No fracture was observed in this location in the internal facesheet of the lower rib.

Forward of the spar, a metal sheet closed the lower end of the LE fairing. The lower side of the metal closure was bent upward at the leading edge from the centerline through three inches to the right of the centerline.

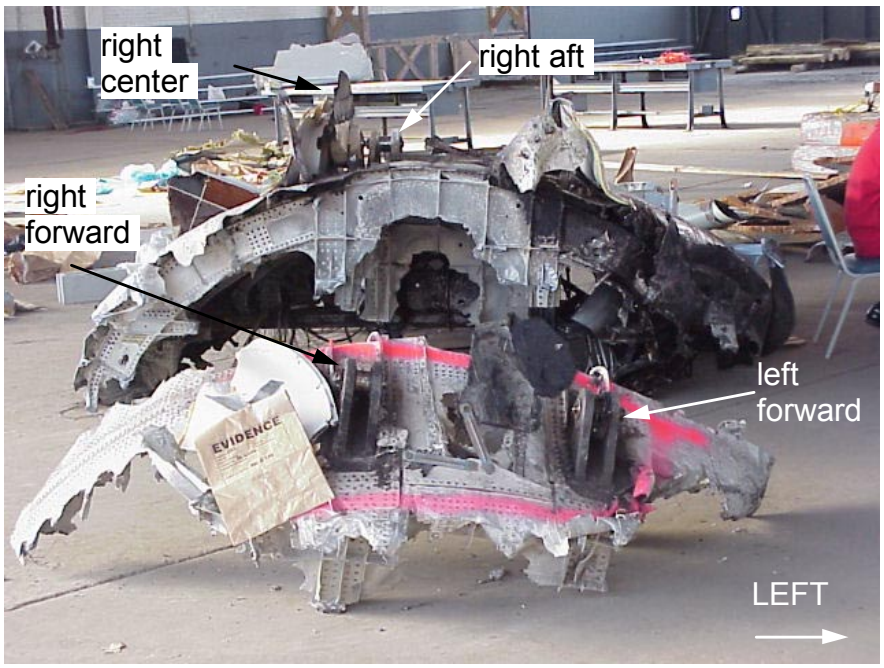
At the lower end of the LE fairing near the centerline, material was peeled from right to left as shown in figure 70. The fiberglass filler in the honeycomb cells was sheared on the right side of the damage. The right side of the washer for the fastener at the centerline was bent forward.

Matthew R. Fox
Materials Engineer



ImageNo:208A0115, Project No:A00386

Figure 1. Overall view of the fuselage pieces as examined at Floyd Bennett Field. The vertical stabilizer is shown in the background.

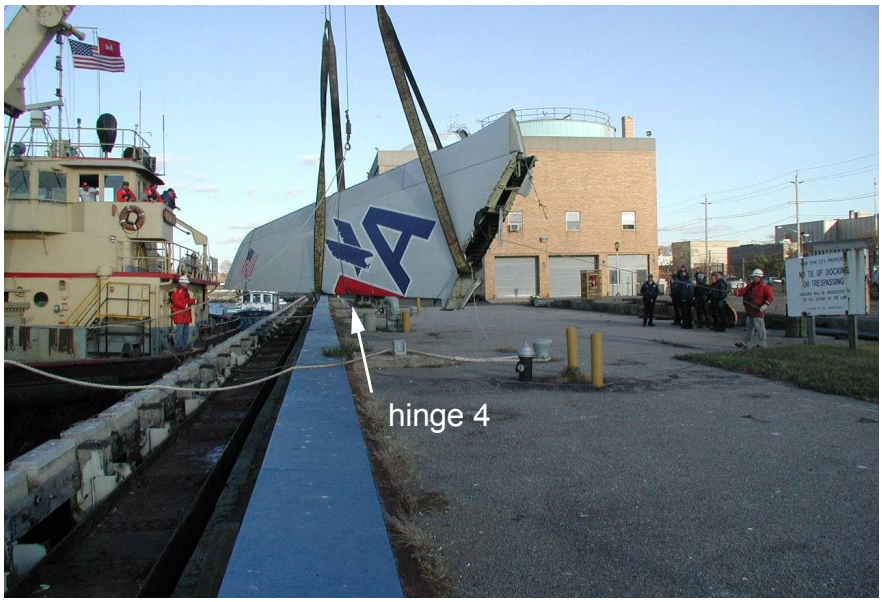


ImageNo: 208A0579, Project No:A00386

Figure 2. The fuselage pieces as viewed looking aft.

ImageNo:208A0112, Project No:A00386

Figure 3. Recovery photo showing the vertical stabilizer being hoisted from the water. Note hinge 5 is not visible and the control rods are swept aft under the strap at the lower end.



ImageNo: 208A0113, Project No:A00386

Figure 4. Another recovery photo showing the right side of the vertical stabilizer. Note the location of the hoist line just above hinge 4.

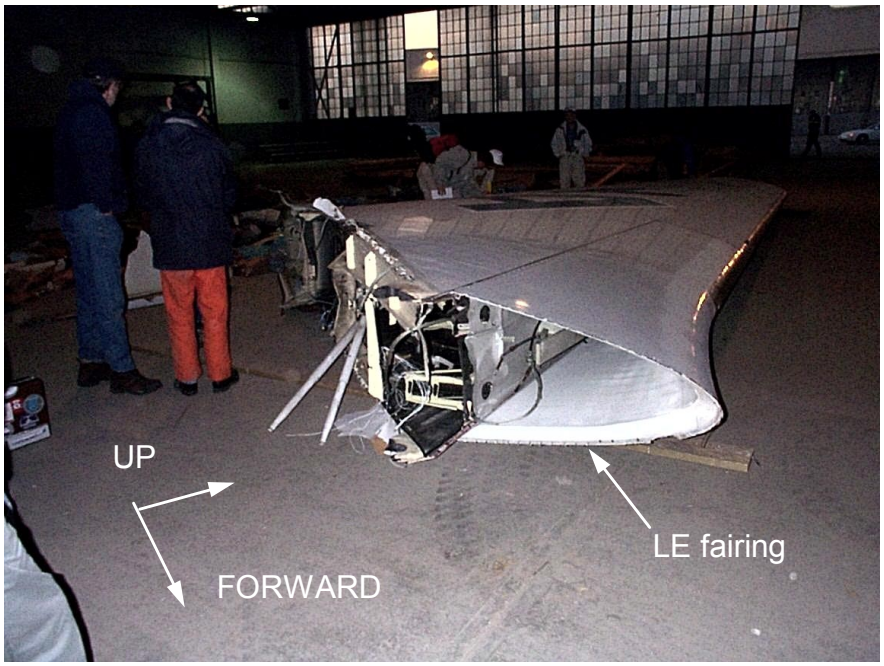


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Figure 5. View of the lower end and leading edge of the vertical stabilizer as it was first placed at Floyd Bennett Field.

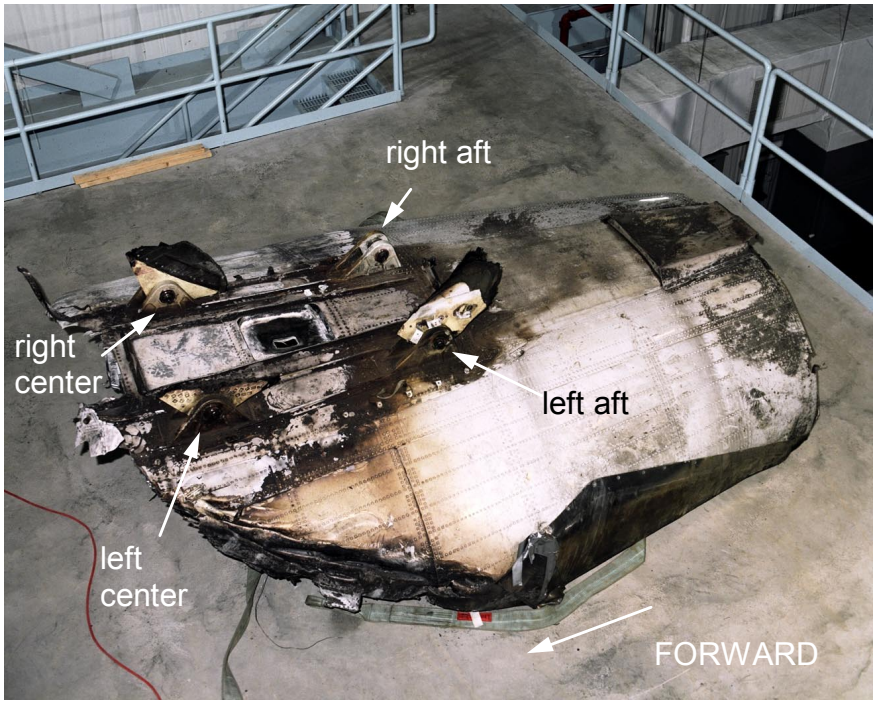


Figure 6. Overall view of the upper side of the aft piece of fuselage as it was examined at NASA Langley. Arrows indicate longitudinal lug attach locations.

ImageNo:208A0124, Project No:A00386

Figure 7. Closer view of the right side fairing clips, indicated by unlabeled arrows, on the aft fuselage piece viewed looking aft.

ImageNo: 208A0123, Project No:A00386

Figure 8. Closer view of the left side fairing clips on the aft fuselage piece viewed looking aft. Arrows indicate the sixth and seventh fairing clips from the aft.

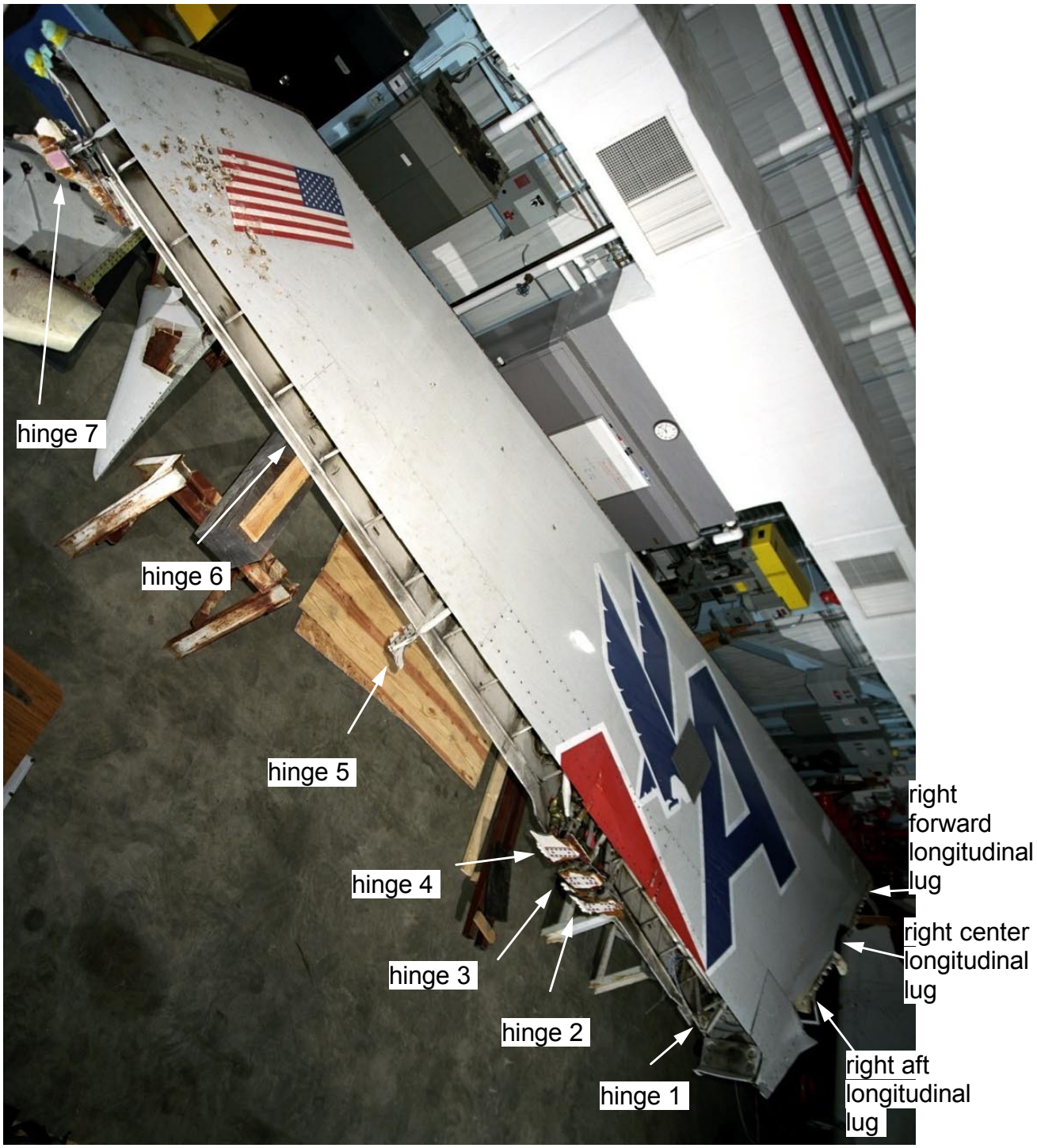
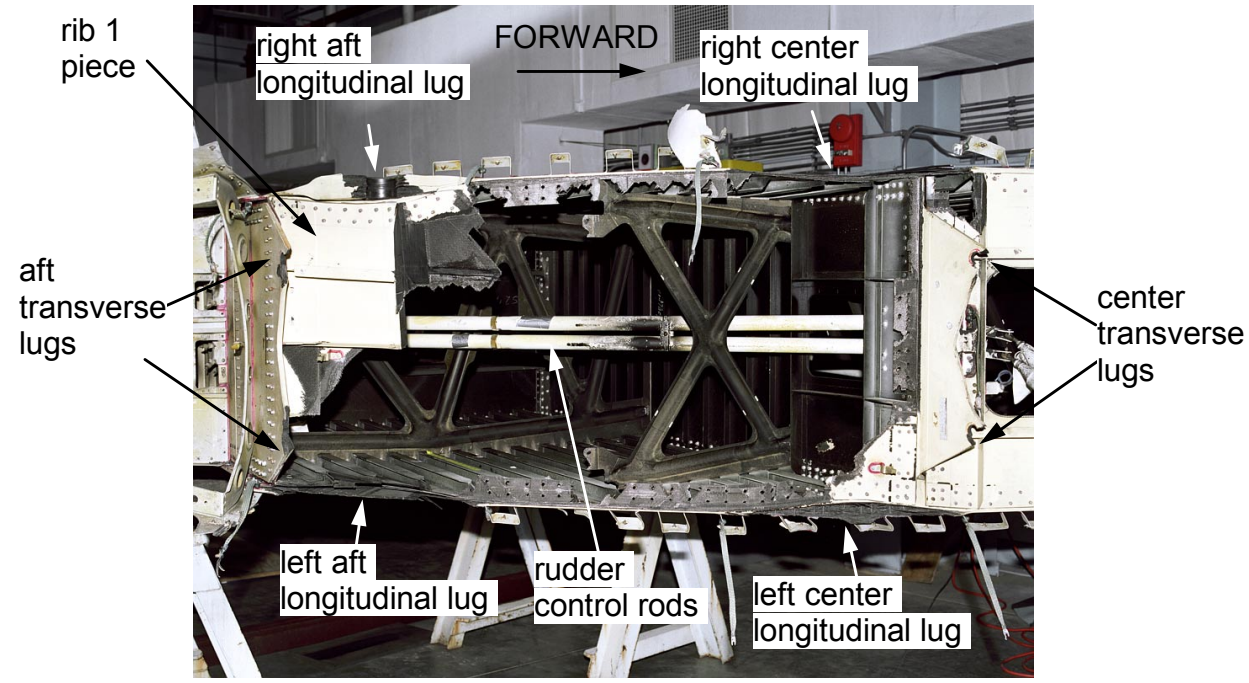
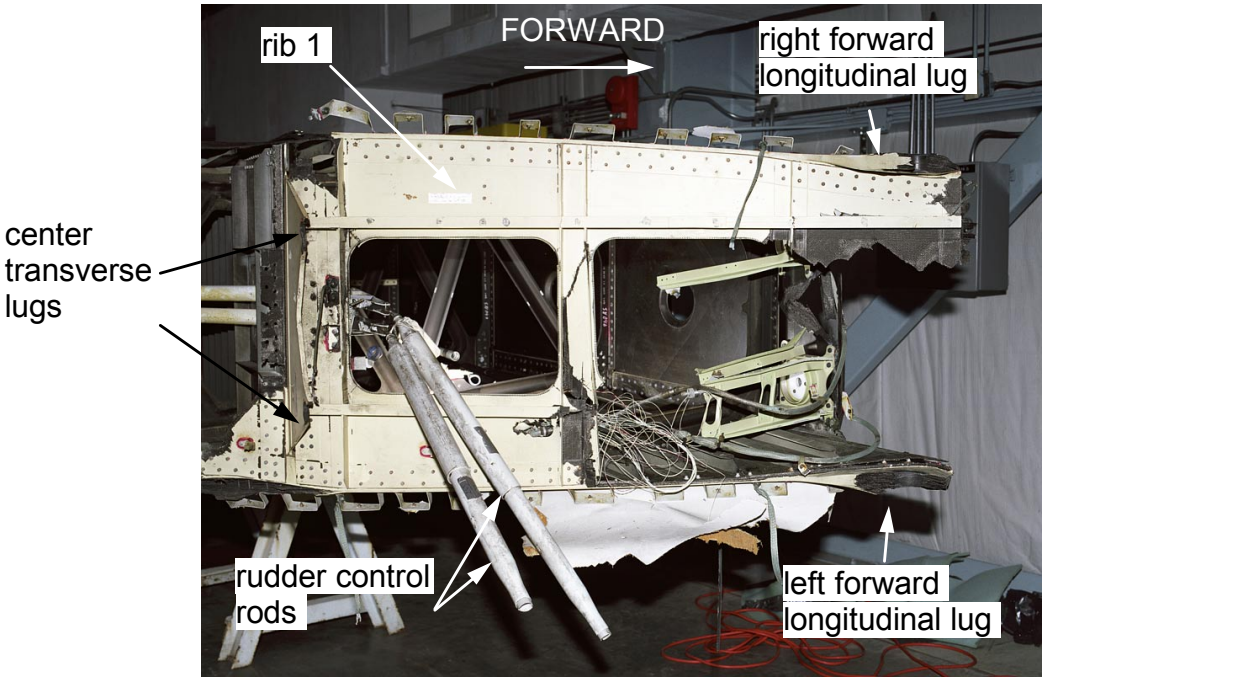


Figure 9. Overall view of the vertical stabilizer as it was examined at NASA Langley.



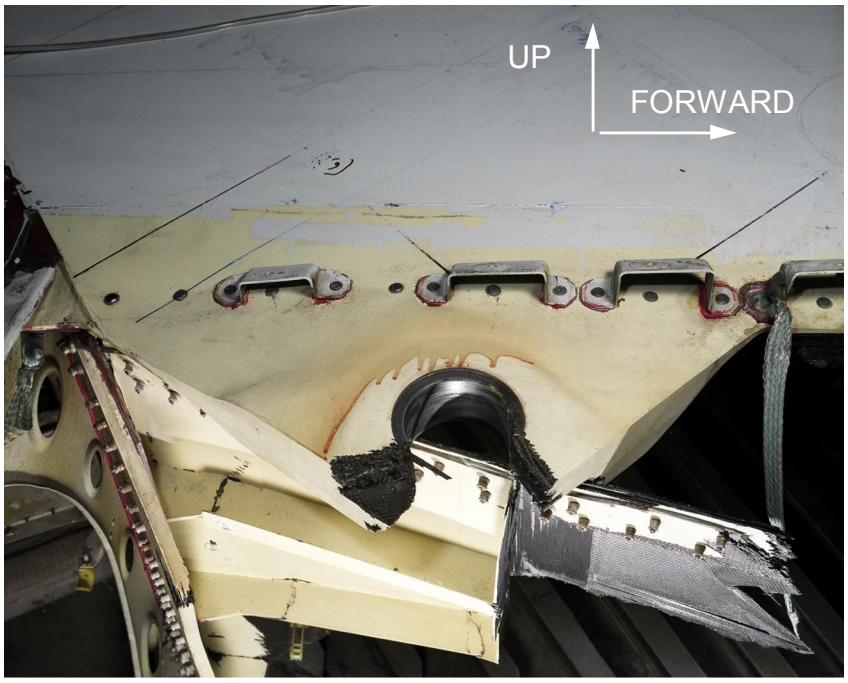
ImageNo:208A0214, Project No:A00386

Figure 10. View of the aft portion of the lower end of the vertical stabilizer.



ImageNo: 208A0215, Project No:A00386

Figure 11. View of the forward portion of the lower end of the vertical stabilizer.

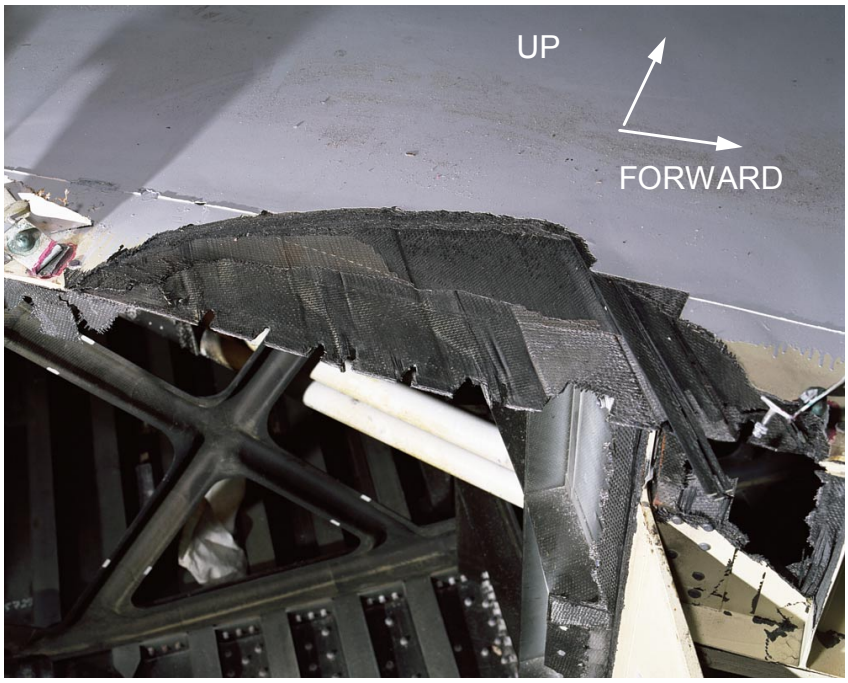


ImageNo:208A0259, Project No:A00386

Figure 12. View of the right aft longitudinal lug on the vertical stabilizer.

ImageNo: 208A0230, Project No:A00386

Figure 13. Another view of the right aft longitudinal lug on the vertical stabilizer shown after the piece of rib 1 that covered part of the fracture was removed.



ImageNo:208A0221, Project No:A00386

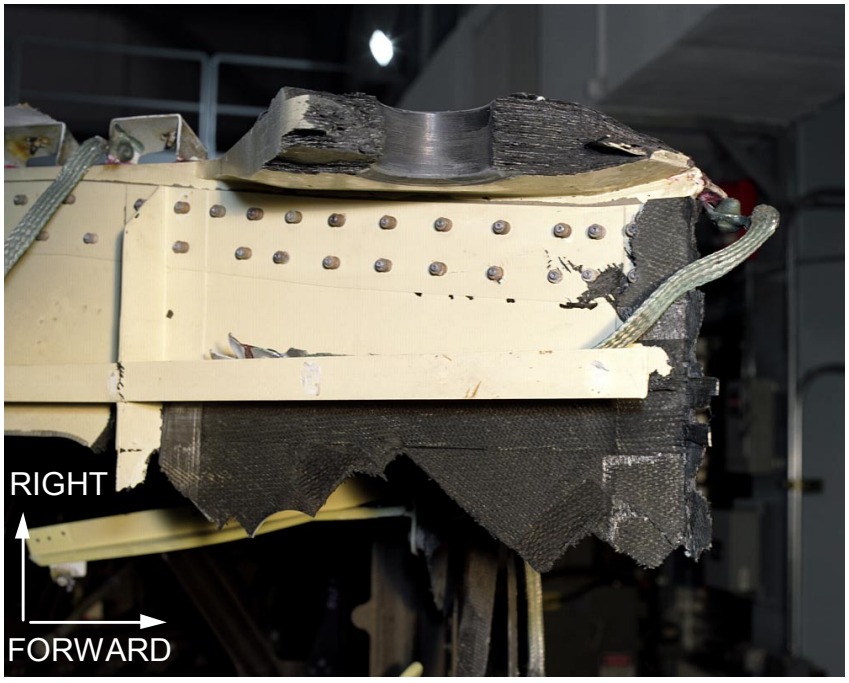
Figure 14. View of the right center longitudinal lug area on the vertical stabilizer.

ImageNo: 208A0254, Project No:A00386

Figure 15. View of the mating piece of the right center longitudinal lug that remained attached to the fuselage.

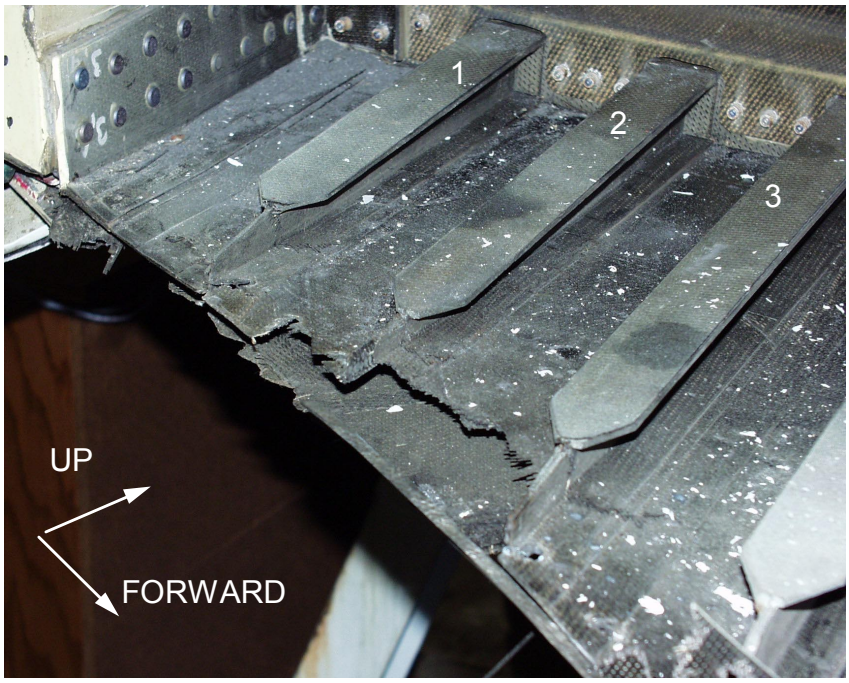
ImageNo:208A0260, Project No:A00386

Figure 16. View of the right forward longitudinal lug on the vertical stabilizer.



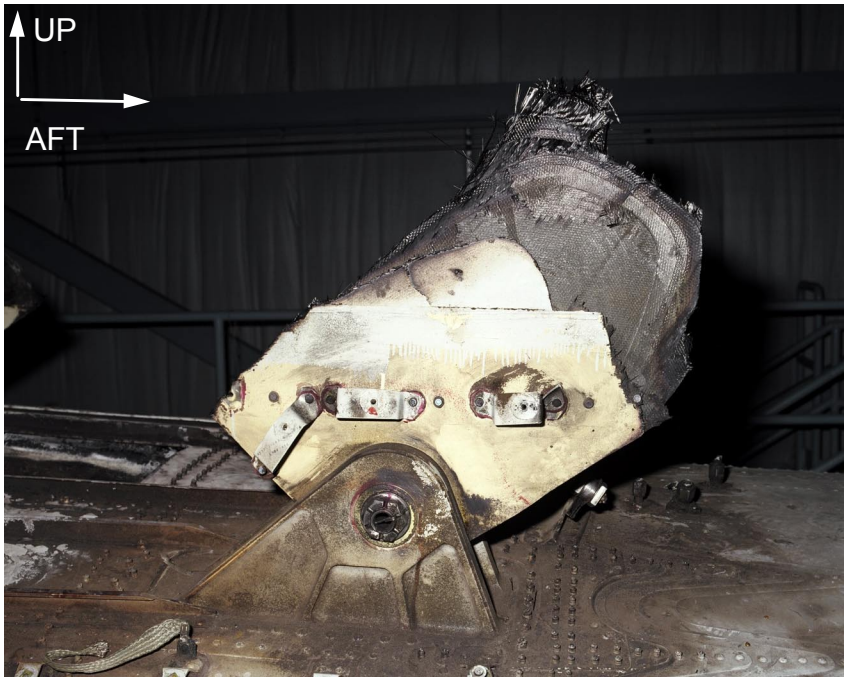
ImageNo: 208A0218, Project No:A00386

Figure 17. Another view of the right forward longitudinal lug on the vertical stabilizer.



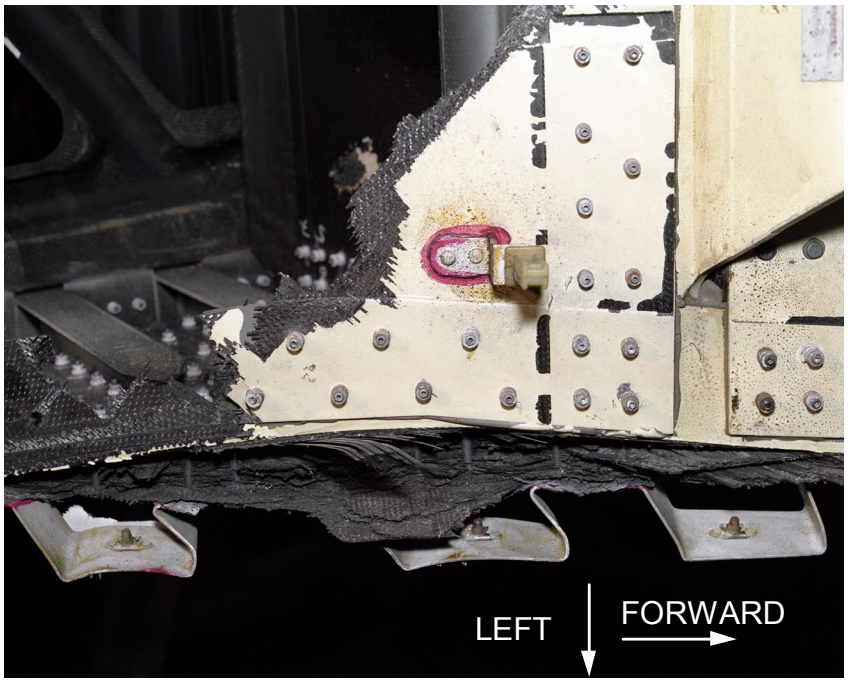
ImageNo:208A0226, Project No:A00386

Figure 18. View of the left aft longitudinal lug area on the vertical stabilizer. Stringers 1, 2, and 3 are labeled.



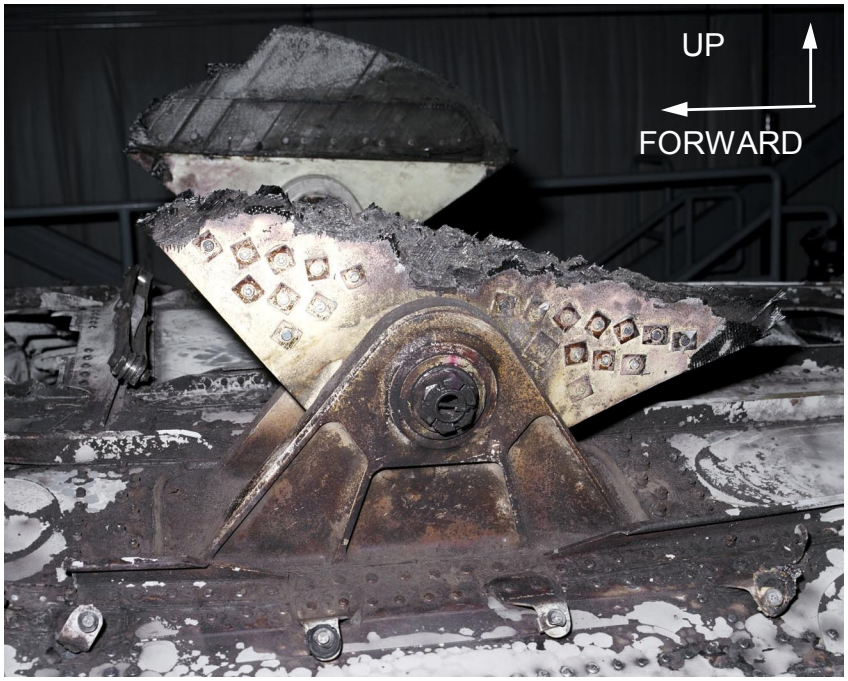
ImageNo: 208A0256, Project No:A00386

Figure 19. View of the mating left aft longitudinal lug piece that remained attached to the fuselage.



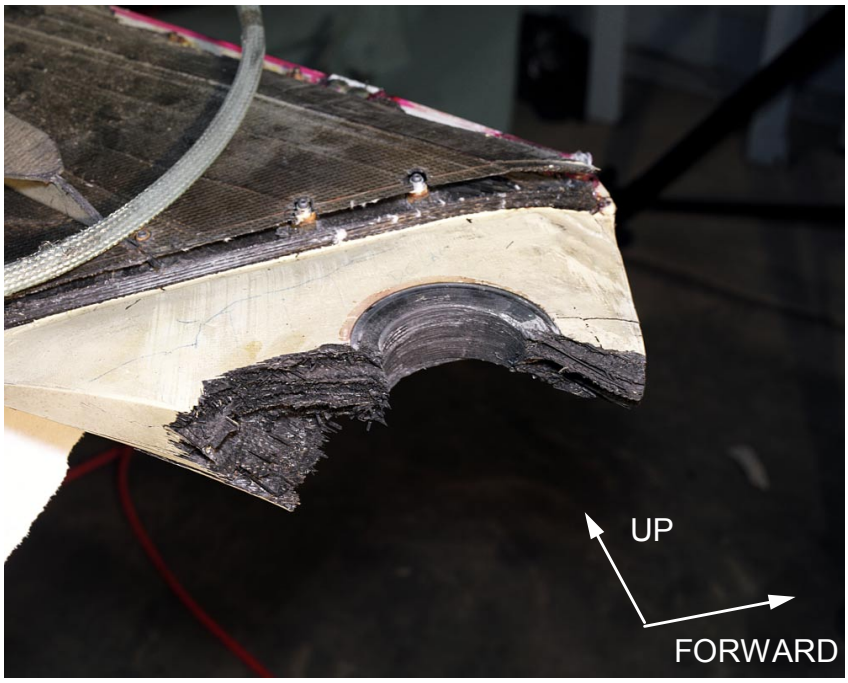
ImageNo:208A0253, Project No:A00386

Figure 20. View of the translaminar fracture for the left center longitudinal lug.



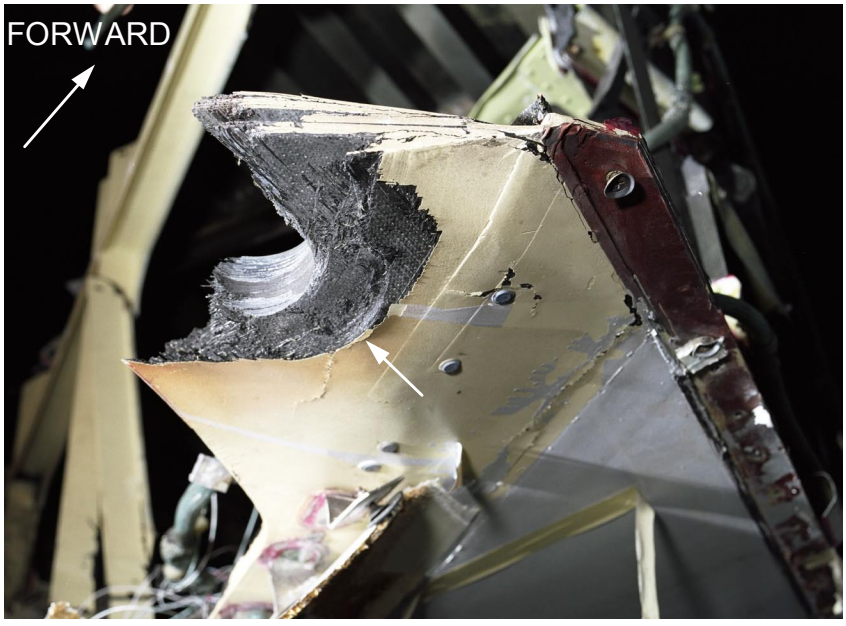
ImageNo: 208A0255, Project No:A00386

Figure 21. View of the left center longitudinal lug that remained attached to the fuselage. Repair rivets with square angle shims are visible on the surface.



ImageNo:208A0219, Project No:A00386

Figure 22. View of the left forward longitudinal lug on the vertical stabilizer.

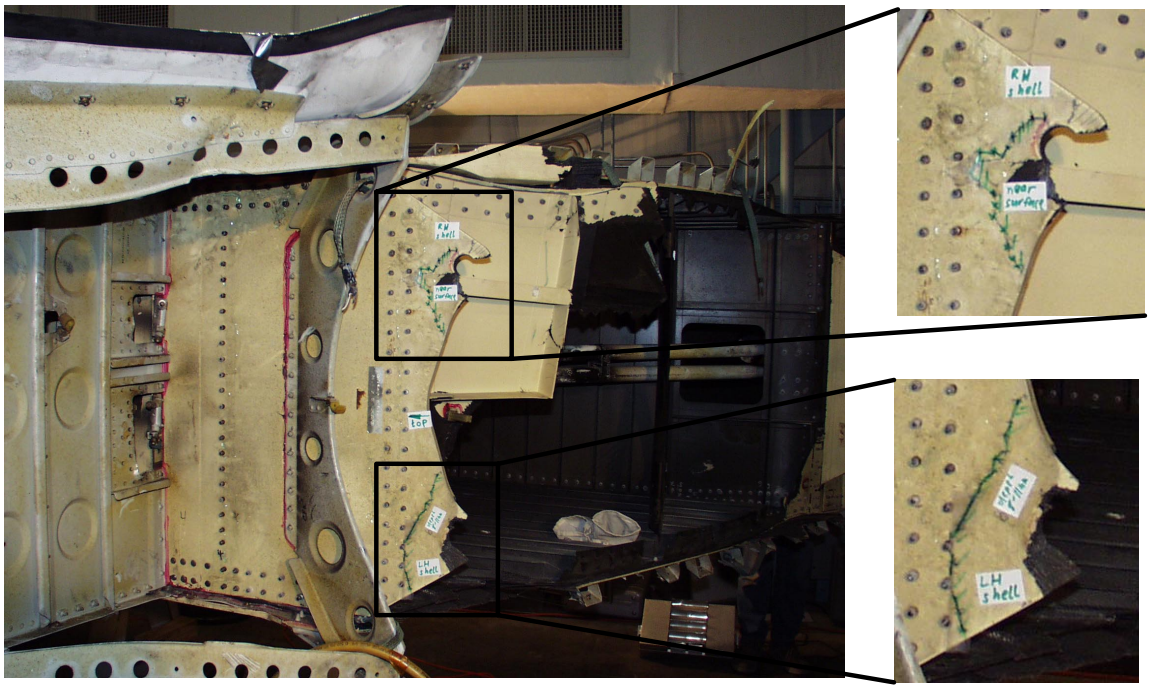


ImageNo: 208A0252, Project No:A00386

Figure 23. Another view of the left forward longitudinal lug on the vertical stabilizer showing the left side. An unlabeled arrow indicates an area of crushing damage corresponding contact with the upper end of the metal fuselage attach fitting lug.

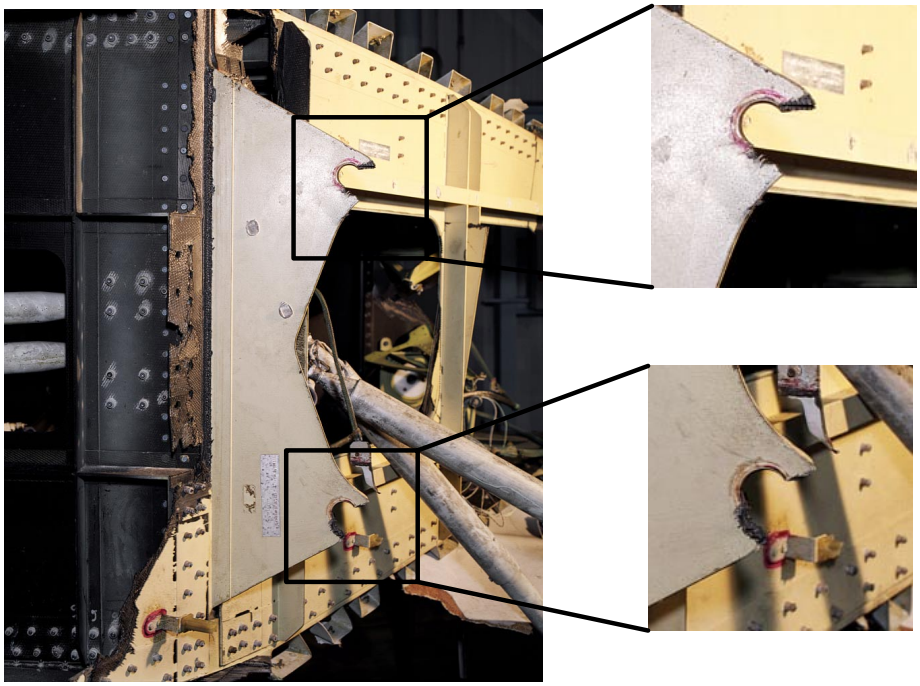
ImageNo:208A0257, Project No:A00386

Figure 24. View of the lower piece of the left forward longitudinal lug that remained attached to the fuselage.



ImageNo:208A0227, Project No:A00386

Figure 25. The aft transverse lugs on the vertical stabilizer as viewed looking upward and forward.

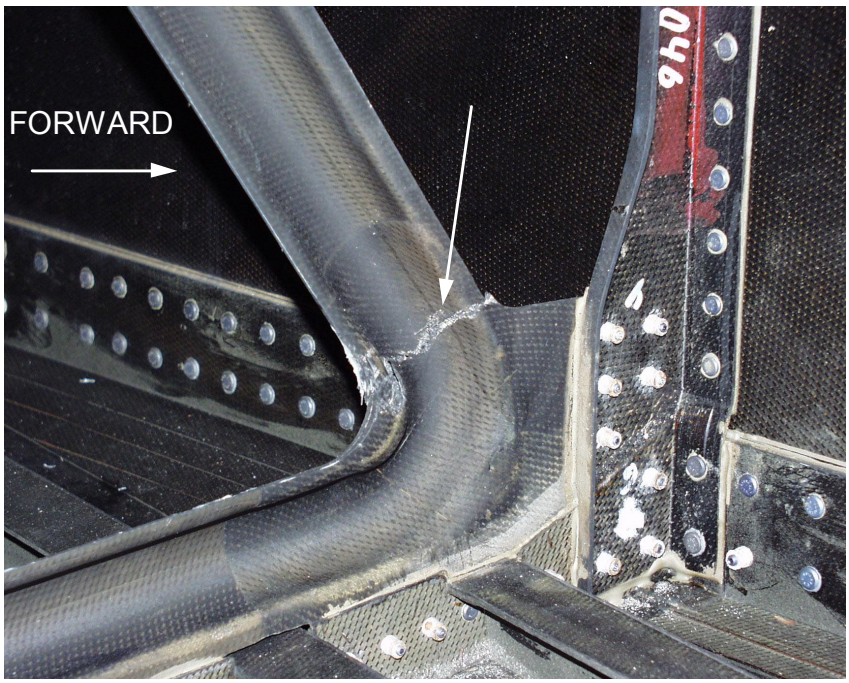


ImageNo: 208A0222, Project No:A00386

Figure 26. The center transverse lugs on the vertical stabilizer as viewed looking upward and forward.

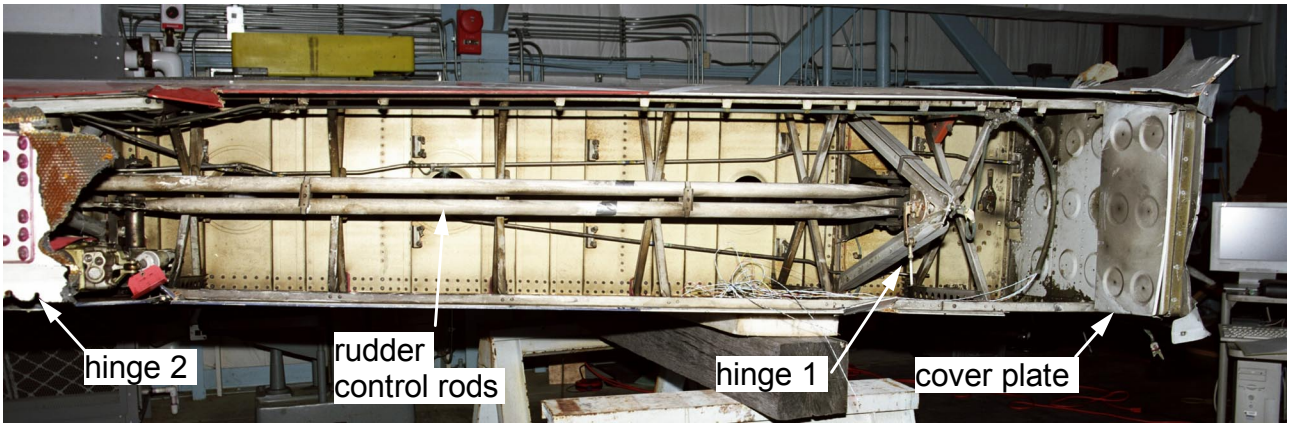
ImageNo:208A0258, Project No:A00386

Figure 27. A piece of the forward spar that remained attached to the fuselage as viewed looking forward. The piece is heavily damaged by heat and fire.

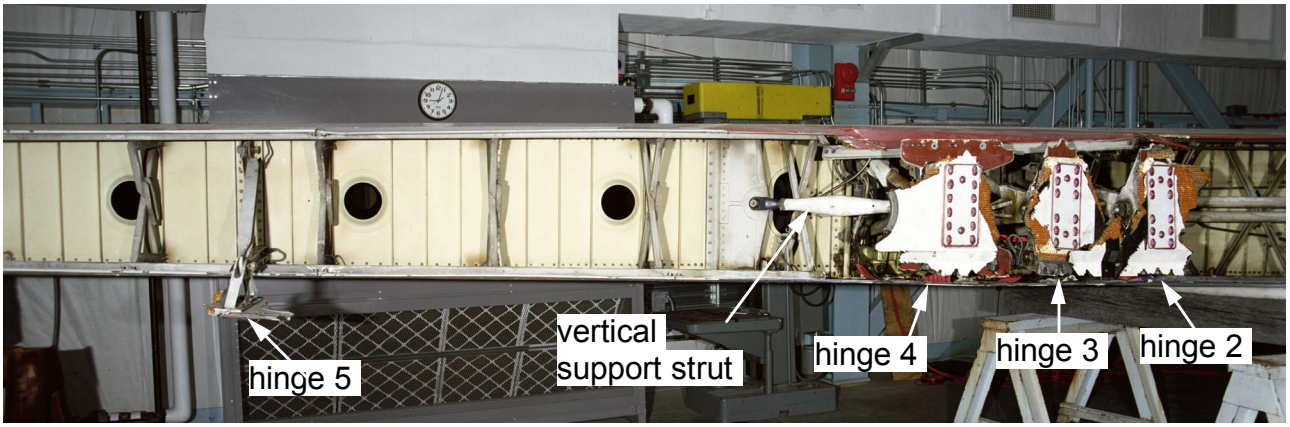


ImageNo: 208A0231, Project No:A00386

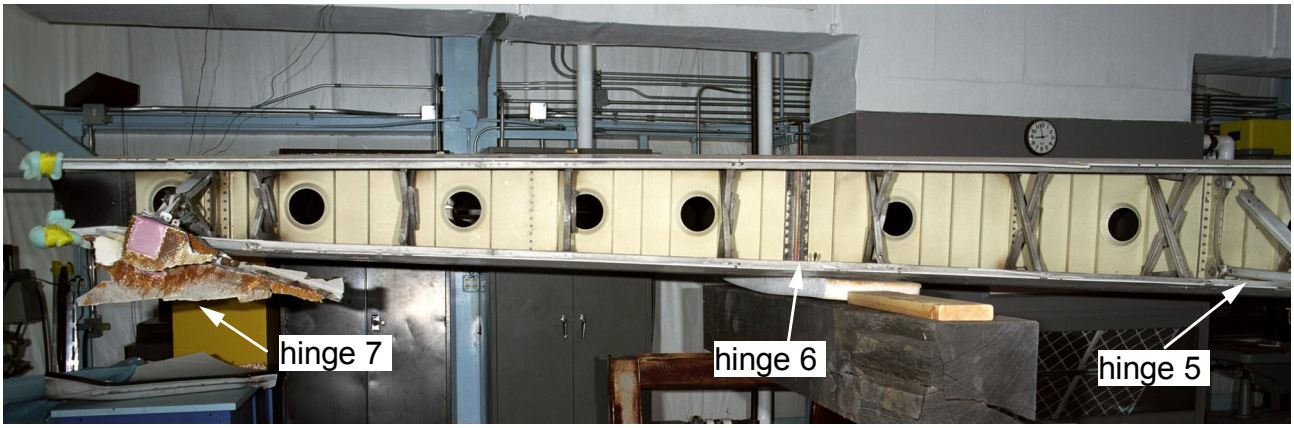
Figure 28. An unlabeled arrow indicates the fracture in the rib 3 diagonal channel as viewed from below.



ImageNo:208A0291, Project No:A00386



ImageNo: 208A0292, Project No:A00386



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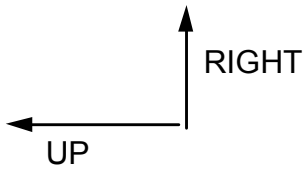
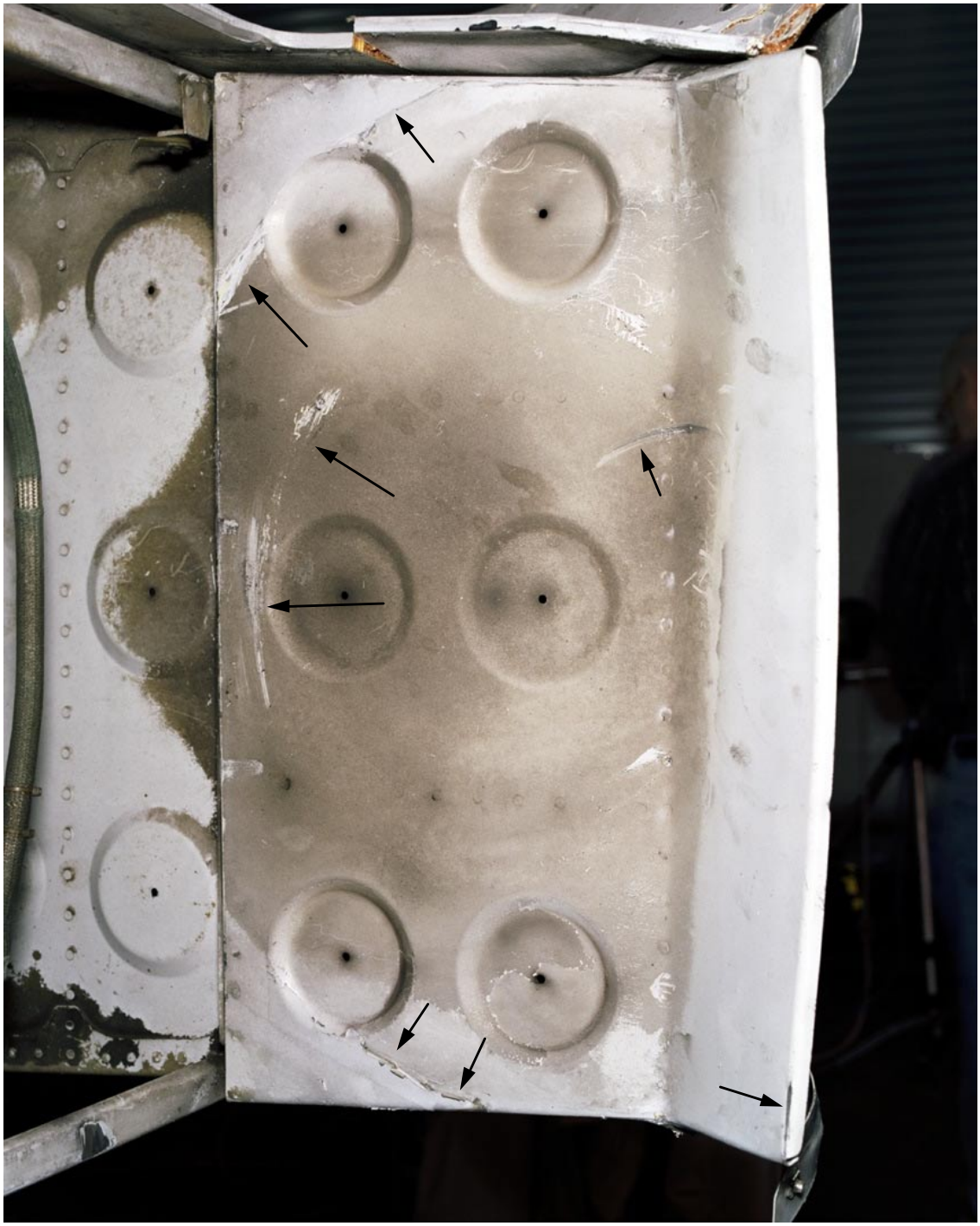


Figure 29. Overall views of the vertical stabilizer trailing edge.



ImageNo:208A0441, Project No:A00386

Figure 30. View of the damaged metal cover plate at the lower end of the hingeline on the vertical stabilizer. Unlabeled arrows indicate witness marks that correspond to contact with the lower end of the LE fairing and the fairing lower metal closure.

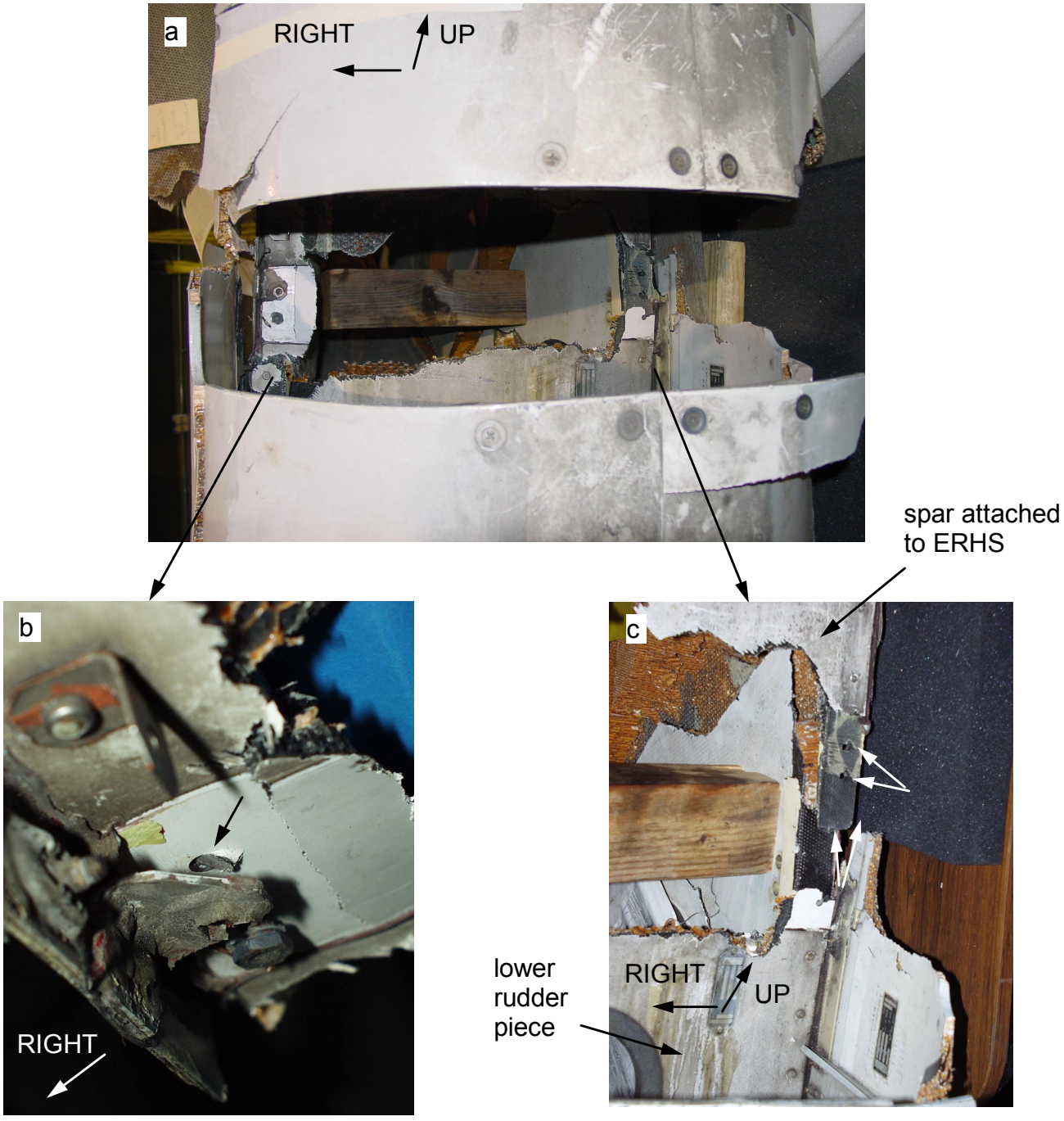


Figure 31. (a) View of hinge 1 aft fitting attach area at the rudder leading edge. (b) Right and (c) left attach bolt areas are shown in detail. The unlabeled arrow in (b) indicates the sheared aft fitting attach bolt. The unlabeled arrows in (c) indicate portions of the left attachment bolt holes in the spar that remained attached to panel ERHS and to the lower piece of the rudder.

ImageNo:208A0294, Project No:A00386

Figure 32. Closer view of the hinge 1 forward fitting fracture.

ImageNo: 208A0304, Project No:A00386

Figure 33. View of the right side hinge 2 aft fitting piece that remained attached to the rudder.

ImageNo:208A0305, Project No:A00386

Figure 34. View of the right hinge 3 aft fitting pieces that remained attached to the rudder.

ImageNo: 208A0307, Project No:A00386

Figure 35. View of the right hinge 4 aft attach area on the rudder spar. The piece of the aft fitting that remained attached to the rudder is shown. Unlabeled arrows indicate attach bolt holes that remained with the large upper rudder piece (including skin piece BRHS and CLHS).

Hinge 2

Hinge 3

Hinge 4

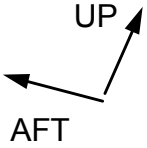
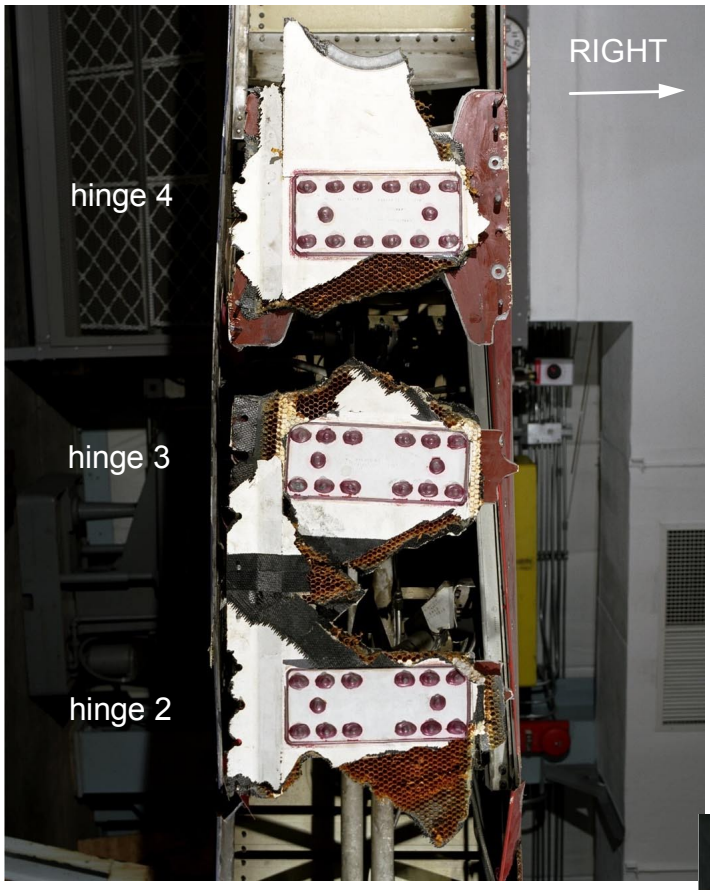


Figure 36. View looking to the left of the left sides of the hinge 2, 3, and 4 aft fitting pieces that remained attached to the rudder, showing fracture surfaces and deformation.



ImageNo:208A0312, Project No:A00386

Figure 37. The hinge 2 to 4 fittings and attached rudder spar pieces that remained attached to the vertical stabilizer as viewed looking forward.

ImageNo: 208A0313, Project No:A00386

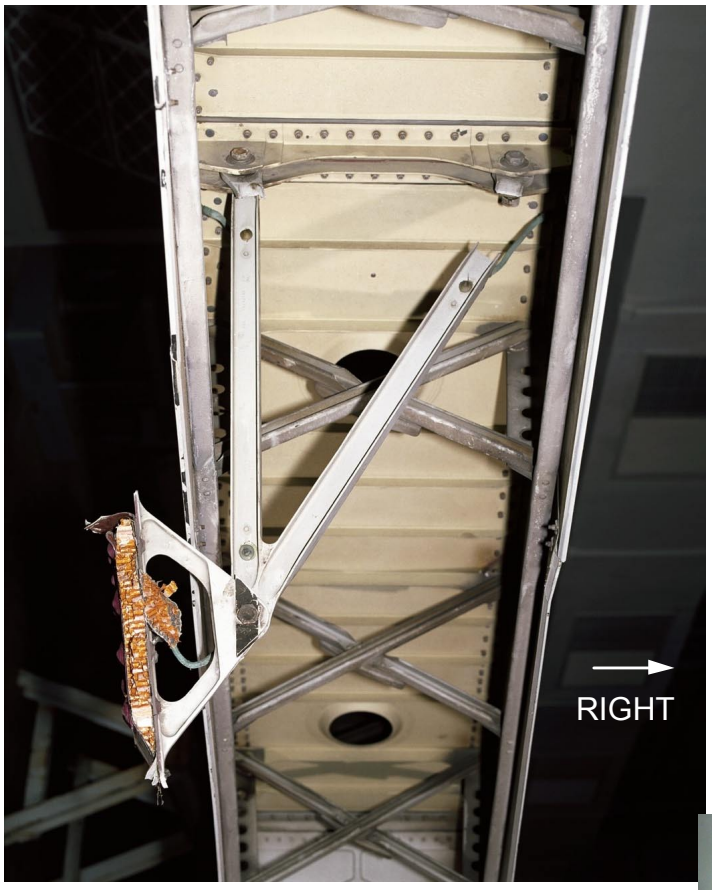
Figure 38. Another view of the hinges 2 to 4 as viewed looking down and forward. The vertical support strut is shown also. An unlabeled arrow indicates damage on the upper side of the support strut.

ImageNo:208A0314, Project No:A00386

Figure 39. A closer view of the damage on the upper side of the vertical support strut.

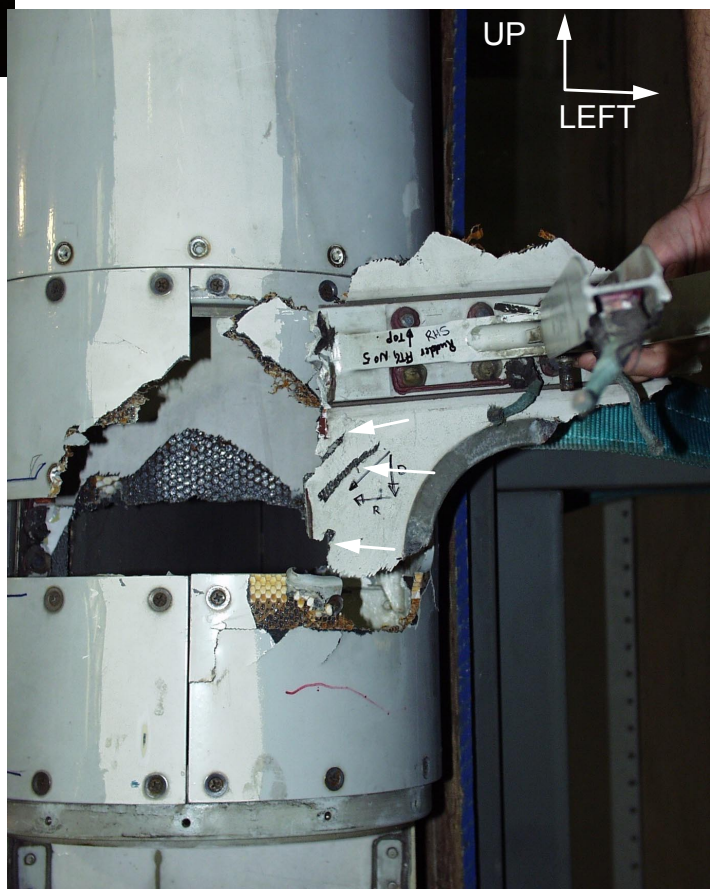
ImageNo: 208A0315, Project No:A00386

Figure 40. A close view of the damage on the left side of the veritcal support strut.



ImageNo:208A0316, Project No:A00386

Figure 41. Pieces of hinge 5 and attached rudder spar pieces that remained attached to the vertical stabilizer as viewed looking down and forward.



ImageNo: 208A0317, Project No:A00386

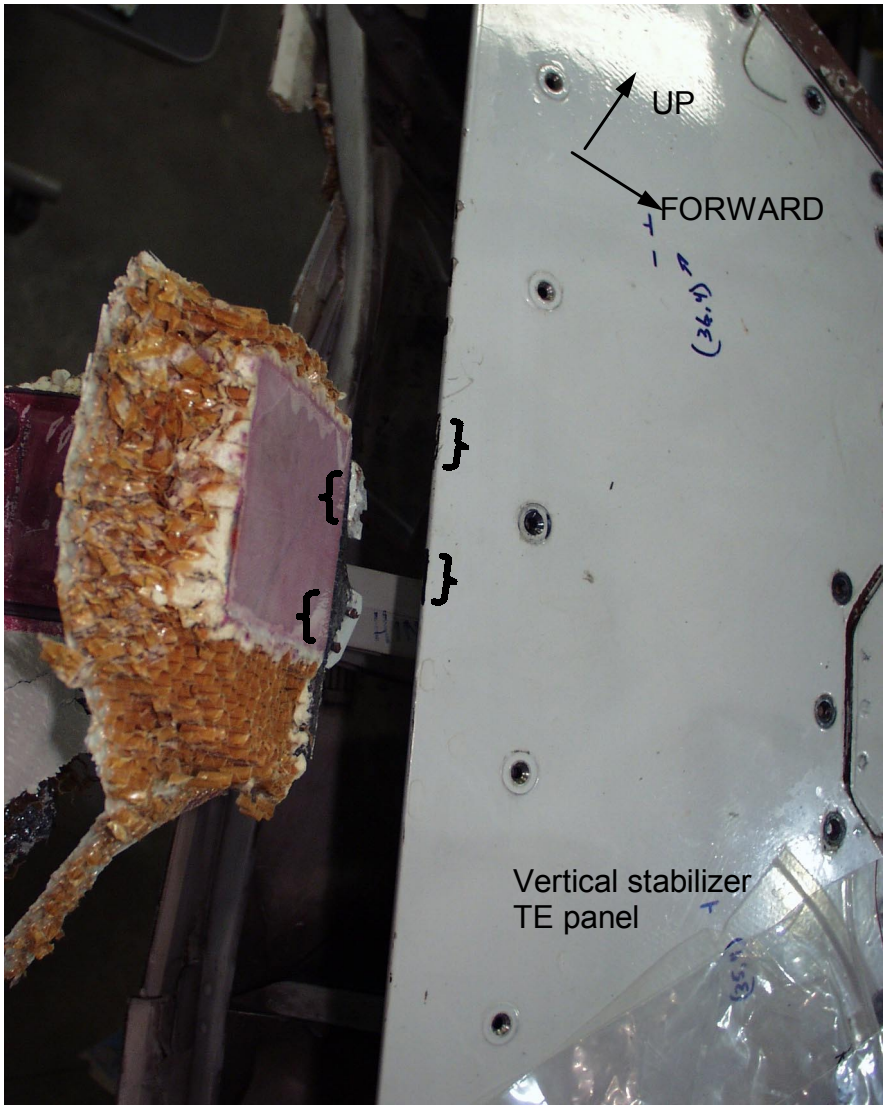
Figure 42. View of the hinge 5 aft fitting and rudder spar adjacent to the rudder LE fairing hinge 5 cutout (shown after fairing pieces below and fasteners above the cutout were removed). Unlabeled arrows indicate marks in the rudder spar corresponding to contact with the lower side of the cutout.

ImageNo:208A0328, Project No:A00386

Figure 43. The hinge 6 forward fitting arms and attached vertical stabilizer rear spar attach angles that remained attached to the forward fitting as viewed looking up and aft. The "right" arrow is shown relative to the forward fitting, and the rudder is in a TEL position relative to the forward fitting.

ImageNo: 208A0333, Project No:A00386

Figure 44. The hinge 7 fittings and attached rudder pieces that remained attached to the vertical stabilizer as viewed looking forward.



ImageNo:208A0334, Project No:A00386

Figure 45. Another view of the hinge 7 fitting from the right side. Brackets indicate fractured and deformed angle brackets on the aft fitting and corresponding marks on the vertical stabilizer TE panel. Note that fasteners for the TE panel were removed.

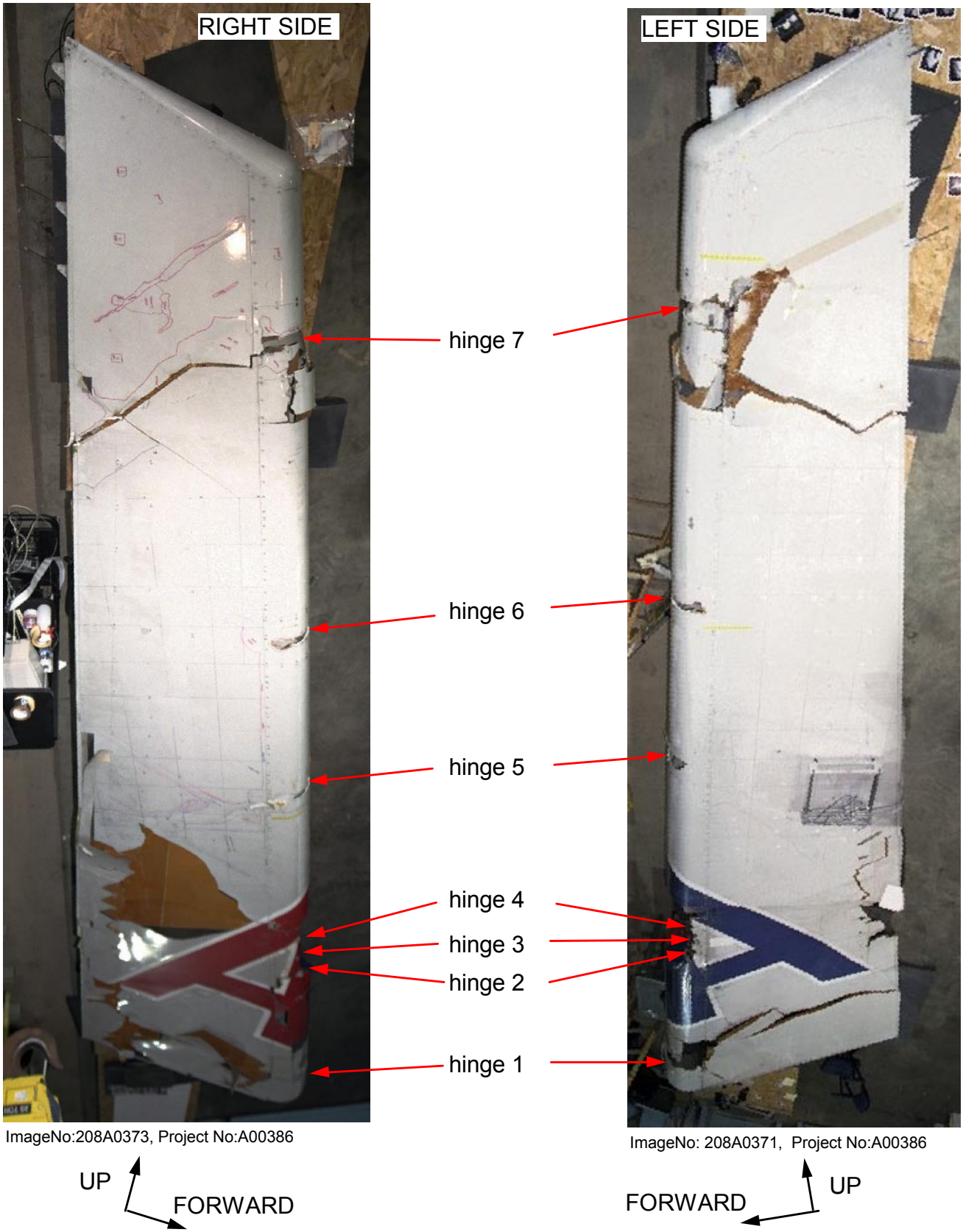


Figure 46. Overall view of the right and left sides of the rudder as viewed from above. With this perspective, the upper and lower ends appear larger and smaller, respectively. Lamb wave equipment used for nondestructive examination is shown on the left skin panel.

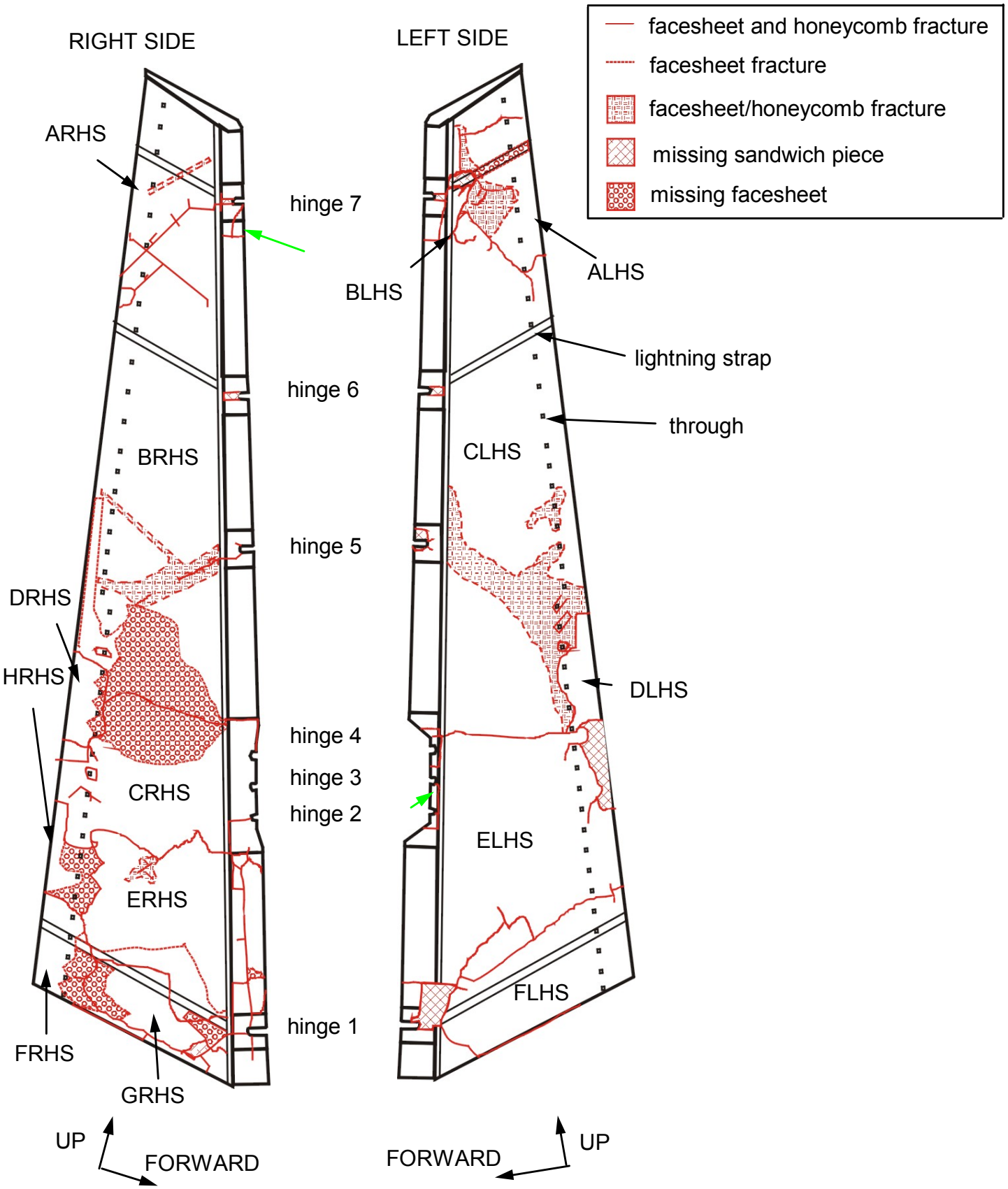


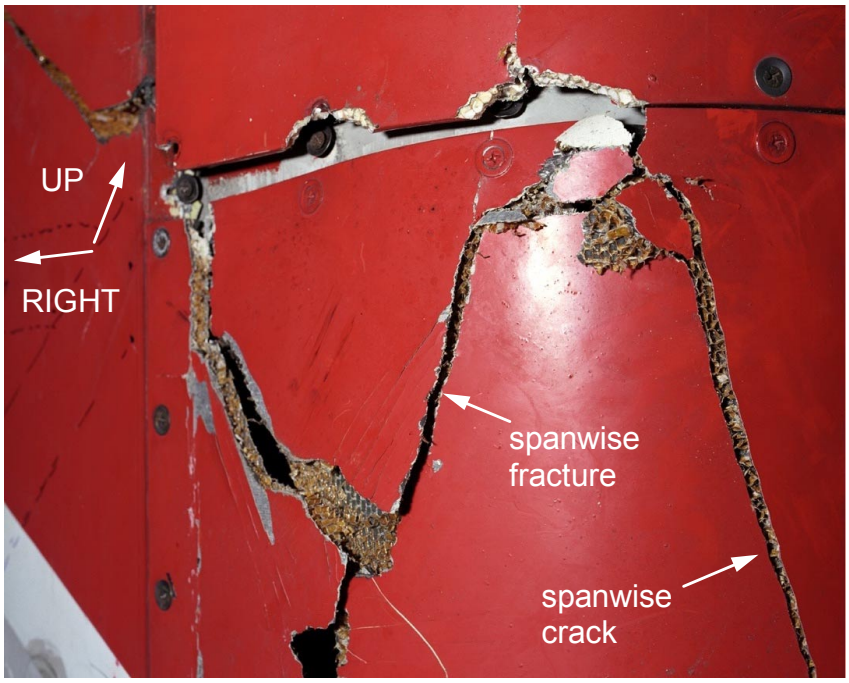
Figure 47. Drawings of the right and left sides of the rudder showing the approximate locations of fractures and missing pieces. Unlabeled green arrows indicate fairing pieces that were found on land. Piece GRHS was also found on land.

ImageNo:208A0386, Project No:A00386

Figure 48. The left side of the LE fairing at hinge 1 as viewed looking mainly aft.

ImageNo: 208A0384, Project No:A00386

Figure 49. View of the right side of the LE fairing at hinge 1 and up to just below hinge 2. Unlabeled arrows indicate where scuffing damage adjacent to the nearly spanwise fracture was greatest.

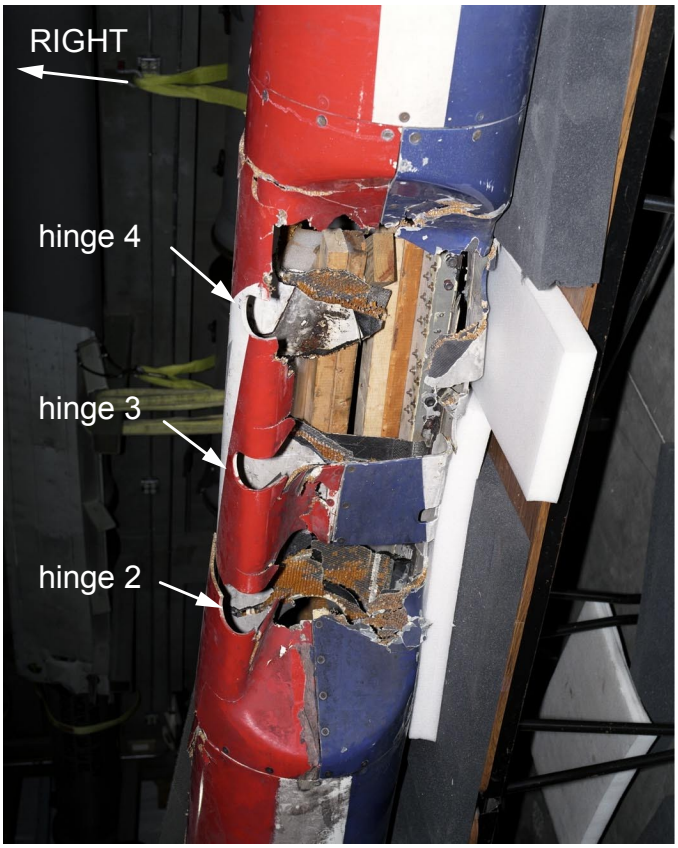


ImageNo:208A0390, Project No:A00386

Figure 50. View of the upper ends of the nearly spanwise fracture and crack on the rudder LE fairing right side just below hinge 2.

ImageNo: 208A0388, Project No:A00386

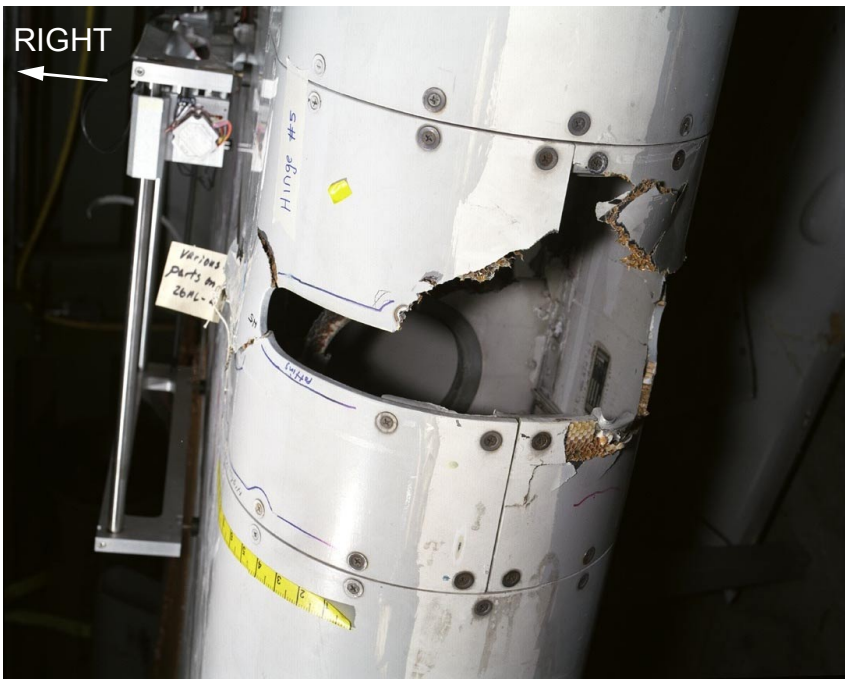
Figure 51. View of the rudder spar at hinge 1 looking mainly aft with fractured pieces of the LE fairing removed.



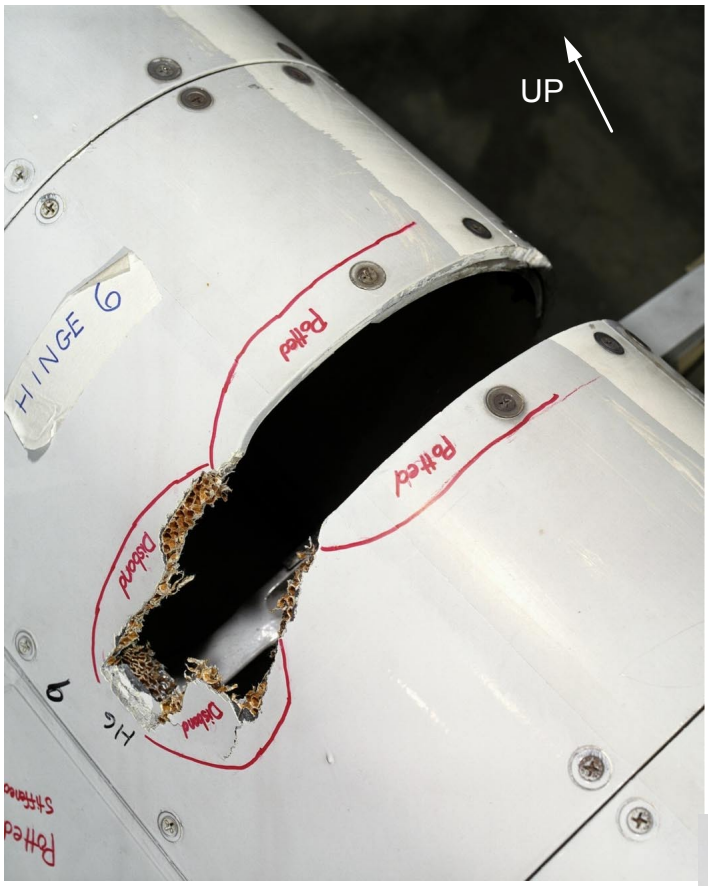
ImageNo:208A0389, Project No:A00386

Figure 52. The LE fairing at hinges 2 to 4 as viewed looking mainly down and aft.

Figure 53. The LE fairing at hinge 5 as viewed looking mainly down and aft. Lamb wave equipment used for nondestructive examination is shown in the background on the right skin panel.



ImageNo: 208A0391, Project No:A00386



ImageNo:208A0396, Project No:A00386

Figure 54. View of the right side of the LE fairing at hinge 6 showing damage to the right cutout end.

ImageNo: 208A0397, Project No:A00386

Figure 55. View of the left side of the LE fairing at hinge 6 showing damage to the left cutout end.

ImageNo:208A0393, Project No:A00386

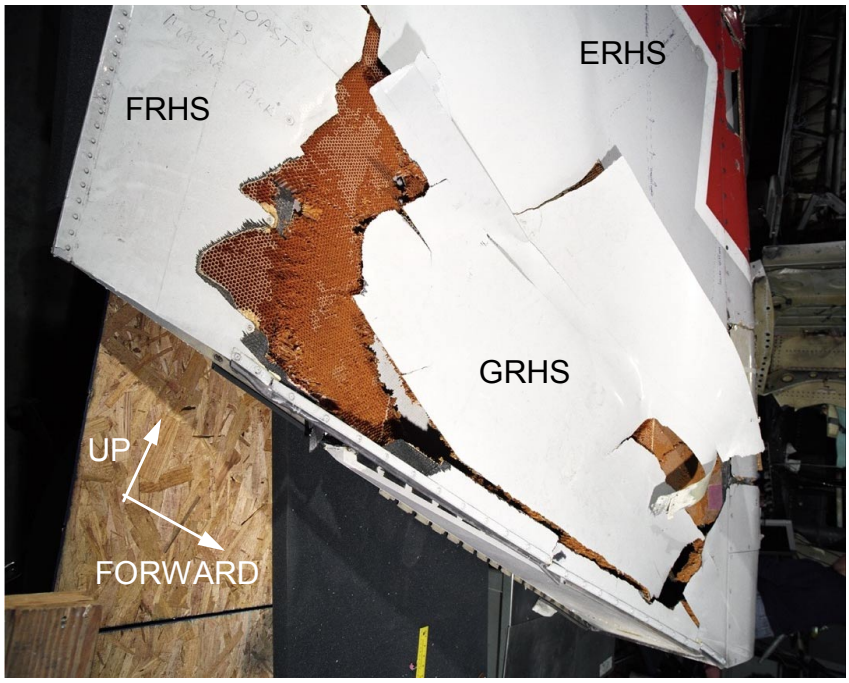
Figure 56. View of the upper side of the hinge 6 rudder LE cutout. Continuous heavy damage was observed between the unlabeled arrows.

ImageNo:208A0394, Project No:A00386

Figure 57. View of the LE fairing at hinge 7.

ImageNo: 208A0395, Project No:A00386

Figure 58. View of the upper side of the hinge 7 LE fairing cutout. Brackets indicate areas of damage on the left side.

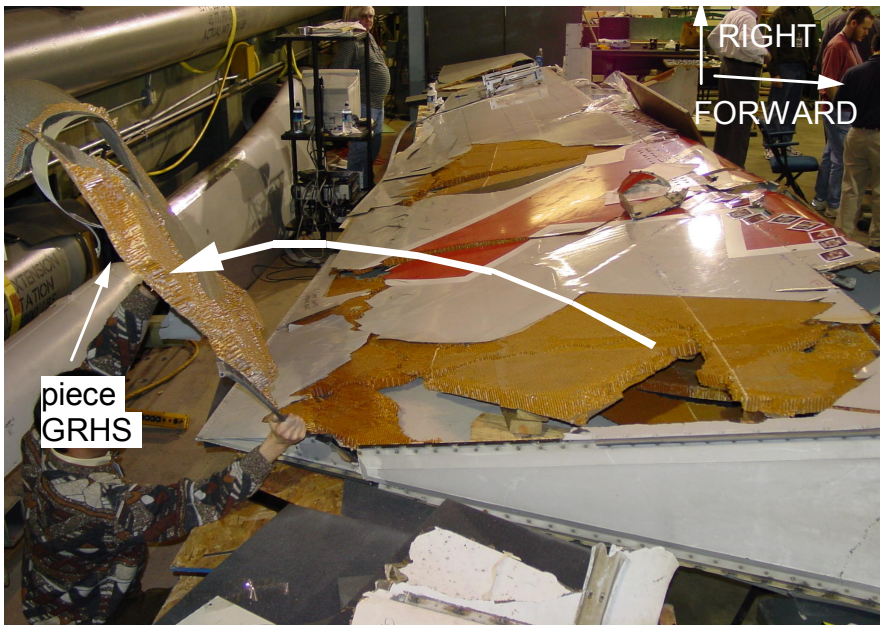


ImageNo:208A0408, Project No:A00386

Figure 59. Closer view of the fractures at the right side lower end of the rudder.

ImageNo: 208A0409, Project No:A00386

Figure 60. Closer view of the fractures on the left side lower end of the rudder.

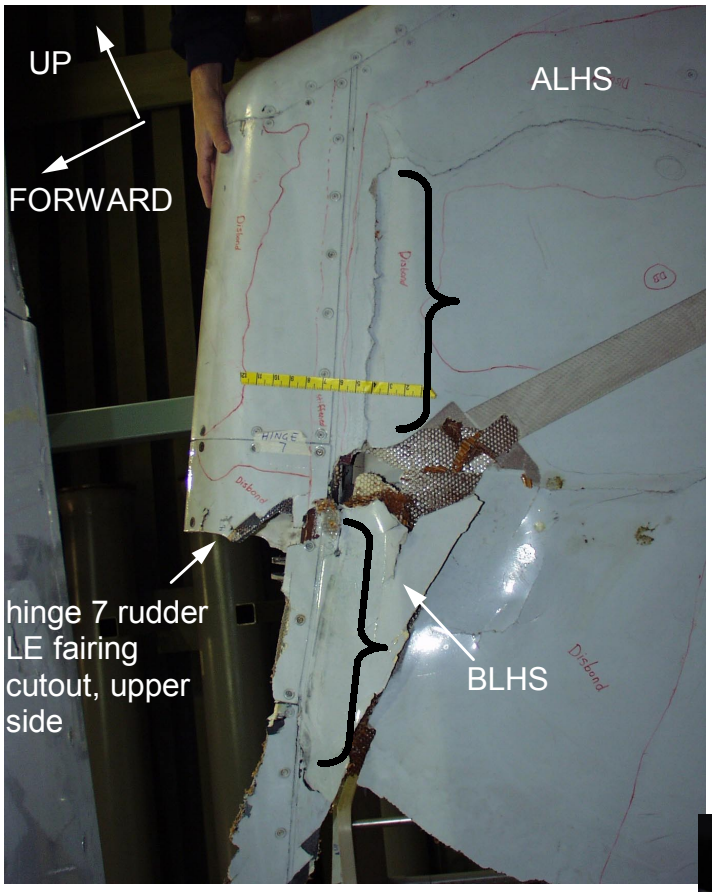


ImageNo:208A0407, Project No:A00386

Figure 61. View of the right side of the lower end of the rudder showing fracture matching of the lower metal retaining strip. The curved arrow indicates the motion of piece GRHS relative to the aft piece of the retaining strip.

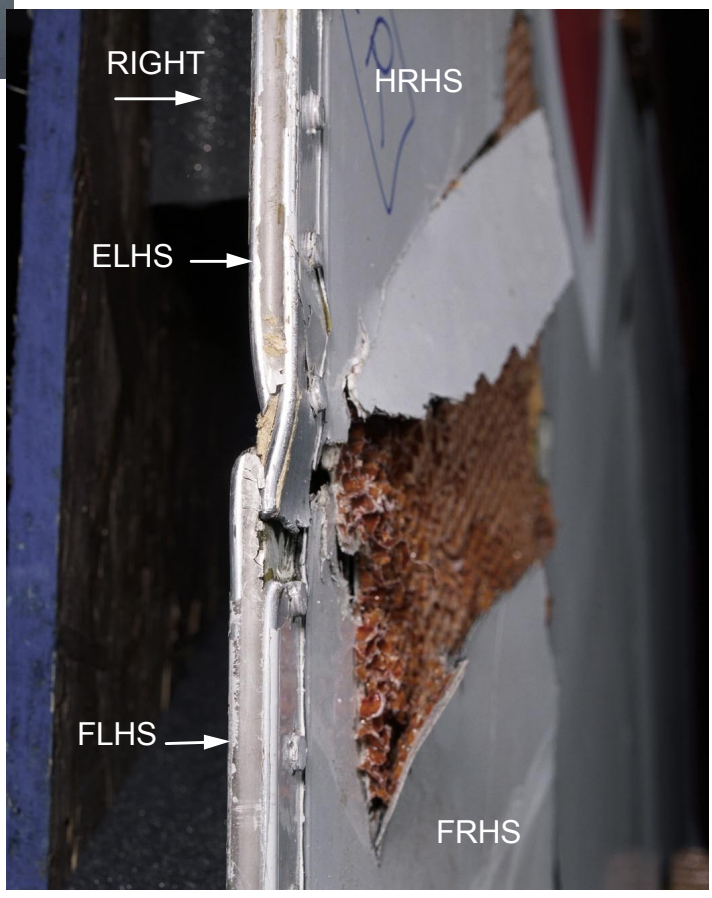
ImageNo: 208A0411, Project No:A00386

Figure 62. View of the fracture where the external facesheet was missing from the right side at the lower end of piece BRHS and the upper end of piece CRHS.



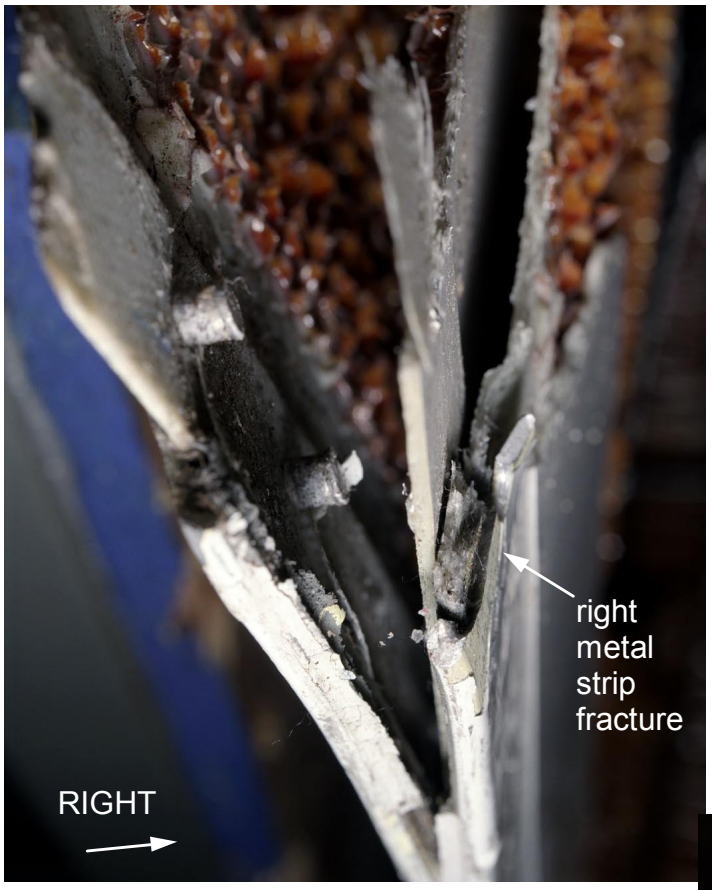
ImageNo:208A0412, Project No:A00386

Figure 63. Left side view of pieces near hinge 7 where bracket indicate damage consistent with contact with the vertical stabilizer TE panel.



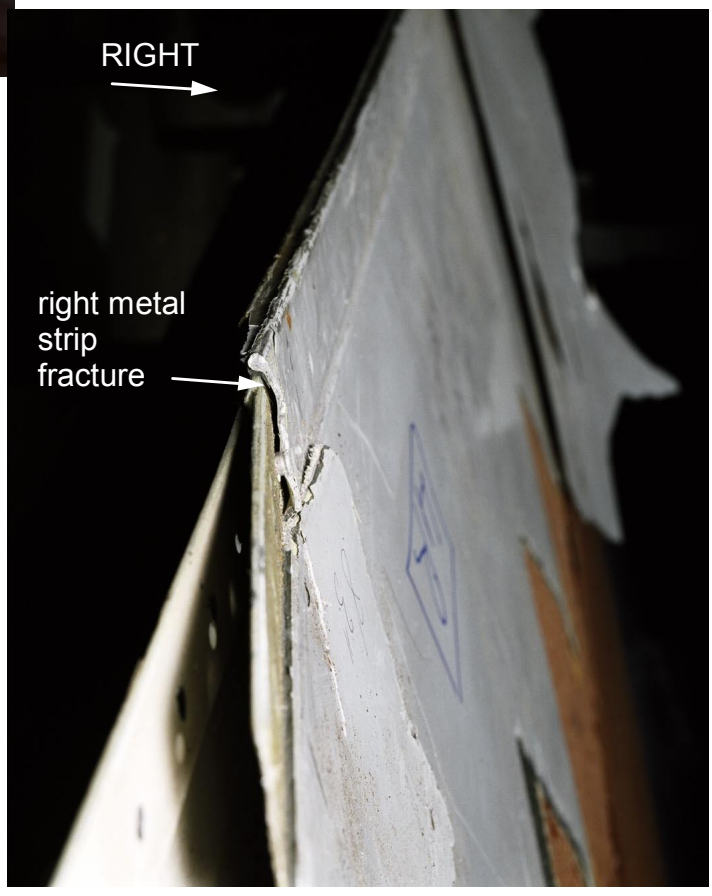
ImageNo: 208A0410, Project No:A00386

Figure 64. Fracture at the trailing edge between pieces FRHS and FLHS and pieces HRHS and ELHS showing local deformation of the metal trailing edge strips.



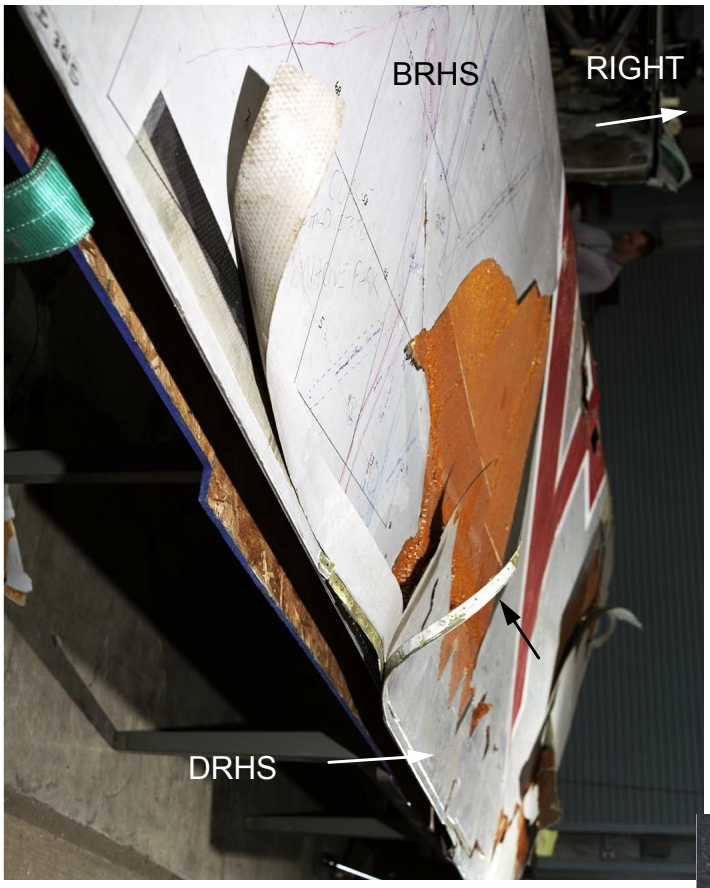
ImageNo:208A0418, Project No:A00386

Figure 65. View looking down at the fracture at the upper end of piece HRHS showing local deformation of the metal trailing edge strips.



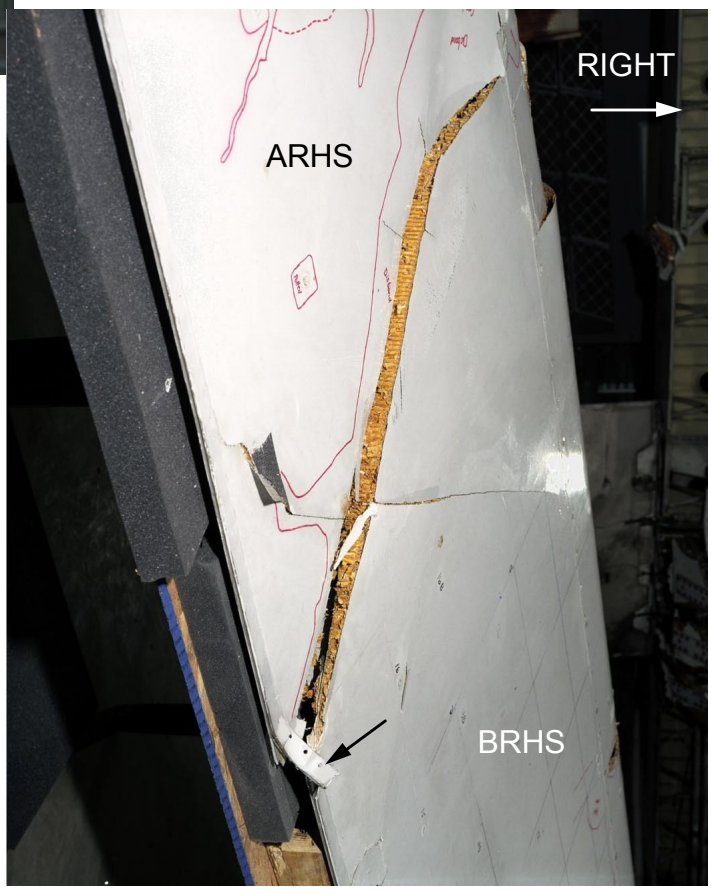
ImageNo: 208A0414, Project No:A00386

Figure 66. View looking up at the fracture at the lower end of piece DRHS showing local deformation of the metal trailing edge strip.



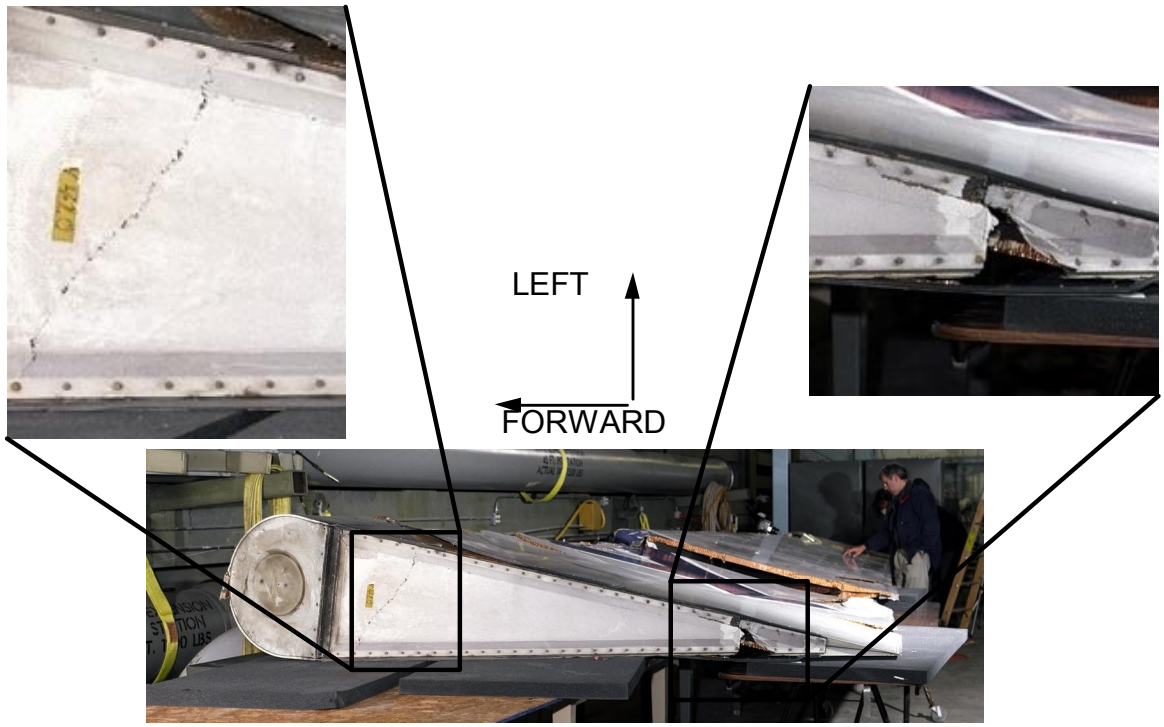
ImageNo:208A0417, Project No:A00386

Figure 67. The trailing edge of the rudder as view looking down and forward. An unlabeled arrow indicates the right trailing edge strip generally deformed near the upper end of piece DRHS.



ImageNo: 208A0416, Project No:A00386

Figure 68. The rudder trailing edge aft of hinge 7 as viewed looking mainly forward. An unlabeled arrow indicates the fracture at the trailing edge between pieces ARHS and BRHS showing local deformation of the metal trailing edge strip.



ImageNo:208A0439, Project No:A00386

Figure 69. Overall view of the lower rob of the rudder with details showing the compression fracture near the forward spar and the fracture near the trailing edge.

ImageNo: 208A0438, Project No:A00386

Figure 70. Damage at the lower end of the LE fairing as viewed looking upward and aft. An unlabeled arrow indicates the bent washer at the centerline fastener.