NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

July 1, 2003

MATERIALS LABORATORY FACTUAL REPORT Report No. 03-033

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

Five pieces from the lower end of the vertical stabilizer:

(1) Right aft longitudinal attachment lug fracture area section.
(2) Right center longitudinal attachment lug fracture area, lower piece.
(3) Left aft longitudinal attachment lug fracture area, lower piece.
(4) Left aft longitudinal attachment lug fracture area, upper section.
(5) Left forward longitudinal attachment lug fracture area, upper section.

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 five on the ground.

D. DETAILS OF THE EXAMINATION

This report documents the x-ray-computed tomography (CT) scanning and imaging of selected fractured pieces and cut sections from the vertical stabilizer as listed in section B, above. The CT scanning was performed for the Safety Board at the United States Army Research Laboratory (ARL) in Aberdeen, Maryland and at the Ford Motor Company's nondestructive evaluation laboratory (Ford) in Livonia, Michigan. Other aspects of the construction and examination of the subject components, such as the visual examination, other nondestructive testing, and fractography, are documented in separate reports including Materials Laboratory Factual Reports 02-077, 02-078, 02-082, 02-083, and 03-018.

1. Construction and Materials

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 skin panels are generally oriented parallel to the stringers and aft spar, which are at an angle of 33.3 degrees to the aft of vertical, with the exception that the zero-degree fibers associated with the front spar flange are parallel with this spar, which is at an angle of 41.5 degrees to the aft of vertical. In the spar web, the zero-degree fiber direction is parallel to the vertical centerline. In the ribs, the zero-degree direction is either parallel to the horizontal centerline for panel ribs, or it is parallel to the longitudinal axis of truss members for truss ribs.

2. CT Scanning Procedure

During CT scanning with x-rays, detectors on the CT scanning equipment measured the transmitted x-ray intensity as each part was translated through the beam and rotated. Computers then calculated relative attenuation of the beam, and generated images showing relative attenuation through the cross-section. Since attenuation is proportional to the physical density of the material, the generated images also showed relative density, where higher density areas appeared white and lower density areas appeared black. To reduce the possibility of obscuring image features in the composite areas of interest, all metal fasteners, clips, and bushings were removed from the sections and pieces.

The right aft lug section, right center lug piece, and lower piece of the left aft fracture area were scanned at ARL. Scans were completed using a Bio-Imaging Research (BIR) 600/420 CT system. The system had a 420-kiloelectron volt x-ray tube and could scan objects up to 24 inches in diameter and four inches in height. The right aft lug section was scanned in planes parallel to the lug flat to produce 12-bit images having a pixel size of 0.56 millimeter (0.022 inch) with a step increment of 0.70 millimeter (0.028 inch) between scans. The right center lug piece also was scanned in planes parallel to the lug flat, but at

[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.

two different settings. The outer portion was scanned to produce 12-bit images having a pixel size of 0.56 millimeter (0.022 inch) with a step increment of 0.65 millimeter (0.026 inch) between scans. The inner portion of the piece was scanned to produce 12-bit images having a pixel size of 0.57 millimeter (0.022 inch) with a step increment of 0.70 millimeter (0.028 inch) between scans. The lower piece of the left aft section was scanned in planes perpendicular to the stringer longitudinal axes, producing 12-bit images having a pixel size of 0.52 millimeter (0.020 inch) with a step increment of 12.7 millimeters (0.5 inch) between scans.

The upper section from the left aft fracture area and the upper section from the left forward fracture area were scanned at Ford. These scans were completed using an Aracor ICT 1500 system. That system had a 9-megaelectron volt x-ray tube and could scan objects measuring up to one meter (39 inches) in diameter and two meters (79 inches) in height and weighing up to 1500 pounds. The sections were scanned in planes perpendicular to the stringer longitudinal axes, producing 16-bit images having a pixel size of 0.21 millimeter (0.0083 inch) with a step increment of one millimeter (0.039 inch) between scans.

In preparing for scanning the panel sections at Ford, a two-inch square piece of undamaged skin panel material from the upper end of the vertical stabilizer (sample LS4) was sent for calibration and setup purposes. While at Ford, the piece was subsequently lost and its location and condition were unknown at the time of writing this report.

The scans produced two-dimensional slice images. These slice images were stacked into VGStudio Max, version 1.1, a visualization software program used to produce three-dimensional images from the collection of two-dimensional slice images. To assist in the visualization process, the resolution of the slice images produced at Ford was reduced such that the pixel size was 0.84 millimeter (0.033 inch). However, individual slice images were examined at the original resolution.

3. Results

Areas where ply separations were observed are indicated in the following slice and visualization images. Ply separations having a small opening displacement will not be detected from these CT scans. Therefore, the extent of ply separations observed from CT scanning results typically were not as large as those observed using ultrasonic testing as documented in Materials Laboratory Factual Report 02-078. However, the CT scans were able to detect multiple delaminations through the thickness where the opening displacements were sufficient to resolve.

Images may contain artifacts, including streaks and discontinuities, resulting from the scanning and visualization process. A slice image is shown in figure 1 where streaks were present in the reconstructed image. These streaks were artifacts that appeared due to the high aspect ratio of the part and due to photon starvation resulting from the long travel distance through the part. In the visualized images, these streaks have a speckled appearance on the exposed surfaces. Discontinuities in the visualized images may appear

as a result of the step increment between slices. In the pieces that were scanned parallel to the lug flat, these discontinuities include steps on the surface that appear much like contour lines on an elevation map. In sections scanned perpendicular to the zero-degree fiber direction, these discontinuities include small steps running parallel to the scan plane. Also, the software provides the visualized images with a wood-grain appearance on the surface, which creates an appearance of depth and contour.

The sections scanned at Ford were held in place with a wood support fixture. Within the visualization software, the support frames were virtually removed from the images. However, the support frames remain visible in individual slice images.

3.1. Right Aft Lug Section

An overall view of the scanned right aft lug section is shown in figure 2 at the left. A total of 29 slices were scanned at the lower end. Characteristic slices from the scanning are shown at the right in figure 2. Unlabeled arrows in figure 2 indicate ply separations. Multiple ply separations through the thickness were observed in slice images at and below the lug attachment hole center. At approximately 0.5 inch above the upper surface of the lug attachment hole, no ply separations were observed. However, the speckled appearance of the cross-section may have obscured the presence of a ply separation with a small opening displacement.

The visualization of the right aft lug section slice images did not produce representative images due to the relatively large step increment between slices.

3.2. Right Center Lug Piece

An overall view of the lower piece from the right center lug fracture area is shown in figure 3. The piece is shown with all metal fasteners, clips, and bushings removed.

The piece was scanned in two portions consisting of 72 slices for the inboard portion and 45 slices for the outboard portion. The slices overlapped across approximately 0.5 inch of the thickness near the center of the piece.

Images from the visualization of each portion of the piece are shown in figure 4. Images in the upper row show the inboard portion, and images in the lower row show the outboard portion. The left images (a) and (d) show overall images of each portion. The center images (b) and (e) show virtual cuts perpendicular to the zero-degree fiber direction, and the right images (c) and (f) show virtual cuts parallel to the zero-degree fiber direction.

Layers from the upper leg of the rib 1 flange were visible on the inboard portion of the right center lug piece, as shown in figure 4, images (a) to (c). Layers of the upper leg of the rib 1 flange appeared mostly separated from the remainder of the piece, as shown in figure 4, images (b) and (c).

A ply separation with a relatively large opening displacement was observed near the forward edge of the piece near the outboard surface, as indicated by arrows in figure 4, images (b) and (e). The aspect ratio of this ply separation was large with the longer dimension parallel to the zero-degree fiber direction. Also, the through-thickness edges were relatively squared off, features consistent with pull-out of zero-degree tape layers.

3.3. Left Aft Lug Fracture Area, Lower Piece

An overall view of the lower piece from the left aft lug fracture area is shown in figure 5 before metal fasteners, clips, and bushings were removed.

Visualized images of the lower piece from the left aft lug fracture area are shown in figure 6, images (a) to (f). An overall image of the piece is shown in figure 6, image (a), as viewed looking forward and to the left. The remaining images in the upper row of figure 6 show virtual cuts perpendicular to the zero-degree fiber direction. Images in the lower row of figure 6 show virtual cuts parallel to the zero-degree fiber direction.

Unlabeled arrows in figure 6 indicate where ply separations were observed. Multiple through-thickness ply separations were observed in areas above the lug attachment hole, as indicated in images (b), (e), and (f). At and below the lug attachment hole, a single ply separation was observed that extended nearly throughout the part.

Above the rib 1 fasteners, a group of layers were fractured and separated from the piece in areas indicated by unlabeled brackets in figure 6, images (b), (e), and (f). The location of these layers was consistent with skin layers that remained attached to the upper section from the left aft lug fracture area. The ply separation that extended nearly throughout the part intersected the innermost surface of these fractured layers.

3.4. Left Aft Lug Fracture Area, Upper Section

An overall view of the upper section from the left aft lug fracture area is shown in figure 7. The section is shown after metal fasteners and clips were removed.

Visualized images of the upper piece from the left aft lug fracture area are shown in figure 8. An overall image of the section as it was visualized is shown in figure 8, image (a). Not all slices for this panel were stacked into the visualization software, and as a result, the overall image does not include the uppermost six inches of the scanned areas. (The piece was cut at least eight inches away from ply separations that were detected by ultrasound inspection.) The remaining images in figure 8 show virtual cut planes perpendicular to the zero-degree fiber direction. Stringers are numbered, and the rear spar flange is labeled in figure 8, image (a).

The resolution of the visualized images was lower than the original slice images. Higher resolution slice images are shown in figure 9 for each of the virtual cut planes shown in figure 8.

Additional visualized images of the upper piece from the left aft lug fracture area are shown in figure 10. Figure 10, image (a) is identical to figure 8, image (c) showing a virtual cut plane perpendicular to the zero-degree fiber direction. The remaining images in figure 10 show additional virtual cut planes parallel to the zero-degree fiber direction.

Two areas of ply separation and layer fracture were observed in the upper section of the left aft lug fracture area. One area, indicated with red arrows in figures 8 to 10, was located near the outboard surface. The other area, indicated with yellow arrows and brackets in figures 8 to 10, was located near the inboard surface.

In the ply separation near the outboard surface (indicated in red), some areas had a relatively large opening displacement where material appeared to be missing. The aspect ratios of these areas were large, with the longer sides oriented parallel to the zero-degree fiber direction. Also, the through-thickness edges were relatively squared off, features consistent with pull-out of zero-degree tape layers. At the lower end of the ply separation, layers were missing from the ply separation outboard to the surface as indicated by red brackets in figures 8 to 10. These missing layers corresponded to the layers that remained attached to the lower piece.

Near the inboard surface (indicated in yellow), ply separations above rib 4 were located just outboard of the stringer outer flanges for stringers 1, 2, and 3 and outboard of the rear spar flange. Below rib 4, layers were missing in areas indicated by yellow brackets in figures 8 to 10. These missing layers also corresponded to the layers that remained attached to the lower piece.

A visualized image indicating where each area of ply separation was located within portions of the structure is shown in figure 11. The ply separation and layer fracture near the outboard surface is indicated in red within the area outlined in blue. The ply separation and layer fracture near the inboard surface is indicated in yellow within the area outlined in green.

3.5. Left Forward Lug Fracture Area, Upper Section

An overall view of the upper section from the left forward lug fracture area is shown in figure 12. The section is shown after metal fasteners and clips were removed.

Visualized images of the upper piece from the left forward lug fracture area are shown in figure 13. An overall image of the section as it was visualized is shown in figure 13, image (a). The remaining images in figure 13 show virtual cut planes perpendicular to the zero-degree fiber direction. Stringers are numbered in each image, and the forward spar flange is labeled in figure 13, image (a).

The resolution of the visualized images was lower than the original slice images. Higher resolution slice images are shown in figure 14 for each of the virtual cut planes shown in figure 13, images (b) to (f).

Additional visualized images of the upper piece from the left forward lug fracture area are shown in figure 15. Figure 15, image (a) is identical to figure 13, image (c) showing a virtual cut plane perpendicular to the zero-degree fiber direction. The remaining images in figure 15 show additional virtual cut planes parallel to the zero-degree fiber direction.

Multiple ply separations through the thickness were observed in the lug area below rib 1 and in locations within approximately four inches above rib 1. These ply separations are indicated by arrows in figure 13, image (b); figure 14, image (e); and figure 15, images (c) to (e). Above rib 1, a ply separation with a relatively large opening displacement was observed just outboard of the stringer outer flanges and the forward spar flange. The edges of this ply separation tapered smoothly to a small opening displacement such that despite the relatively large opening displacement, no material appeared to be missing from between the separated surfaces.

Matthew R. Fox
Materials Engineer

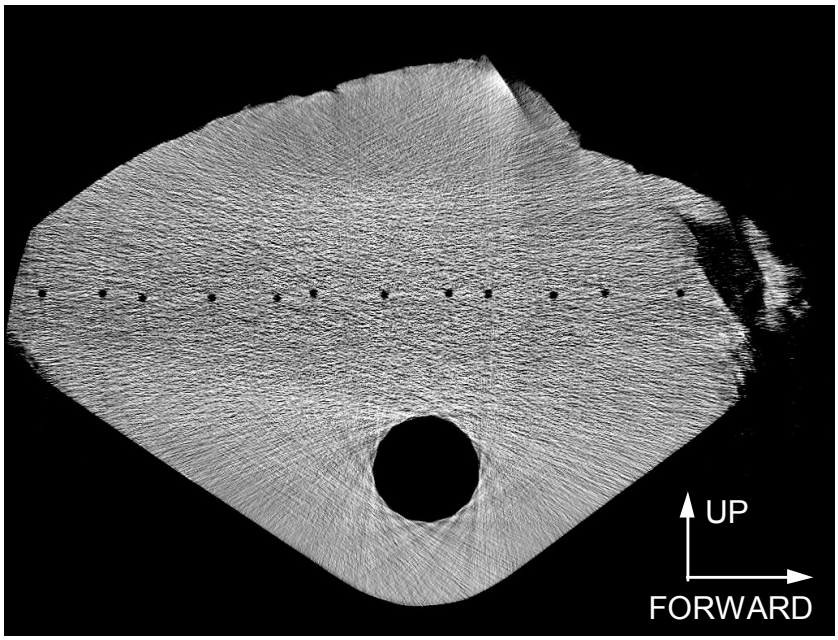
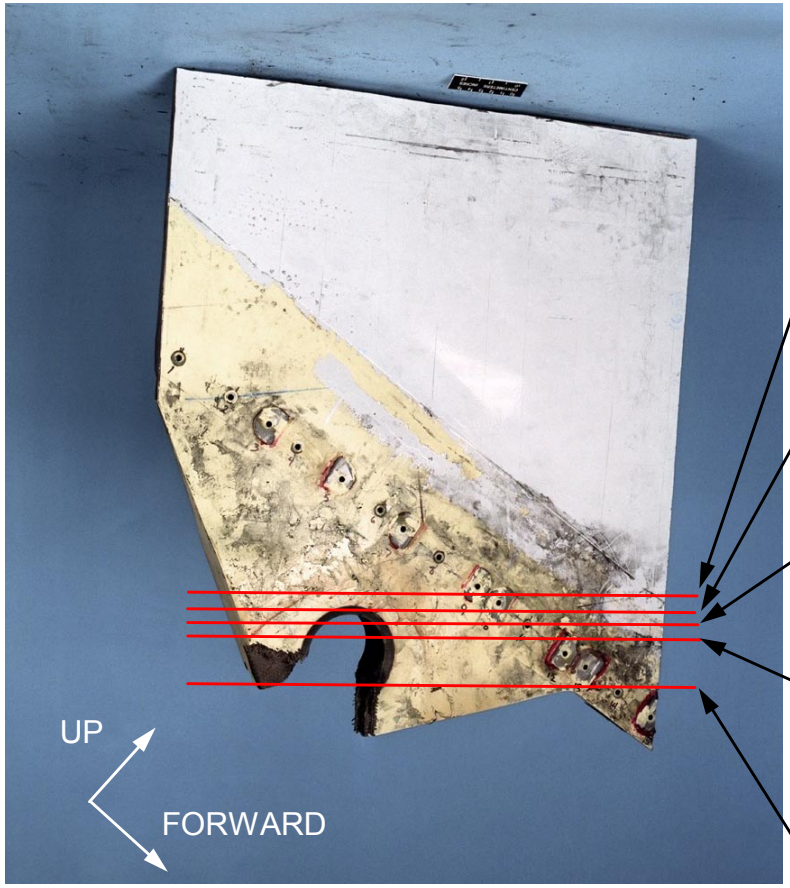


Figure 1. One slice image from the CT scan of the inner portion of the right center lug piece. The image shows the speckled or streaked appeance, which was an artifact of the scanning and reconstruction process.



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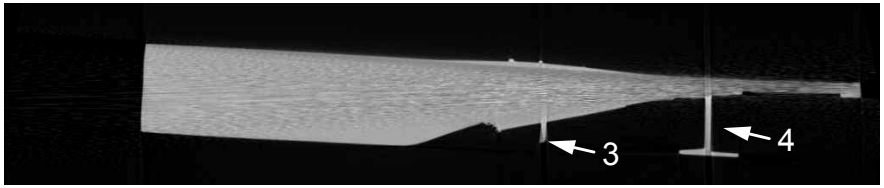

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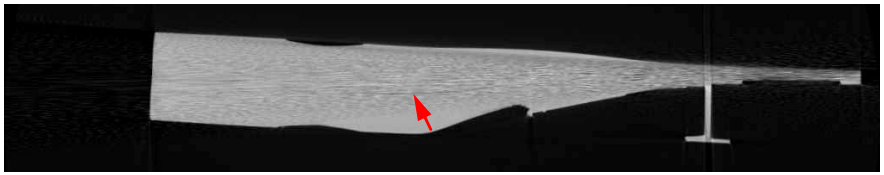

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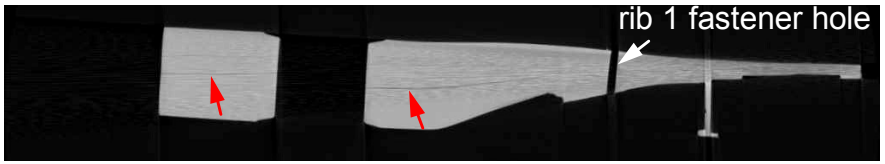

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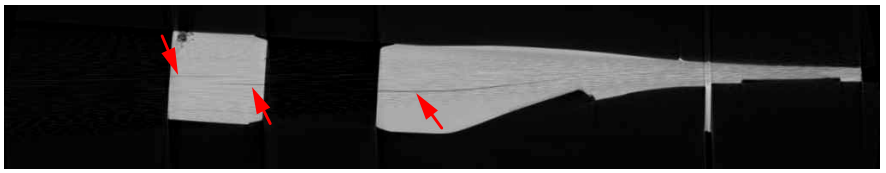

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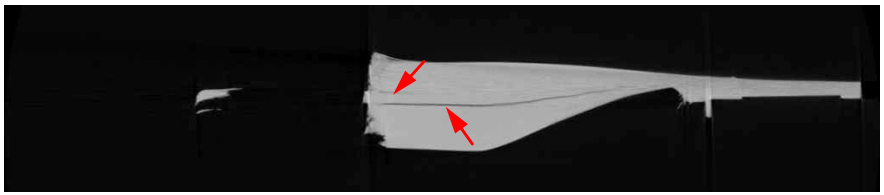

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100 mm

RIGHT

UP and FORWARD

Figure 2. Overall view of the right aft lug fracture area section after removal of the clips and fasteners for CT scanning is shown at the left. Red lines on the photo shown at the left indicate the approximate location of each representative CT slice image shown at the right. The CT slice images are shown as viewed looking upward parallel to the zero-degree fiber direction. Unlabeled arrows on the images indicate ply separations. Stringer numbers are indicated in the uppermost slice image.

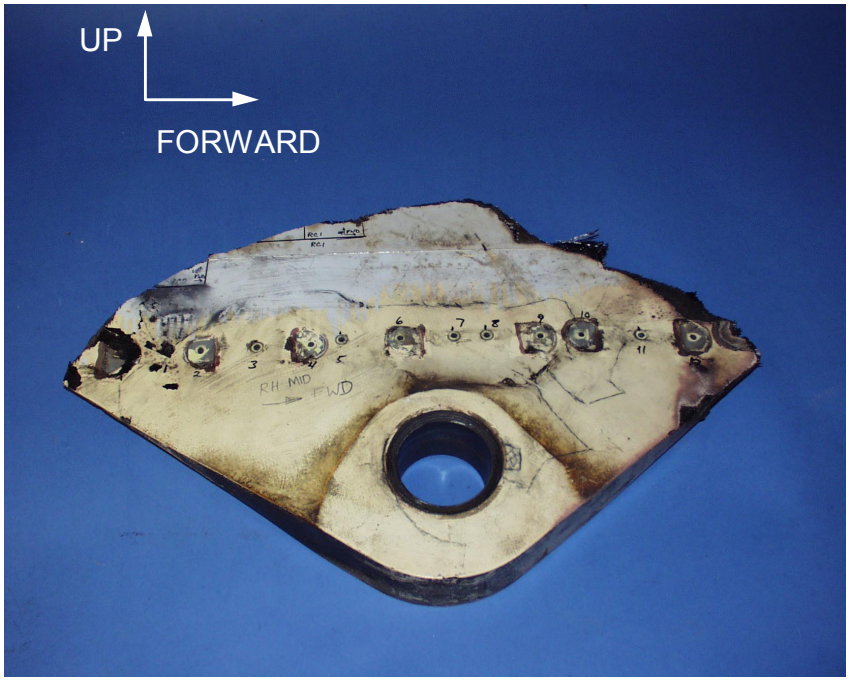


Figure 3. Overall view of the right center lug piece after metal bushings, clips, and fasteners were removed prior to CT scanning.

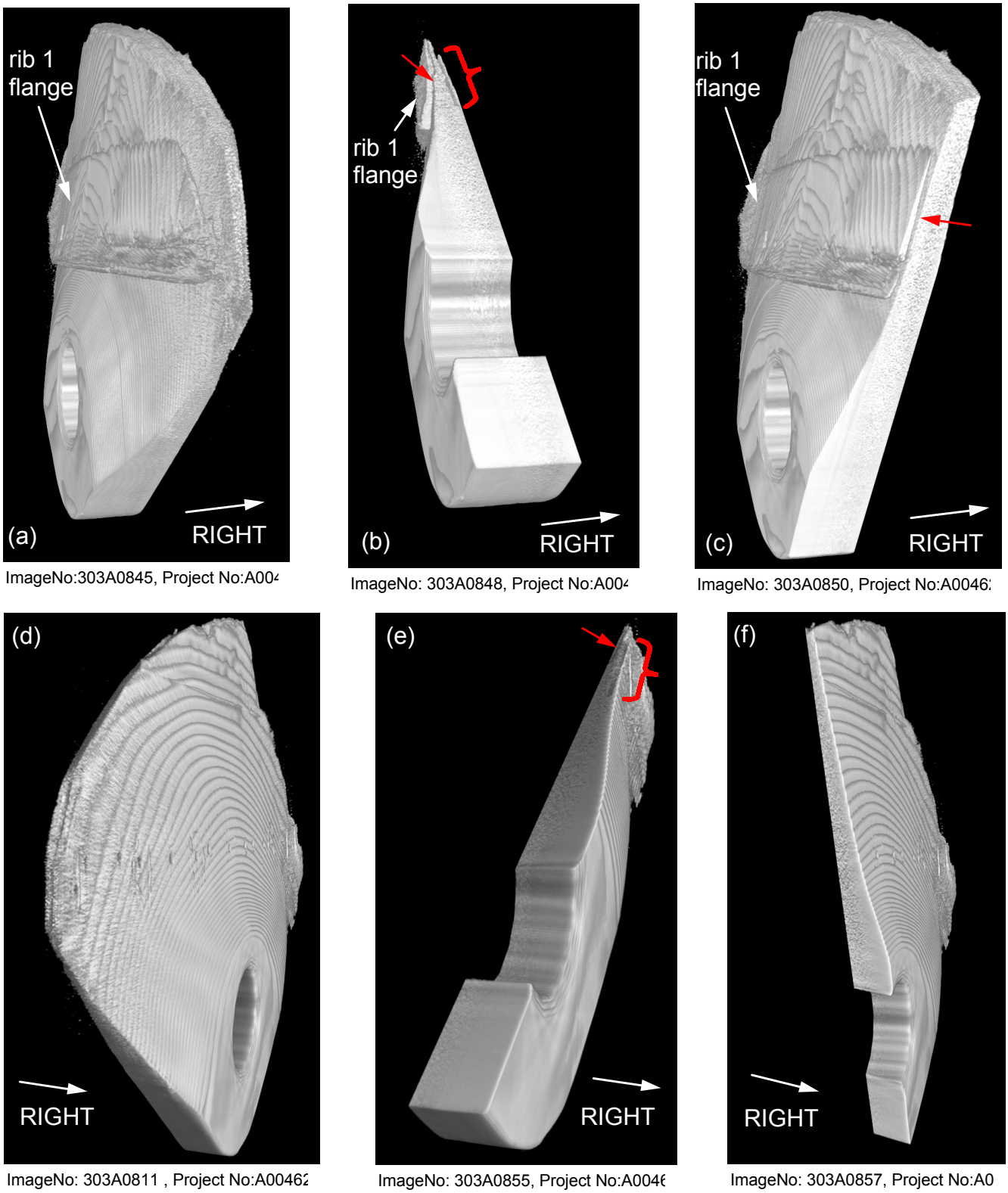


Figure 4. Three-dimensional visualization images of the CT scans from the right center lug piece. The upper and lower rows show scans from the inner and outer overlapping portions of the piece, respectively. The center and right images show virtual cut planes perpendicular and parallel to the zero-degree fiber direction, respectively. Unlabeled arrows indicate ply separations, and unlabeled brackets indicate where layers fractured from the piece. (In images (b) and (c), the delaminations are the same, indicating the extent of overlap.)

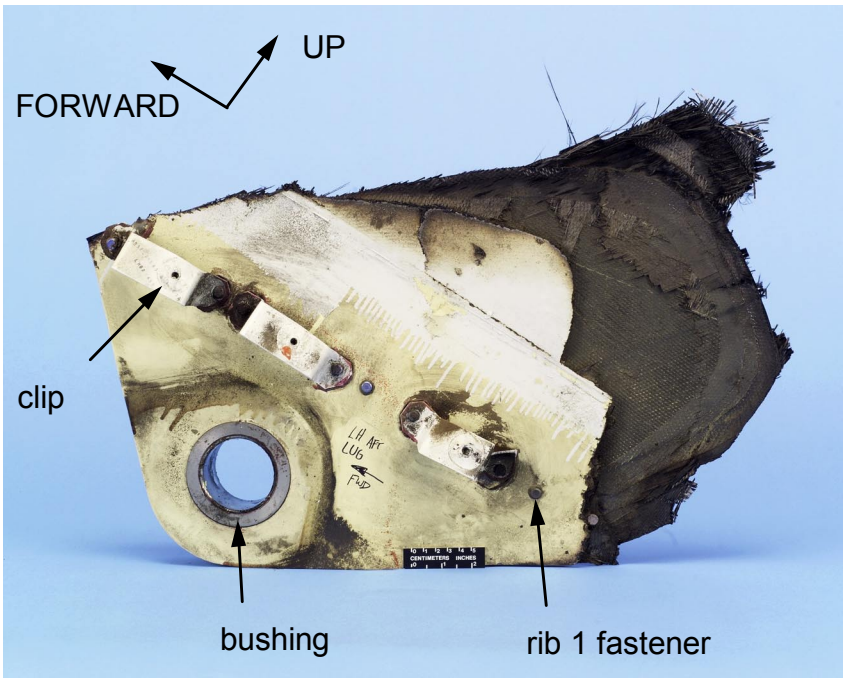
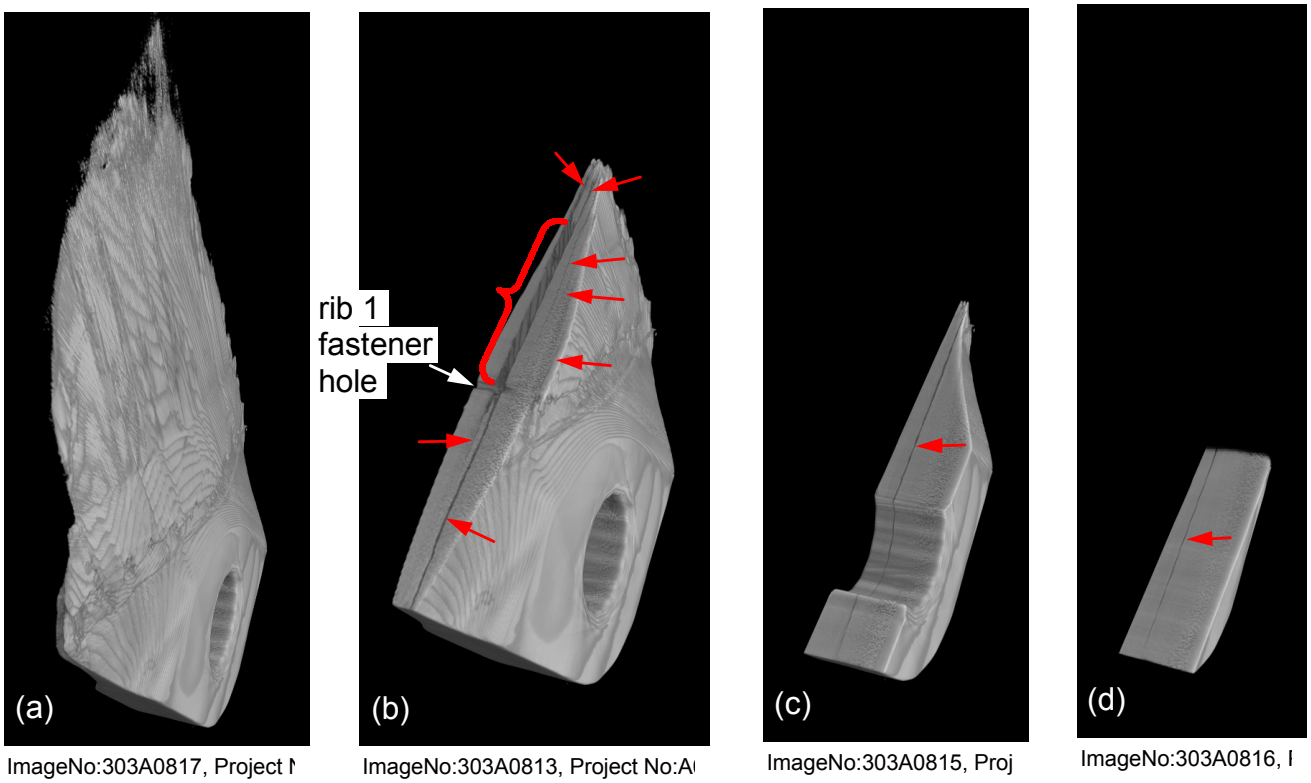
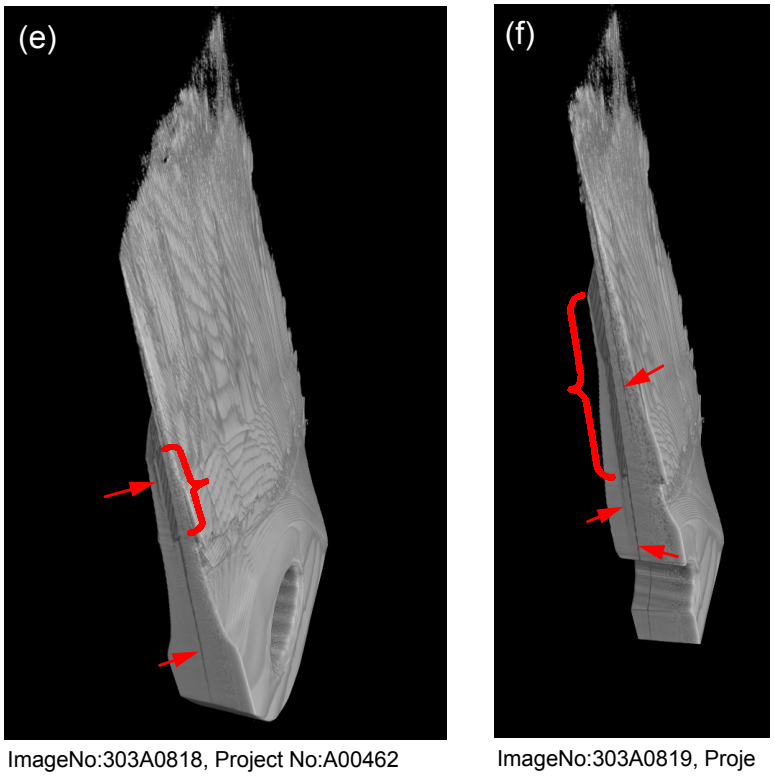


Figure 5. Overall view of the lower piece from the left aft lug fracture area. Metal bushings, clips, and fasteners were removed before CT scanning.





LEFT

Figure 6. Three-dimensional visualization images of the CT scans from the lower piece of the left aft lug fracture area as viewed looking forward and to the left. An overall view is shown at the upper left image. The remainder of the upper row shows virtual cut planes perpendicular to the zero-degree fiber direction, and the lower row shows virtual cut planes parallel to the zero-degree fiber direction. Unlabeled arrows indicate ply separations, and unlabeled brackets indicate where layers fractured from the lower piece, remaining attached to the upper piece.

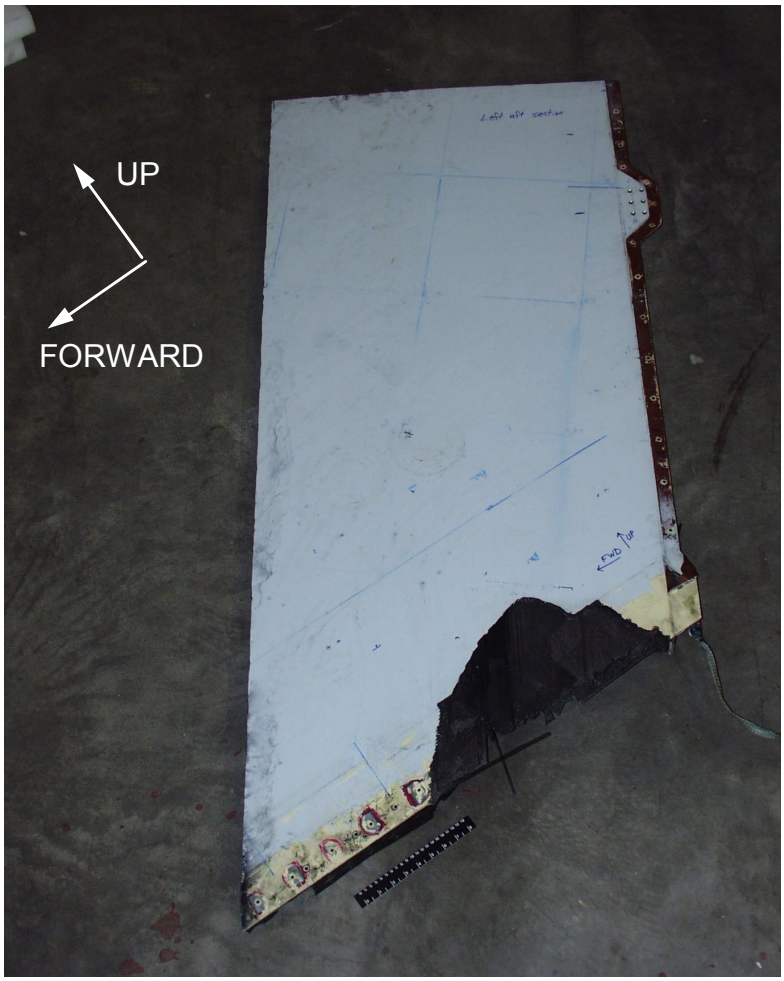


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Figure 7. Overall view of the upper section from the left aft lug fracture area after metal fasteners and clips were removed for CT scanning.

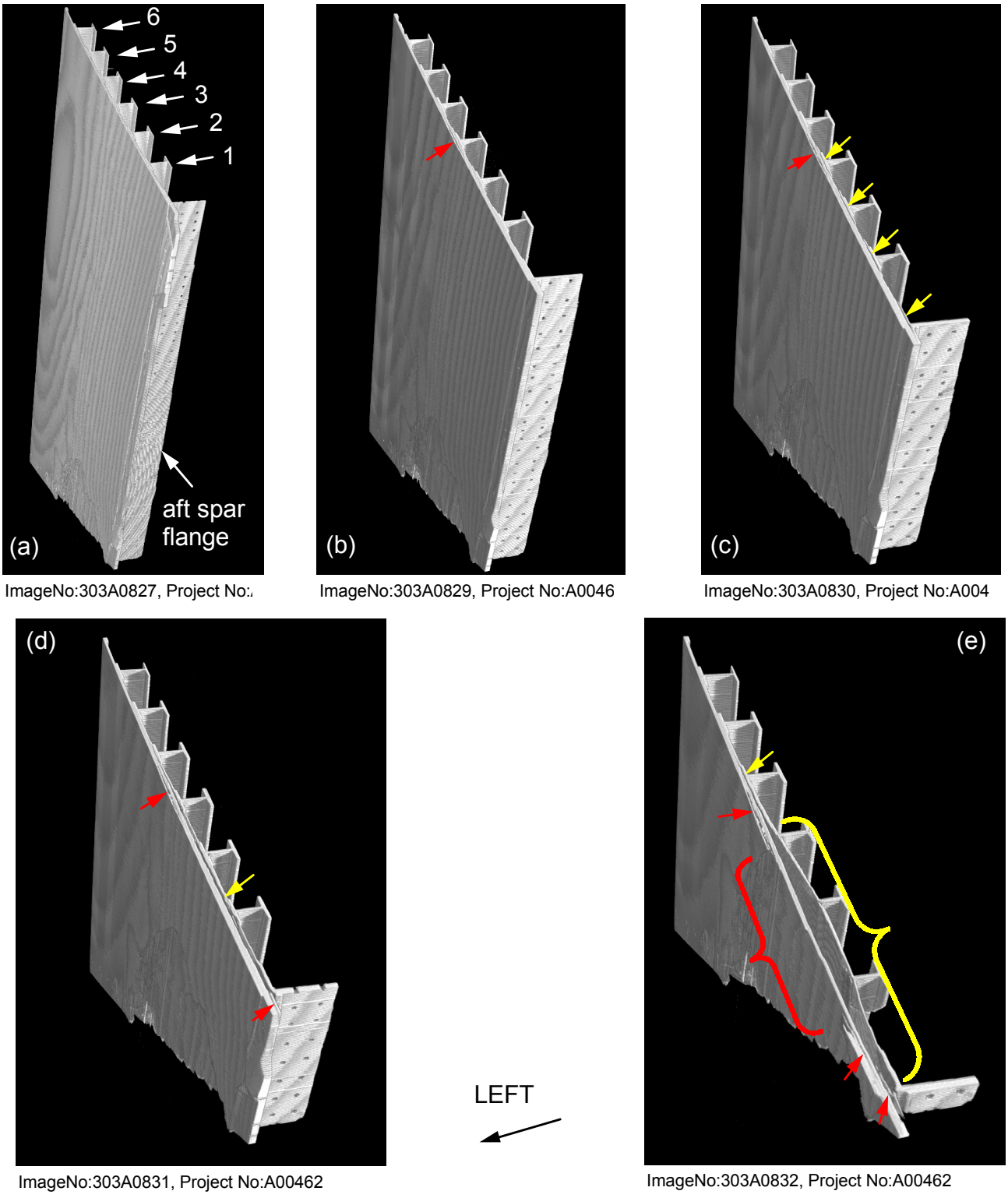

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Figure 8. Three-dimensional visualization images of the CT scans from the upper section of the left aft lug fracture area as viewed looking forward and to the right. An overall view (not including the uppermost six inches) is shown at the upper left. The remainder of the upper row and the lower row show virtual cut planes perpendicular to the zero-degree fiber direction. Unlabeled arrows indicate ply separations, and unlabeled brackets indicate where skin layers fractured from the upper piece, remaining attached to the lower piece. The six stringers in the panel are numbered as indicated in image (a).

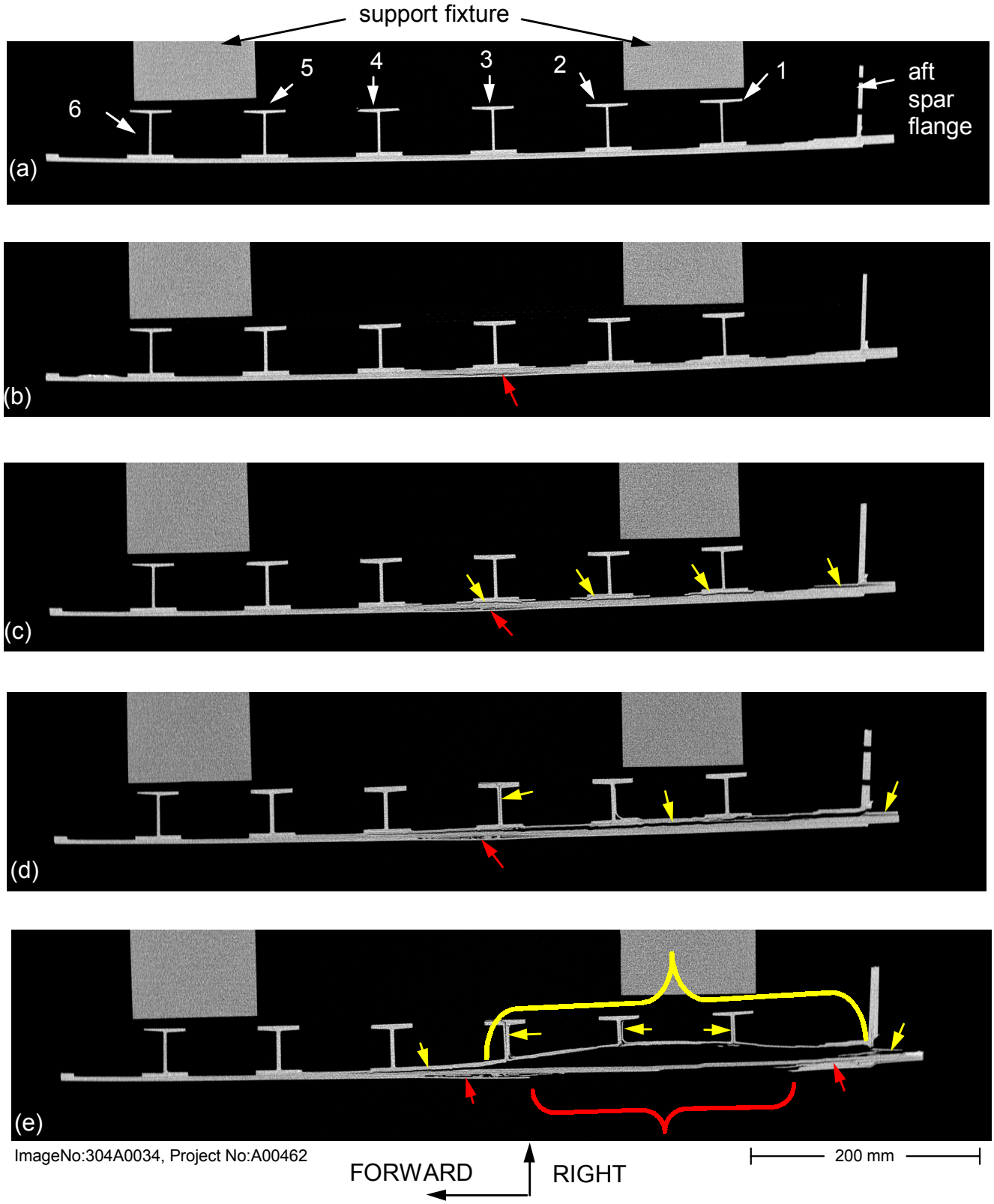


Figure 9. Higher-resolution CT slice images for the upper section of the left aft lug fracture area. Images are for the cut planes shown in figure 8, images (a) to (f), as viewed looking downward parallel to the zero-degree fiber direction. Unlabeled arrows indicate delaminations, and unlabeled brackets indicate the locations where layers fractured from the upper section and remained attached to the lower piece.

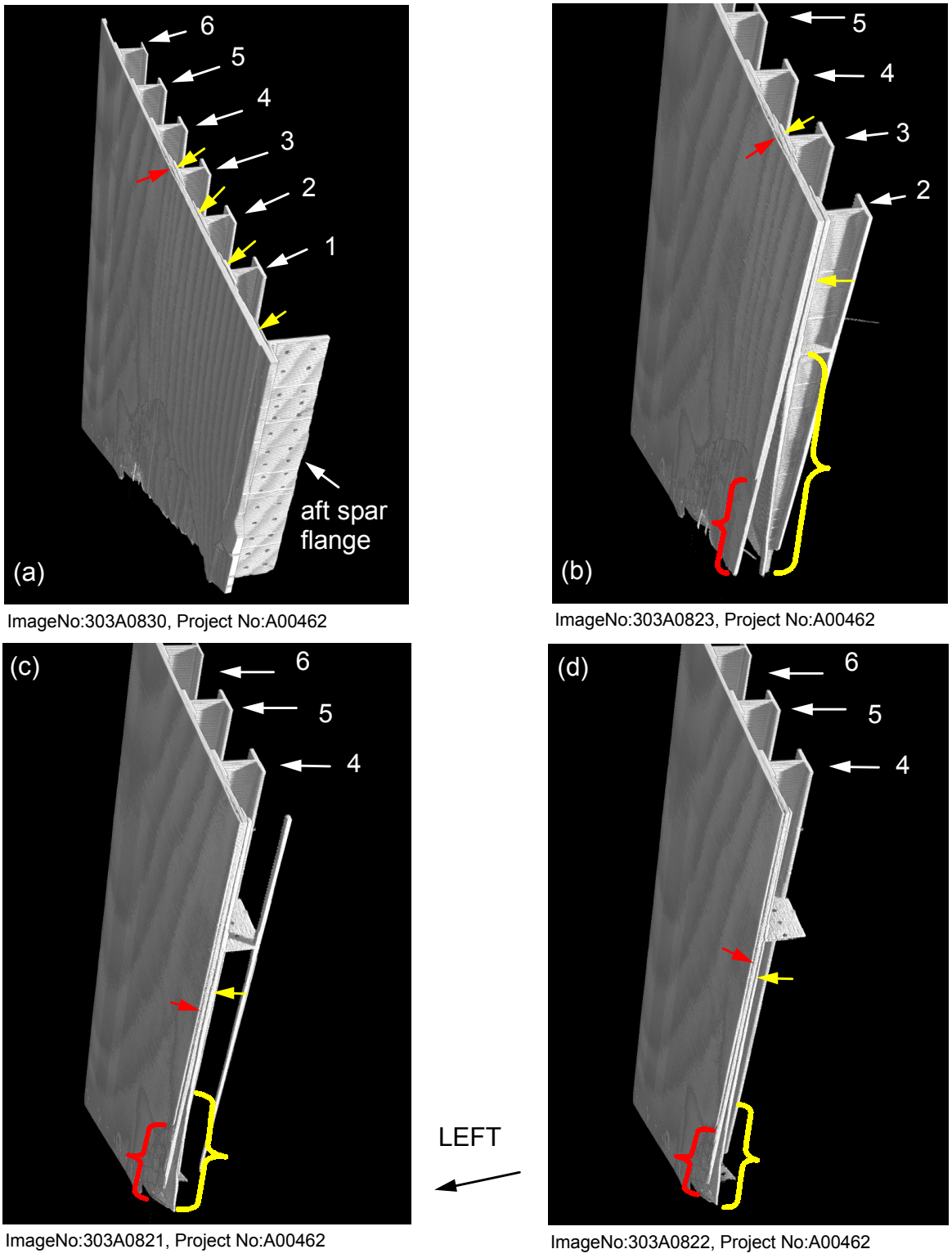


Figure 10. Three-dimensional visualization images of the CT scans from the upper section of the left aft lug fracture area as viewed looking forward and to the right. Image (a) is identical to figure 8, image (c). Images (b) to (d) show additional virtual cut planes parallel to the zero-degree fiber direction. Unlabeled arrows indicate ply separations, and unlabeled brackets indicate where layers fractured from the section and remained attached to the lower piece. The six stringers in the panel are numbered as indicated.

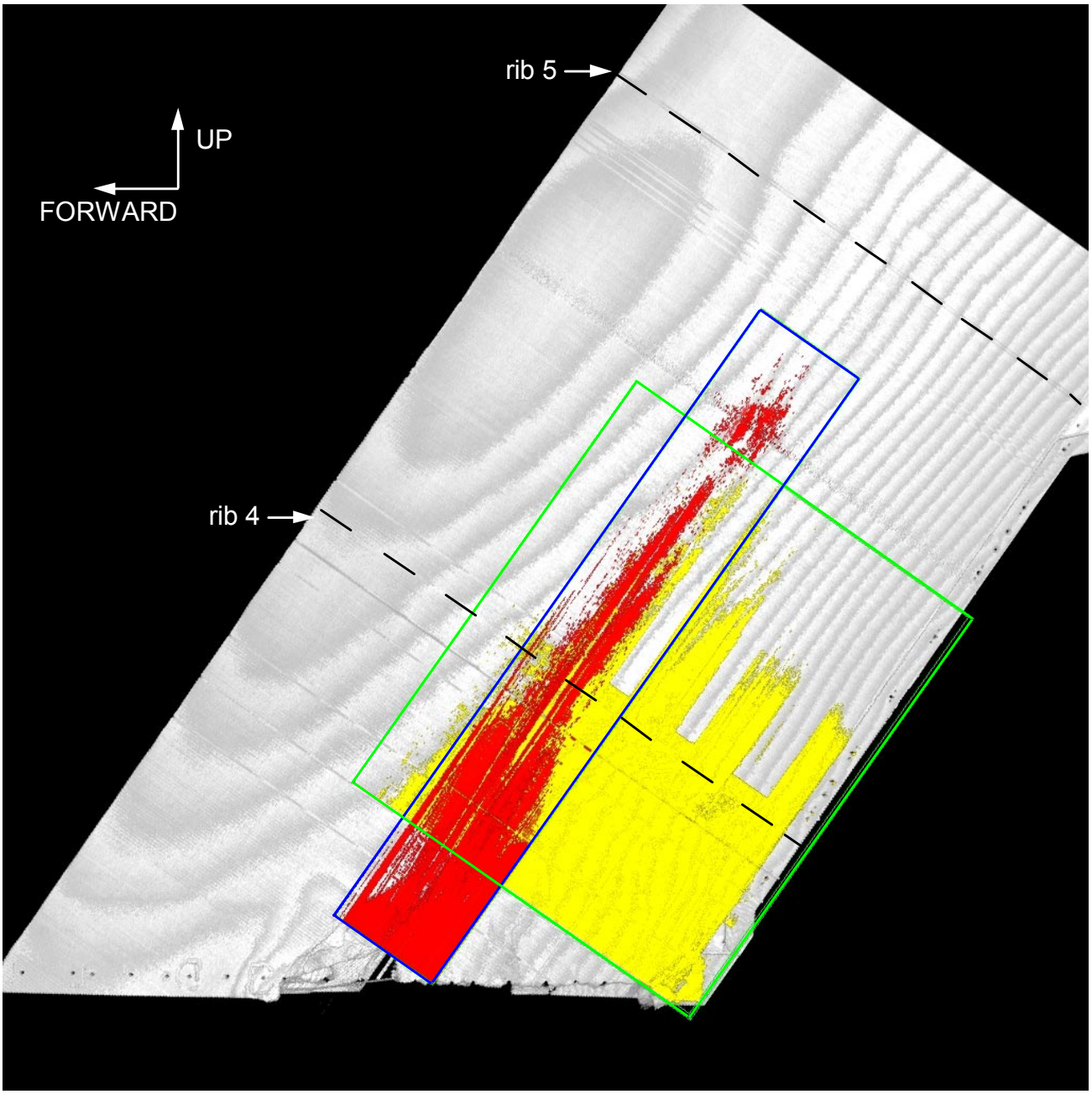


Figure 11. Three-dimensional visualization image of the CT scans from the upper section of the left aft lug fracture area as viewed looking to the right. Within the area outlined in blue, ply separation and layer fracture near the outboard surface is shown in red. Within the area outlined in green, ply separation and layer fracture near the inboard surface is shown in yellow.

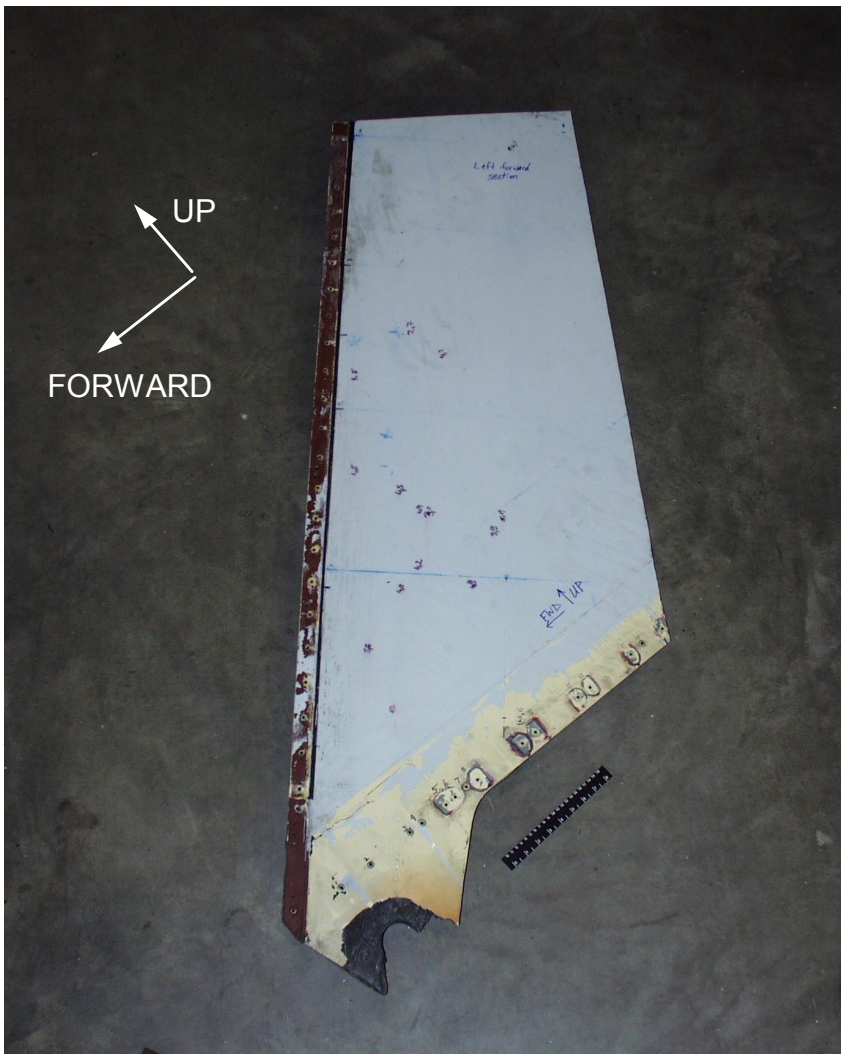


Figure 12. Overall view of the left forward lug fracture area section after metal fasteners and clips were removed for CT scanning.

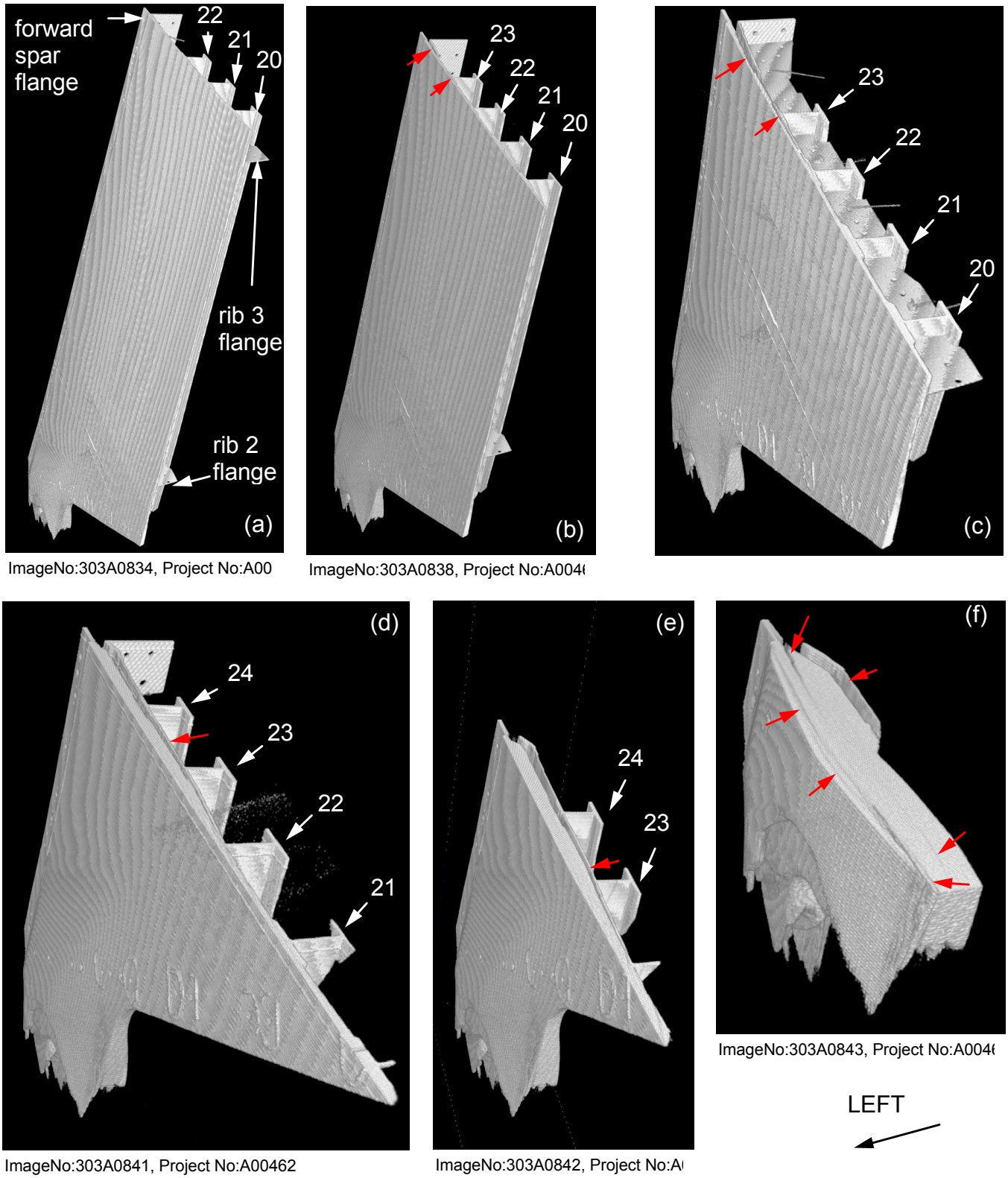


Figure 13. Three-dimensional visualization images of the CT scans of the left forward lug fracture section as viewed looking forward and to the right. An overall view is shown in (a). The remainder of the upper row and the lower row show virtual cut planes perpendicular to the zero-degree fiber direction. Unlabeled arrows indicate ply separations. The stringers in the section are numbered as indicated in the images.

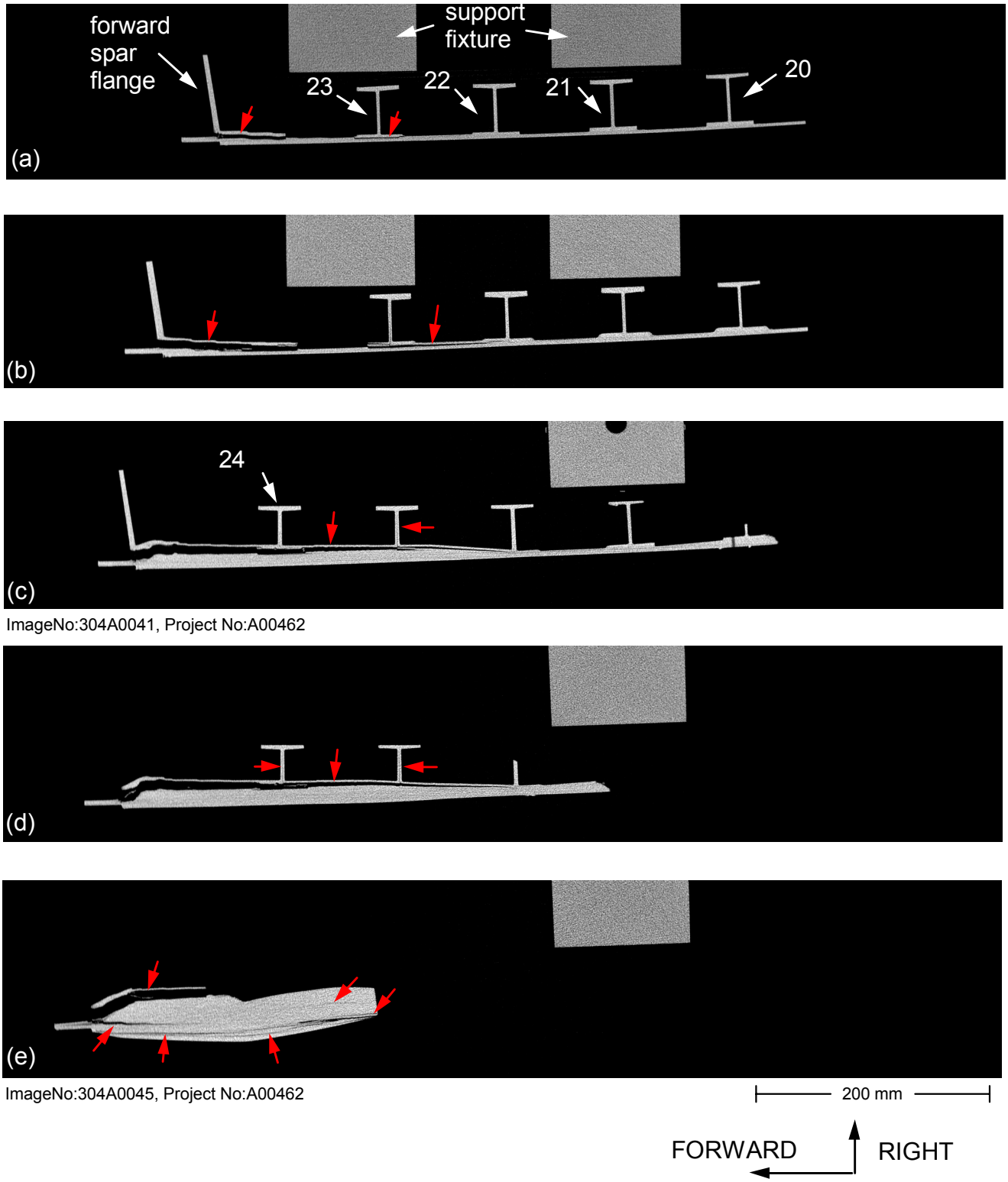
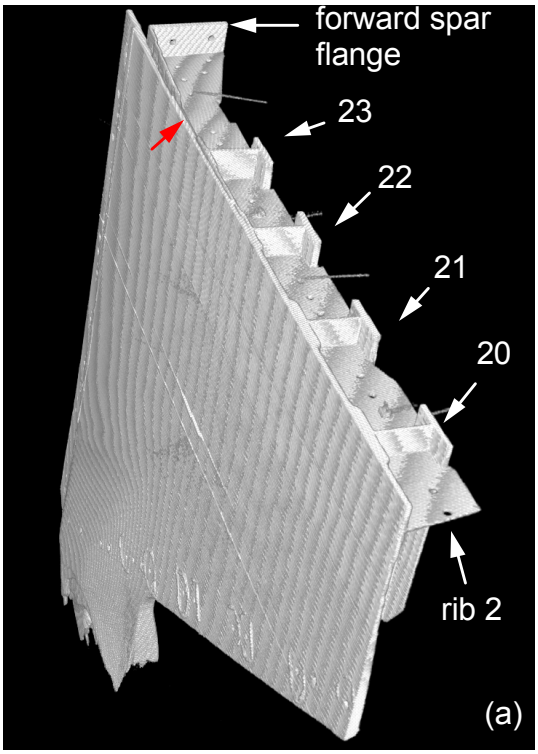


Figure 14. Higher-resolution CT slice images for the left forward lug fracture area section. Images are for the virtual cut planes shown in figure 13, images (b) to (f) as viewed looking downward parallel to the zero-degree fiber direction. Unlabeled arrows indicate delaminations.



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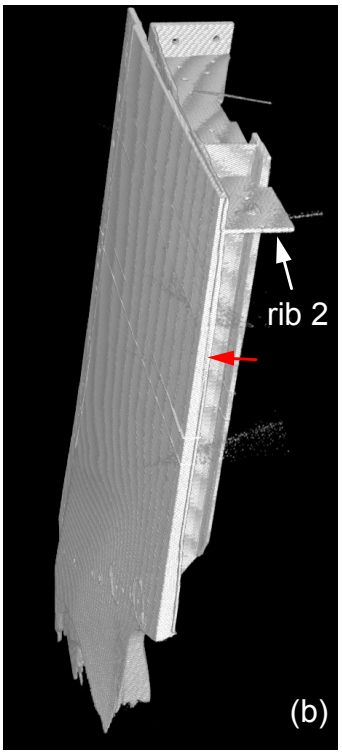

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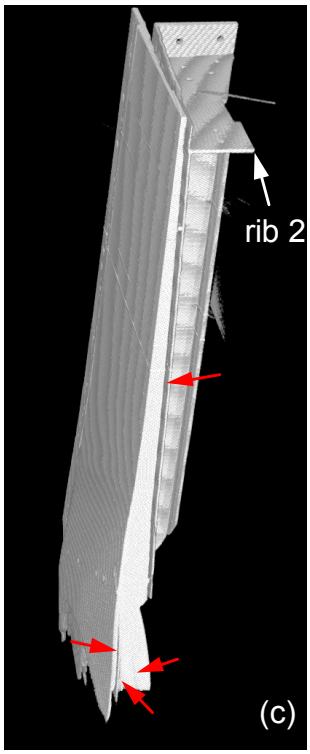
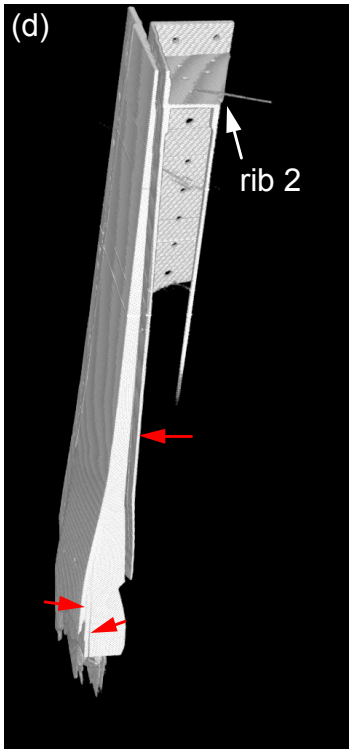
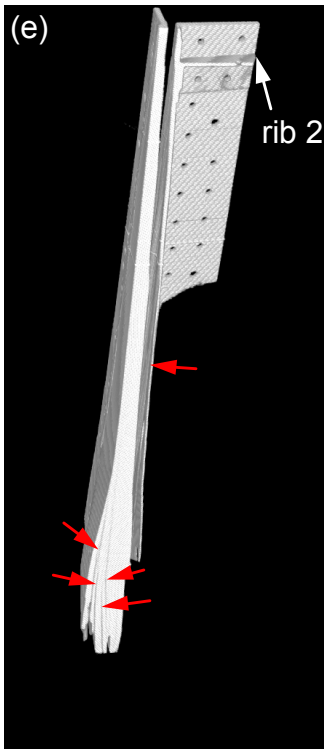


ImageNo:303A0835, Project I



ImageNo:303A0836, Project No:A



ImageNo:303A0837, Project N

Figure 15. Three-dimensional visualization images of the CT scans from the left forward lug fracture area section as viewed looking forward and to the right. Image (a) is identical to figure 13, image (c). Images (b) to (e) show additional virtual cut planes parallel to the zero-degree fiber direction. Unlabeled arrows indicate ply separations. The stringers in the panel are numbered as indicated.