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

April 9, 2010

MATERIALS LABORATORY FACTUAL REPORT Report No. 10-005

A. ACCIDENT

Place : Butte, Montana
Date : March 22, 2009
Vehicle : Pilatus PC-12/45, N128CM
NTSB No. : WPR09MA159
Investigator : Dennis Diaz

B. COMPONENTS EXAMINED

Left fuel boost pump volute housing, impeller, and impeller cover.
Right fuel boost pump drive shaft / armature assembly, volute housing, impeller, and impeller cover.
Fuel filter bypass indicator
Fuel / oil heat exchanger
Low-pressure engine-driven fuel pump

C. DETAILS OF THE EXAMINATION

C.1. EXAMINATION OF LEFT AND RIGHT FUEL BOOST PUMPS

The fuel boost pumps were received in a disassembled state by the Materials Laboratory as shown in figure 1a. The pumps were centrifugal volute pumps (model #: RR35710K) that operated at 7,900 RPM[1]. The left drive shaft / armature assembly was not recovered. The end of the right drive shaft indicated by the arrow had two parallel flats on opposing sides forming a “Double-D” shown in figure 1b. The width of each flat was 0.170 inch as measured by calipers. As situated on the aircraft the armature sat above the volute housing. The shaft passed through a through-hole in the volute housing and emerged into the volute chamber that housed the impeller. Figure 2 shows the left volute housing as viewed from underneath. The drive shaft emerges out of the page into the volute chamber in this view. The appearance of the right fuel boost pump was consistent with exposure to fire. The right pump housing, impeller cover, and armature assembly were brown/black. The right impeller was black and had expanded to fill the volute chamber. The center of the impeller had expanded into the suction side inlet hole and the edge of the impeller had expanded into the pressure side outlet. The lower left corner of the left impeller cover (see figure 1) was fractured. The appearance of the fracture surface was consistent with an overstress fracture.

Deformation marks on the volute housings and metal transfer on the right drive shaft were consistent with contact between the drive shaft and through-hole. Deformation marks were observed on the through-holes of the left and right pump housings. The through-hole is identified on the pump housing in figure 2. An angular reference system was used to identify the location of the deformation marks on the walls of the through-holes. The angle was defined starting in the forward direction along the line intersecting the center of the through-hole and the pressure-side outlet of the boost pump and progressing clockwise. The angles were measured on digital macrophotographs. The locations of the deformation marks are shown in figures 3a and 4a for the left and right housings, respectively. The left pump housing had deformation marks that extended the entire length of the through-hole at 186° and 253° as shown in figure 3b. The right pump housing had marks that extended approximately half the length of the through-hole at similar angles of 189° and 258° as shown in figure 4b. Between these marks were two additional smaller contact marks. The linear distance between the deformation marks was 0.171 inch and 0.166 inch on the left and right housings, respectively as measured on calibrated digital images. This length was consistent with the 0.170 inch width of the flat on the drive shaft. The right armature drive shaft was examined by scanning electron microscope (SEM) in backscatter mode. Aluminum metal transfer from the housing to the drive shaft was observed on a flat face of the drive shaft and an adjacent curved surface. Figure 5a shows the region of aluminum transfer, identified as a dark strip near the edge of the flat face, and figure 5b shows an energy dispersive spectroscopy (EDS) spectrum within the strip confirming the presences of aluminum.

The post-crash orientation of the left and right boost pump impellers and armatures was estimated from photographs of the recovered wreckage shown in figures 6 and 7 for the left and right boost pumps, respectively. The photographs were taken at an off-normal angle so that the angles were approximate. Using the angular reference system described above, the orientation of each impeller (and driveshaft) was defined by a line perpendicular to the flat on the driveshaft as shown in figure 1b. It was determined by measuring angles from the center of the shaft to both edges of the flat and averaging the values (see figure 1b). Using this definition, the post-crash orientations of the left and right drive shafts were 222° ± 3° and 268° ± 3°, respectively. The same technique was used on the deformation marks left by the drive shaft flat on the volute housing to determine the orientation of the drive shaft as it made contact with the through-hole. The orientation of the deformation marks on the left and right through-holes was 220° and 224°, respectively. For the left pump, the orientation of the contact marks and the post-crash orientation of the impeller / drive shaft were the same. For the right pump, they differed by approximately 44°.

The angular orientation of the left pump impeller vane tips relative to the drive shaft was measured on a digital image. One vane tip lagged the drive shaft by 6.8° as defined in figure 8a. The other vane tips were space at 45° around the impeller. The left pump impeller vanes were fractured, cracked, and/or exhibited deformation marks. The impeller is shown in figure 8a as it appeared oriented post-crash in the volute chamber. The view is from above as situated on the aircraft so that the face in contact with the volute housing is face up. All eight vanes facing the housing had deformation marks at the tip as shown in figure 8b. Some of the marks were at a slight angle to the direction of rotation. Two of the marks were comparatively light with one only visible with a microscope (indicated in figure 8a). The height of the marks was consistent with a 0.030 inch step edge around the perimeter of the volute housing as indicated in figure 2. Six of eight vanes had cracked or fractured tips similar to that shown in figure 8b. Two of the vane tips had fractured completely (see figure 8a). One of the two fractured vane tips was still attached by a fine ligament to the body of the impeller when received by the lab but detached shortly thereafter. The remaining four cracks were shorter and the vane tips remained attached. The fracture surfaces were consistent with an overstress event. The presence or absence of contact marks or cracks on the right pump impeller could not be determined due to its exposure to heat.

Polymer transfer marks from the impeller were detected along the raised edge that ran around the perimeter of the left volute chamber. The raised edge was examined by backscatter SEM. Occasional transfer marks were observed as dark spots along the raised edge. A typical example is shown in figure 9. Figure 9a shows a photograph of the left volute housing. While examining the raised edge by backscatter SEM, a transfer mark was observed at the location indicated by the white box. Figure 9b shows the backscatter SEM image from that location. In the image, the transfer mark, consisting of low atomic mass elements such as carbon, nitrogen, and oxygen, appeared as a dark region against the bright background of the aluminum housing. To confirm that the material was from the impeller, the composition of the impeller was first determined by EDS (not shown). The detected peaks included carbon, oxygen, and titanium, consistent with Torlon® 4203/4503, a titanium dioxide-filled polyamide-imide (the two grades are of similar composition)[2]. Fabrication of the impeller from Torlon 4503 was allowed according to RG57169[1]. The EDS spectrum taken in the region inside the square in figure 9b is shown in figure 9c. The titanium peak on the transfer mark was consistent with the impeller material. A graph depicting the location of transfer marks on the impeller housing is shown in figure 10. The view of the graph is from the top of the volute housing as situated on the aircraft. Transfer marks were found around the perimeter of the housing but were heaviest between 165° and 225°. There were no detected marks between 50° and 120°.

C.2. EXAMINATION OF FUEL FILTER BYPASS INDICATOR

The fuel filter bypass indicator was received by the Materials Laboratory as shown in figure 11a. The red indicator stem was missing. The base of the indicator housing and the identification plate were deformed. Figure 11b shows the indicator after disassembly with arrows indicating the position of the pieces with respect to one another. The compression spring was housed inside the indicator guide. The bottom of the spring made contact with the top of the indicator piston which, along with the diaphragm retainer, slipped over the hollow post on the indicator housing. The magnet/spacer assembly was inserted through a hole in the bottom of the indicator housing into the hollow post. A ring-shaped magnet at the bottom of the indicator piston actuated the magnet/spacer assembly. If the red indicator stem were present, a sufficient pressure differential across the fuel filter would have bypassed the filter and popped the stem, indicating the fuel filter had been bypassed.

Prior to disassembly, the fuel filter was examined by X-ray radiography at the FBI Materials Laboratory, Quantico, Virginia. A side view of the indicator is shown in figure 12. A gap was observed between the top of the indicator piston and the upper interior surface of the indicator guide. The magnet/spacer assembly was near the top of the cavity inside the hollow post. The post was examined by stereomicroscope and by backscatter SEM for signs of impact marks or material transfer, but none were found. The elastomer rolling diaphragm was soft, cracked, and torn apart as shown in figure 13.

C.3. EXAMINATION OF FUEL/OIL HEAT EXCHANGER

The fuel/oil heat exchanger was received by the Materials Laboratory as shown in figure 14. The fuel entered the heat exchanger through the in-port, travelled to the opposite end, and back as indicated in the figure. The heat exchanger was cut by a band saw along the dashed line approximately 0.5 inch inside the weld line. There were a few drops of fuel in the heat exchanger; otherwise it was empty. The cut section looking back at the fuel in and out ports is shown in figure 15. There were no observable obstructions on either the fuel in or fuel out sides.

C.4. EXAMINATION OF LOW-PRESSURE ENGINE-DRIVEN FUEL PUMP

The low-pressure engine-driven fuel pump was received by the Materials Laboratory as shown in figure 16. The pump housing was fractured in the vicinity of where the gear engaged the impeller drive shaft. The fracture surfaces were consistent with overstress fractures. The vanes and offset cylinder were removed from the housing and examined by eye. The cylinder and vanes are shown in figures 17a and b, respectively. The components were discolored across a range of brown, blue, and purple, consistent with exposure to fire. The contact surfaces between the cylinder and vanes had wear marks consistent with routine use. There were no gouges or plow marks on any contact surfaces.

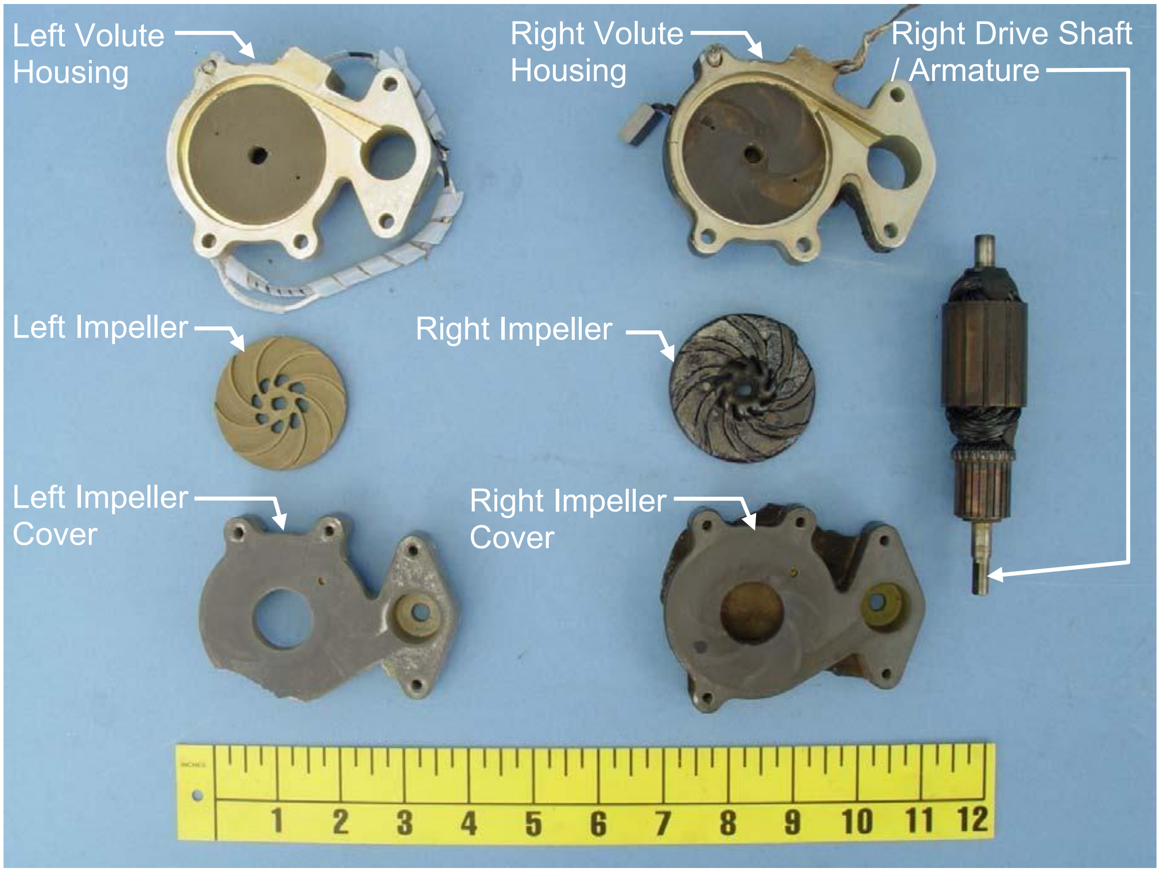
C.5. ACKNOWLEDGEMENT

NTSB would like to thank Michael Smith at the FBI Materials Laboratory, Quantico, VA for his assistance with the radiography of the fuel filter bypass indicator.

D. REFERENCES

1) Crane Aerospace, Personal Communication, 2009.
2) Torlon 4203 PAI ,MSDS Sheet, Quadrant Engineering Plastic Products, 2003.

Donald Kramer
Materials Engineer

a) 

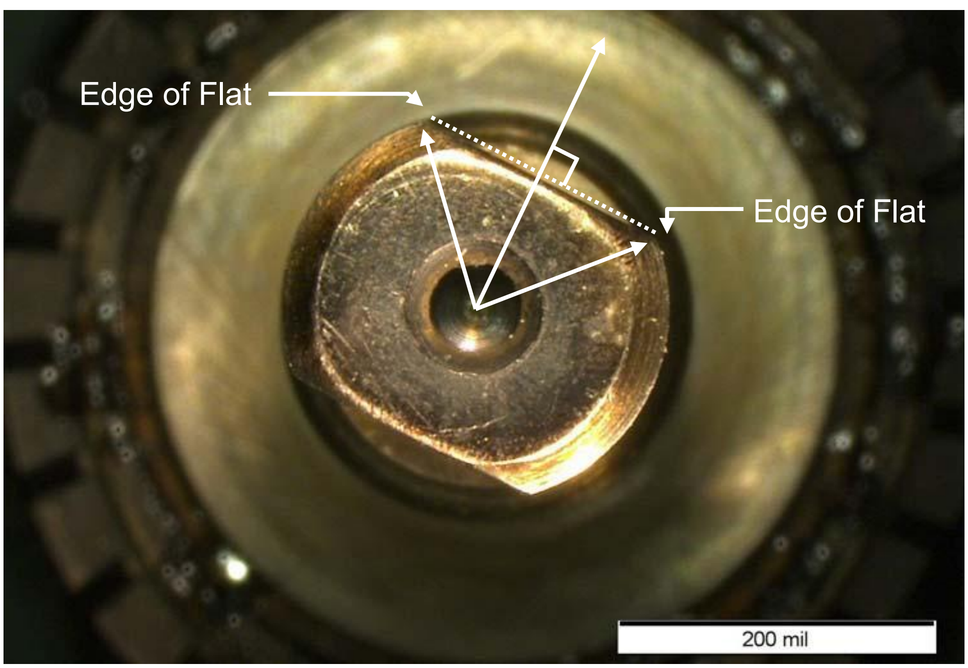
b) 

Figure 1: a) Left and right boost pump components as received; b) Double-D drive shaft at end of armature. The Dashed line is parallel to the flat.

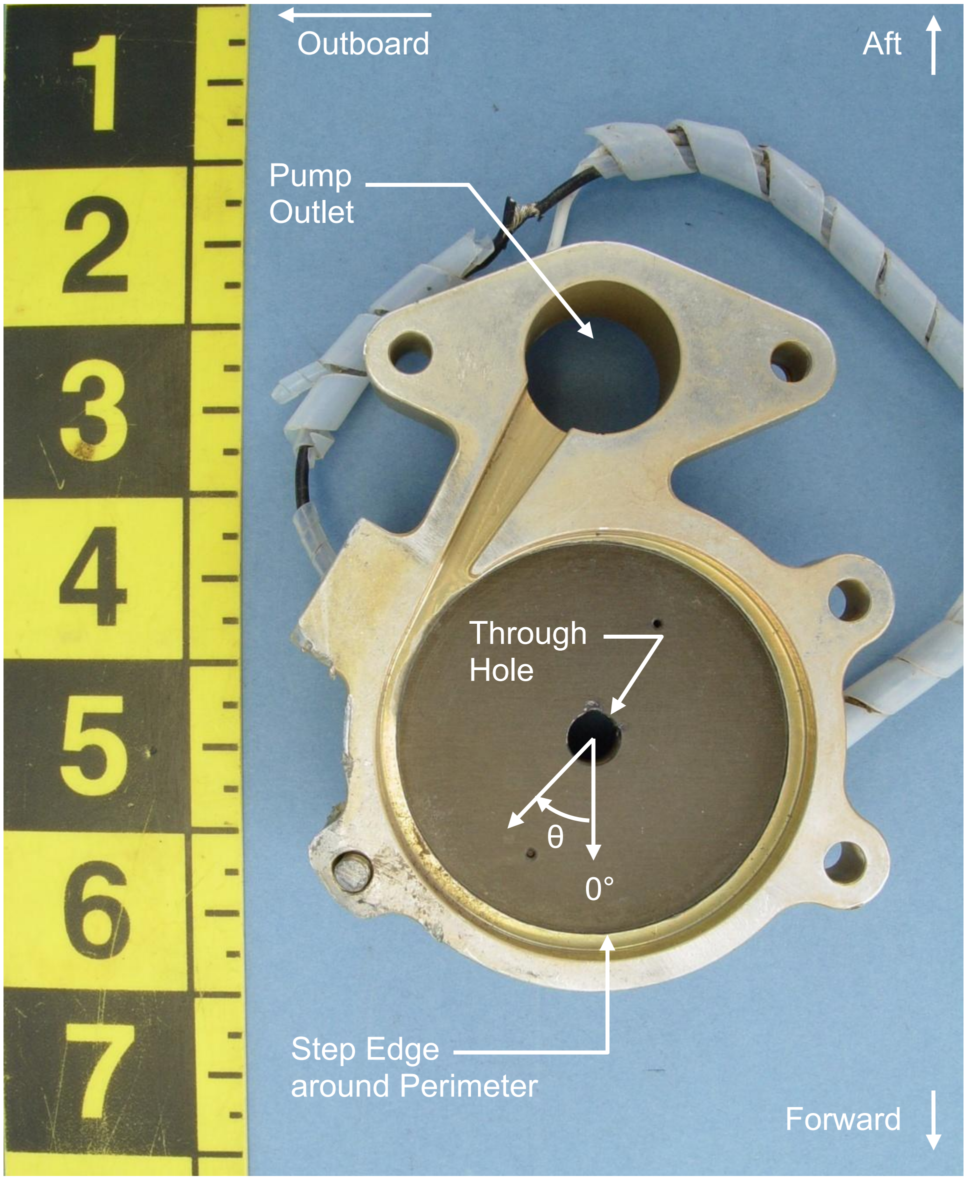
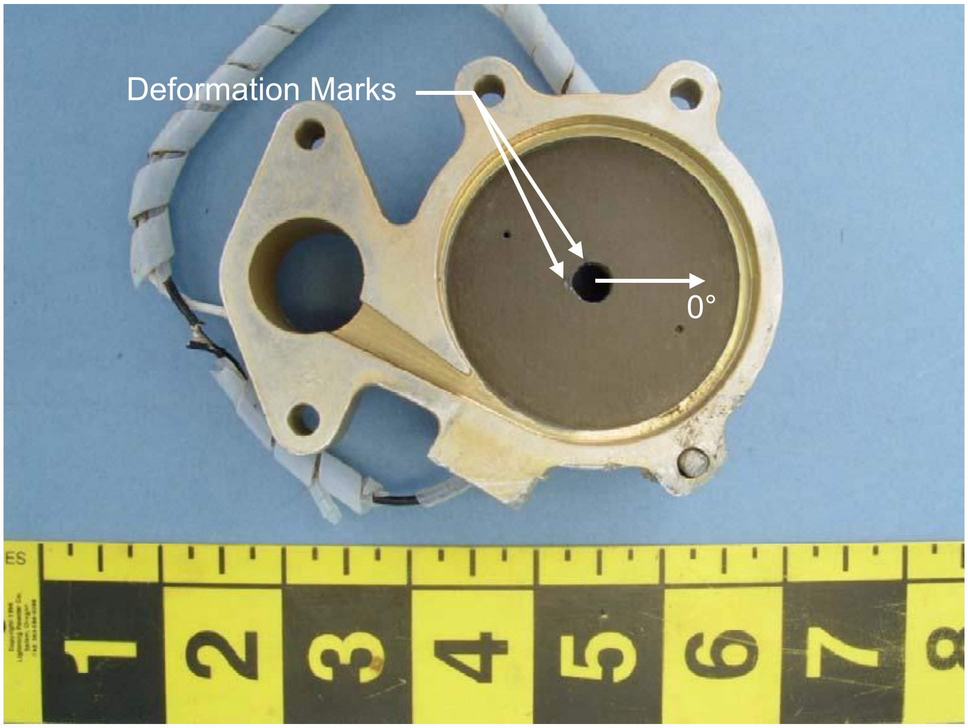


Figure 2: Left boost pump volute housing viewed from the underside as oriented on the aircraft.

a) 

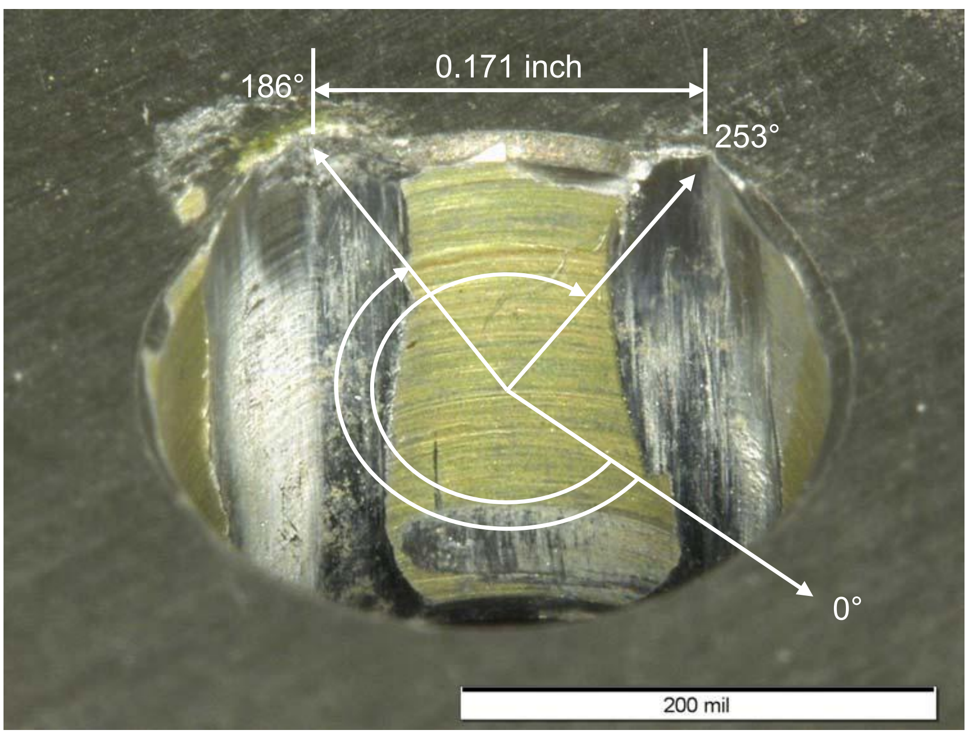
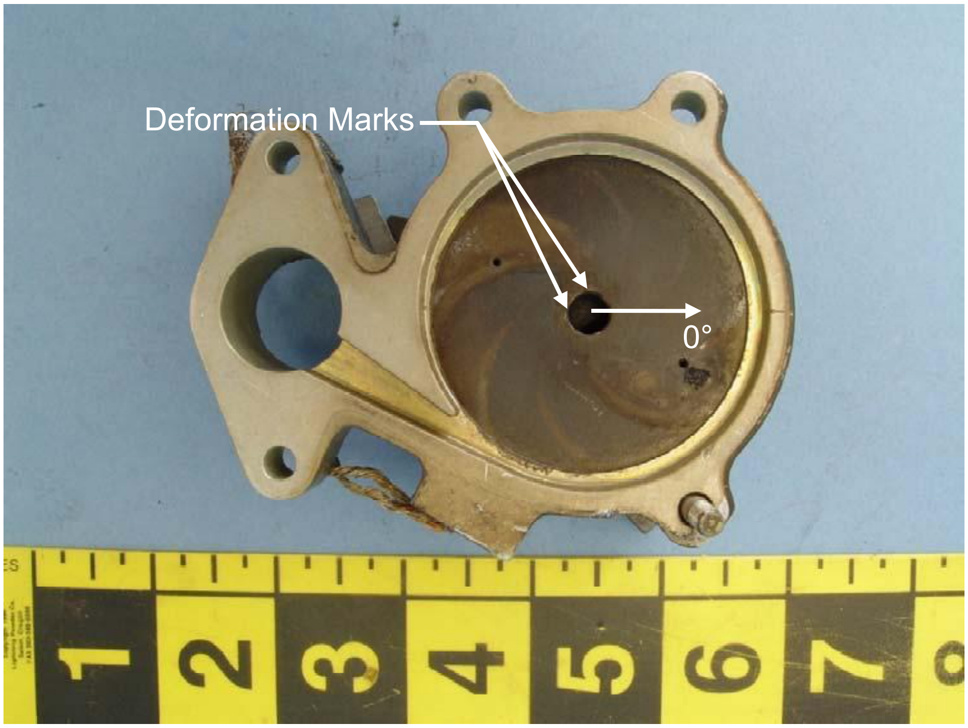
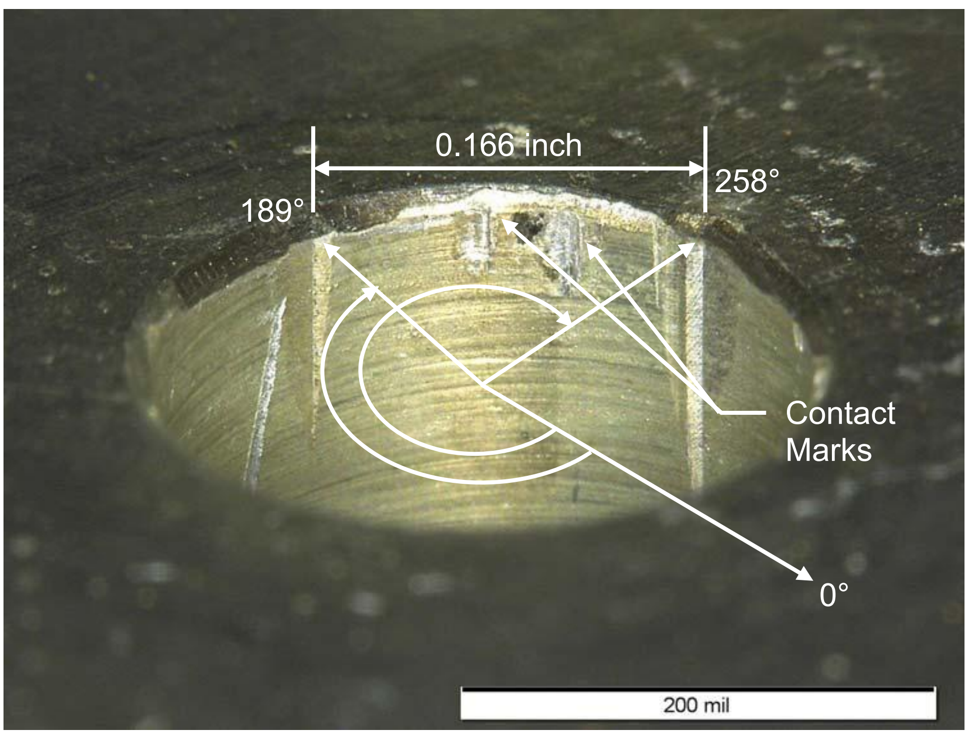
b) 

Figure 3: a) Photograph of the left volute housing. The location of deformation marks are indicated on the through-hole; b) photomacrograph of the through-hole from part a) at an oblique angle.

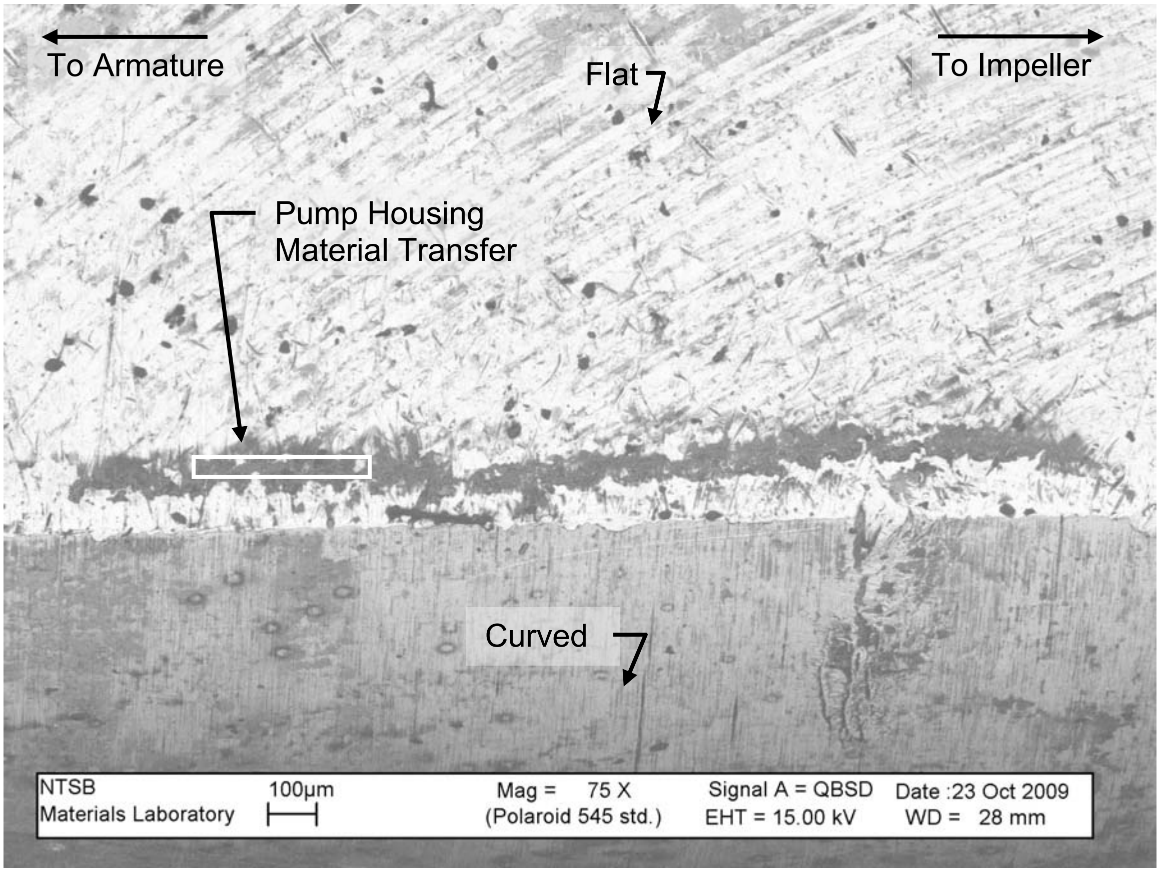


a)

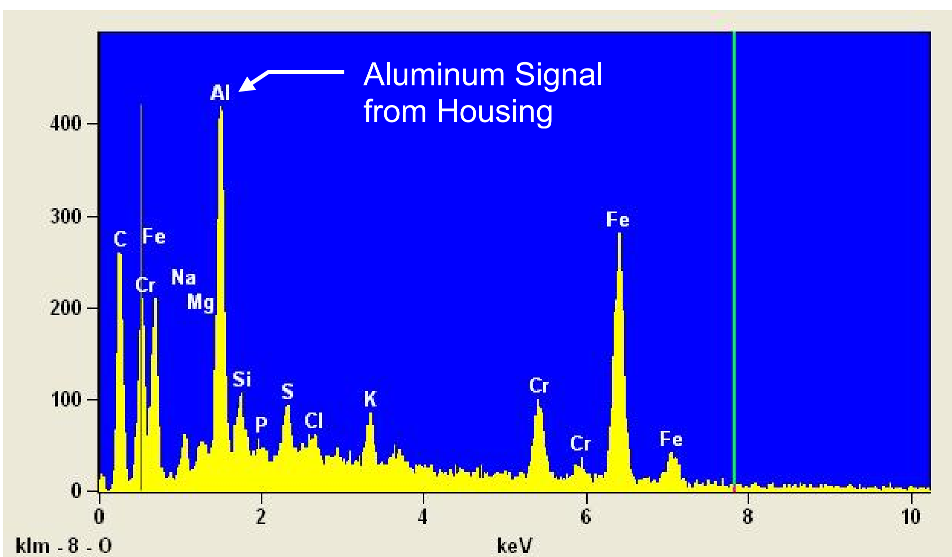


b)

Figure 4: a) Photograph of the right volute housing. The location of deformation marks are indicated on the through-hole; b) photomacrograph of the through-hole from part a) at an oblique angle.



a)



b)

Figure 5: a) Backscatter SEM image of the right boost pump double-D drive shaft showing material transfer on a flat face; b) EDS spectrum from the region indicated by the box in part a) showing aluminum material transfer from the volute housing.

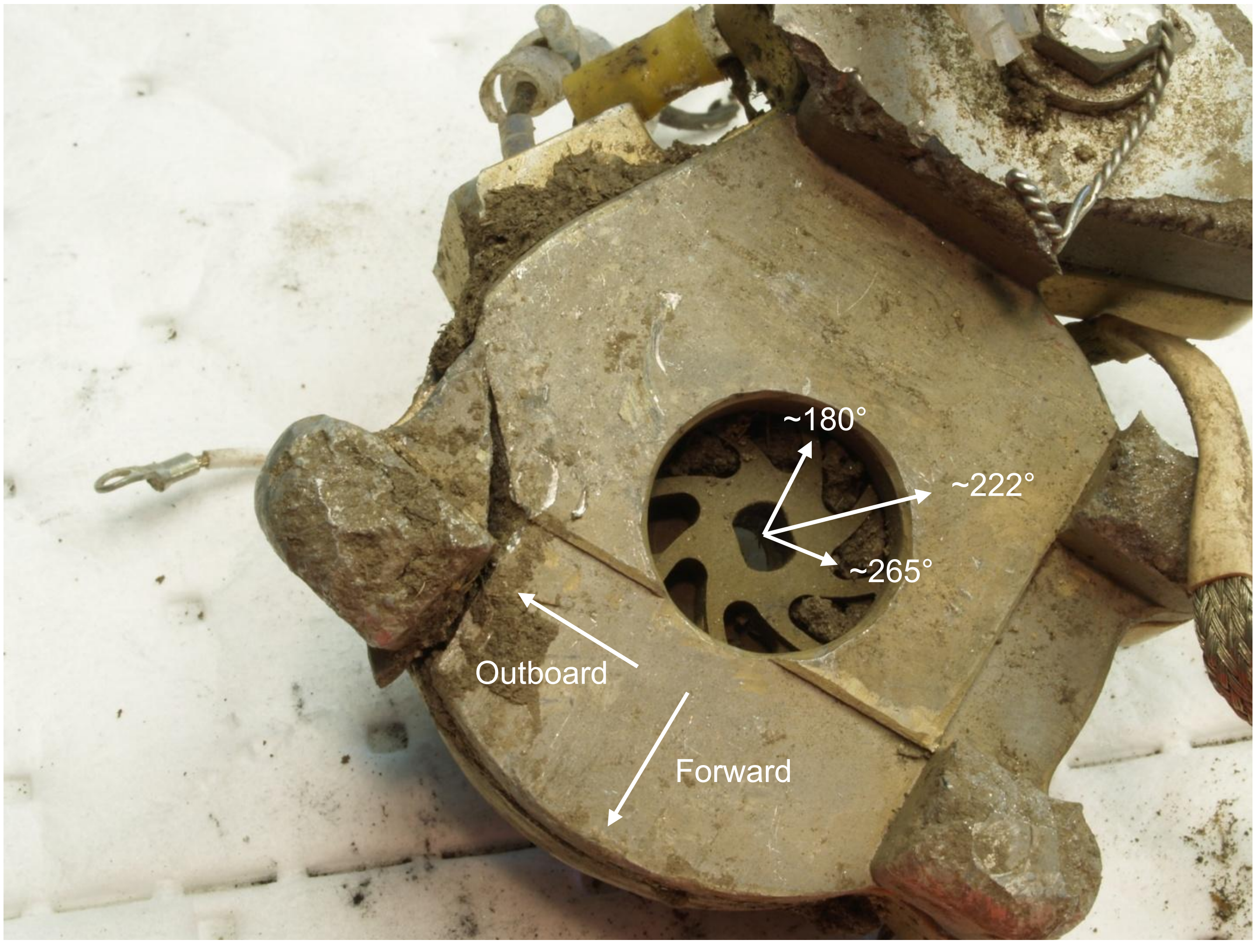


Figure 6: Photograph of the left boost pump prior to teardown (Photo by D. Diaz). The view is of the suction side from underneath the pump as situation on the aircraft.

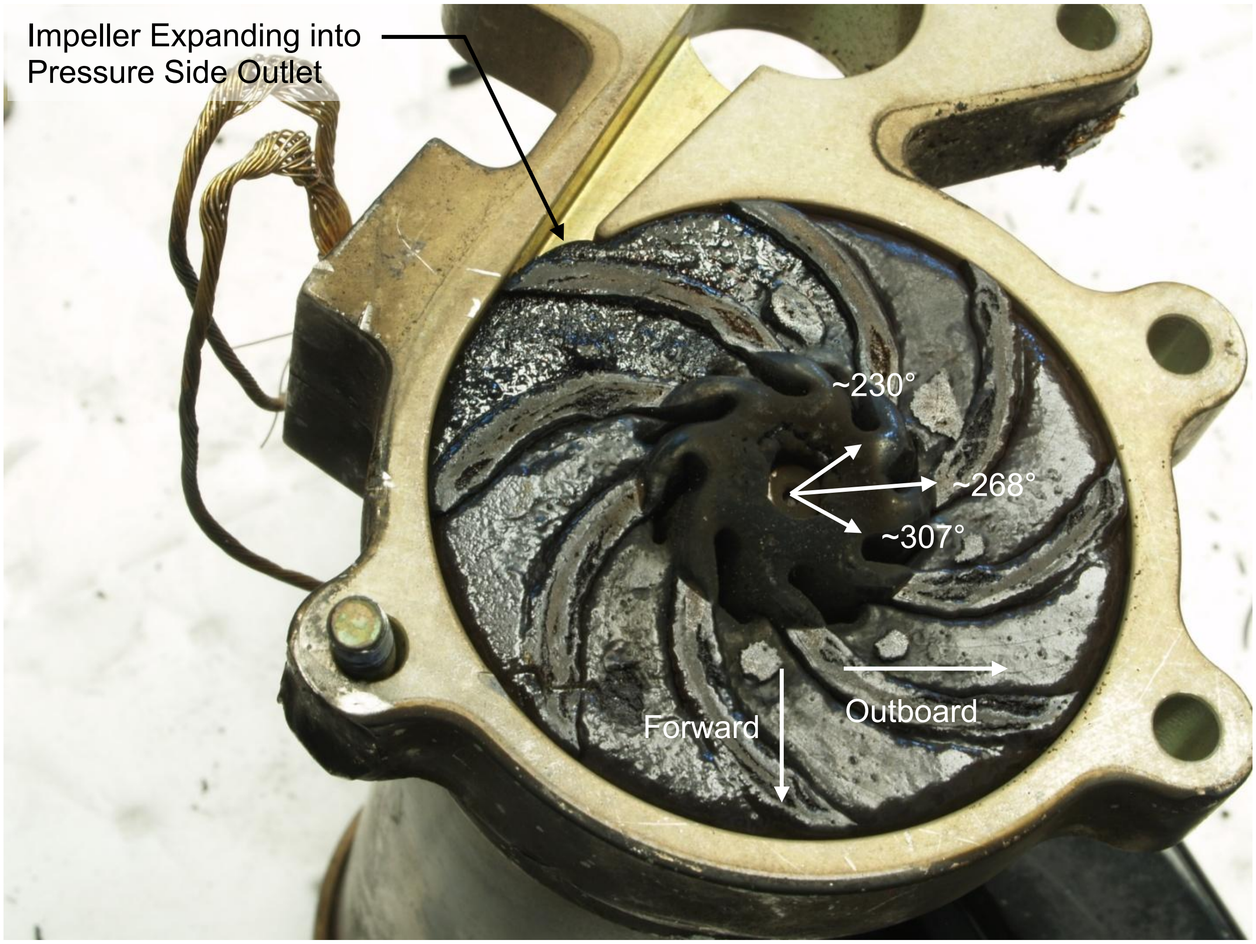
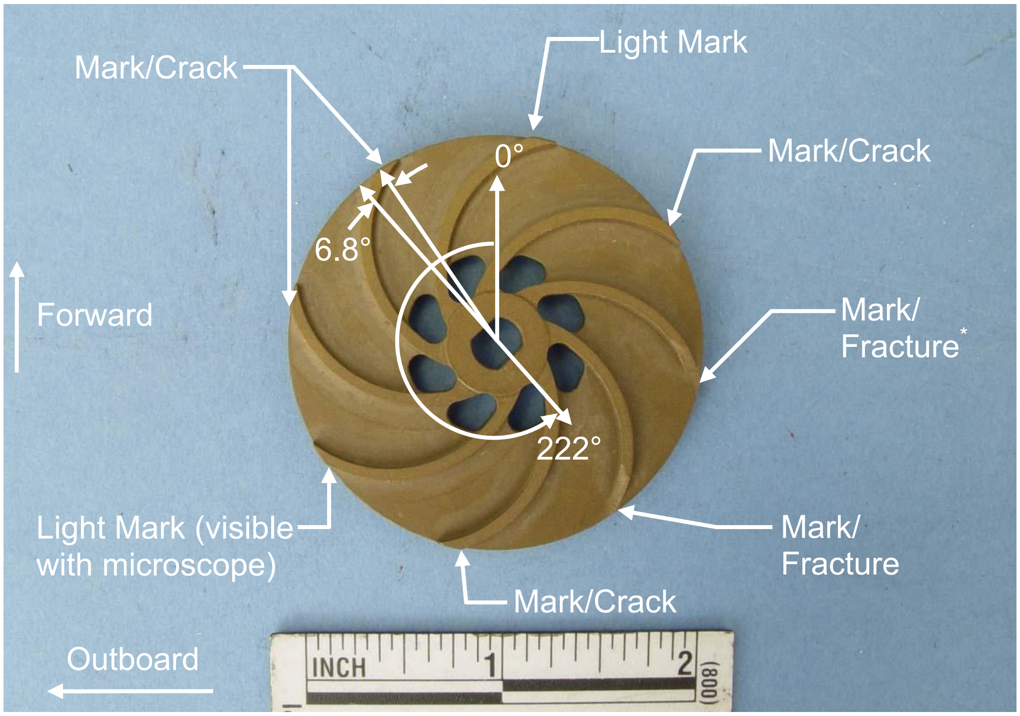


Figure 7: Photograph of the right volute housing and impeller during teardown (Photo by D. Diaz). The view is from underneath as situated on the aircraft.

a) 

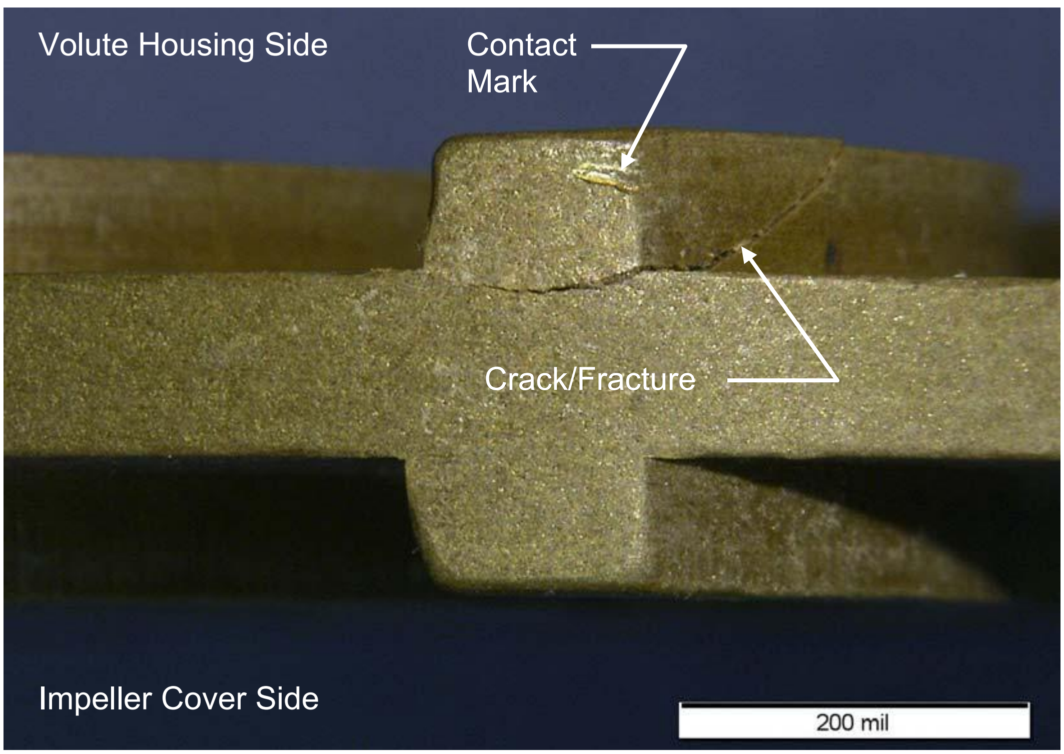
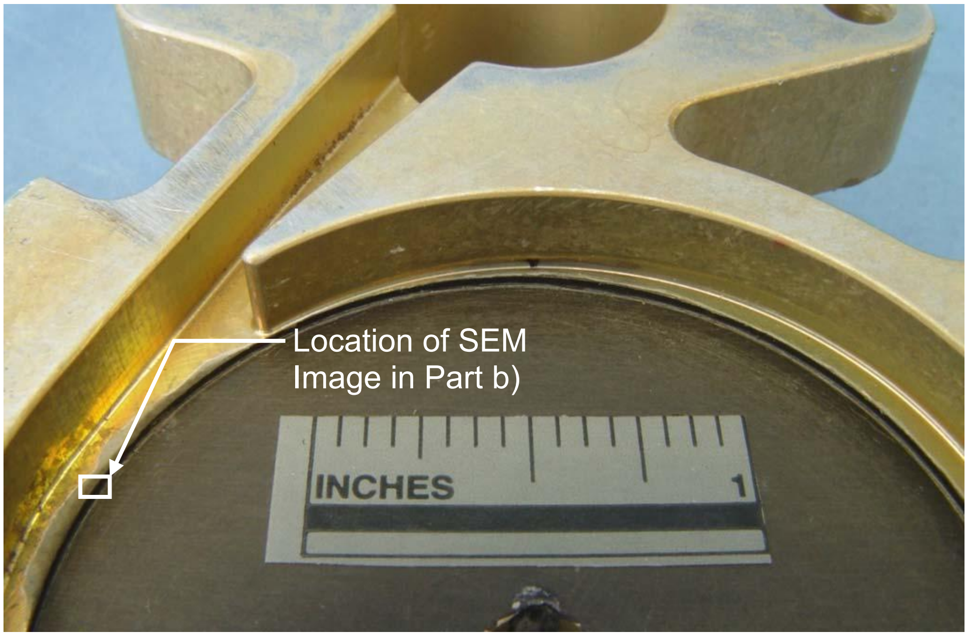
b) 

Figure 8: a) Photograph of left boost pump impeller viewed from above in its post-crash orientation. *Tip originally attached by small ligament; b) side view of an impeller vane tip showing a typical contact mark and cracked vane tip.

a)



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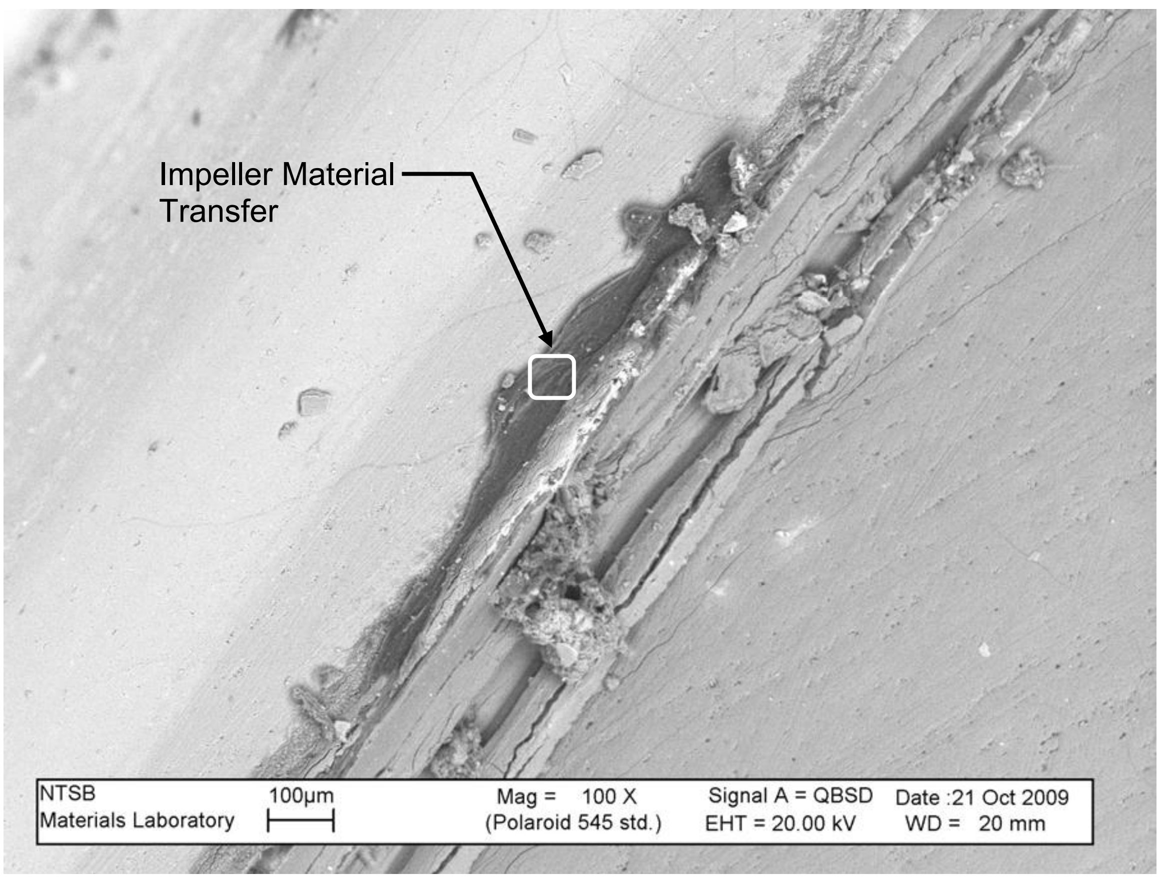


Figure 9: a) Photograph showing the location of the SEM image in part b); b) Backscatter SEM of a material transfer mark left by the impeller on the raised edge of the volute housing.

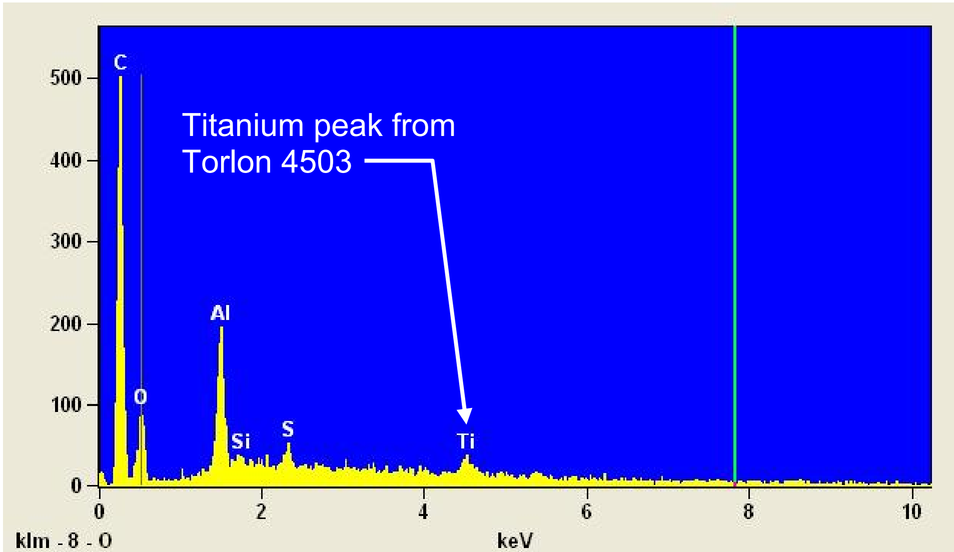
c) 

Figure 9 (cont.): c) EDS spectrum of the material transfer mark with the same titanium signature as the impeller material.

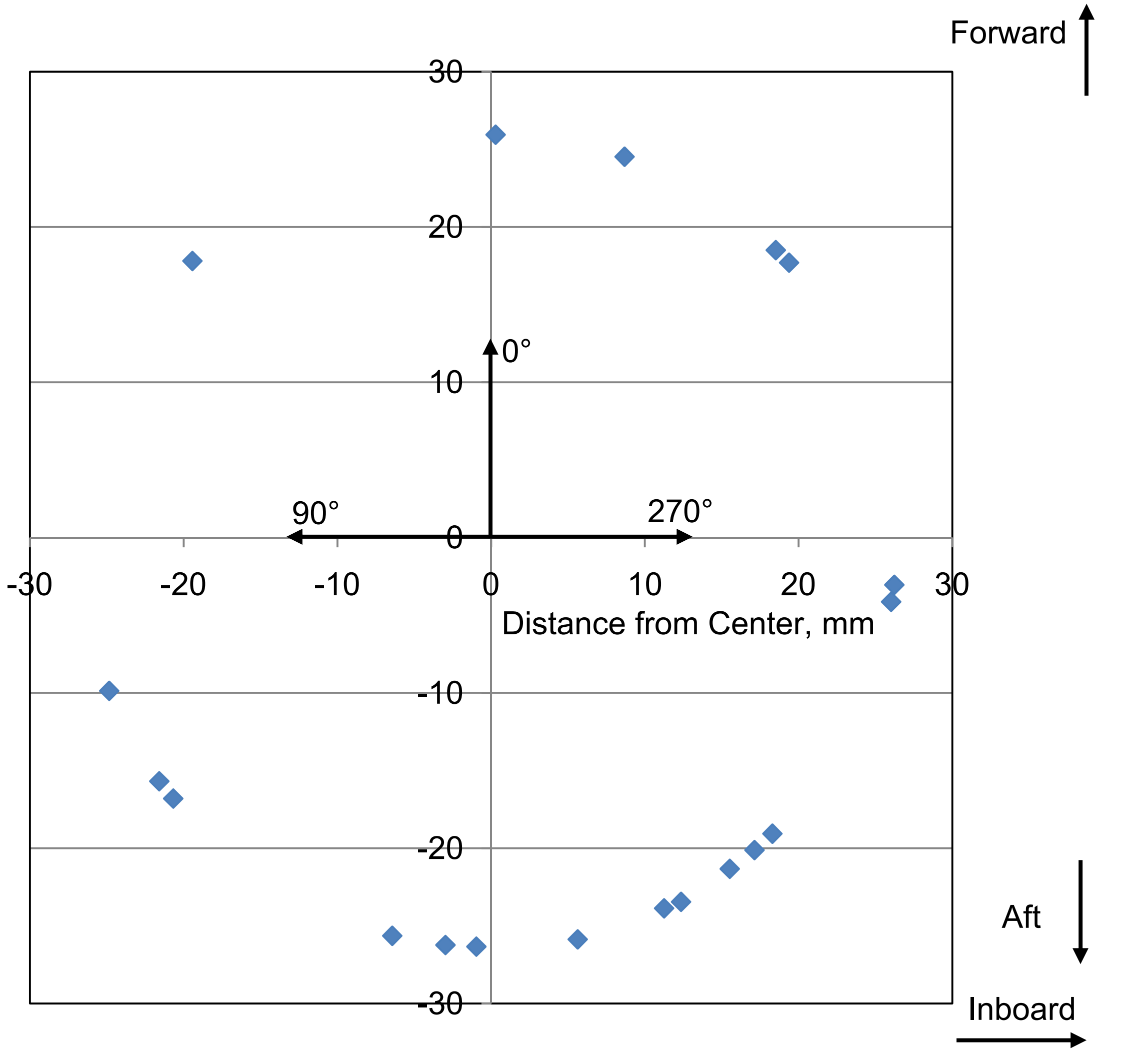
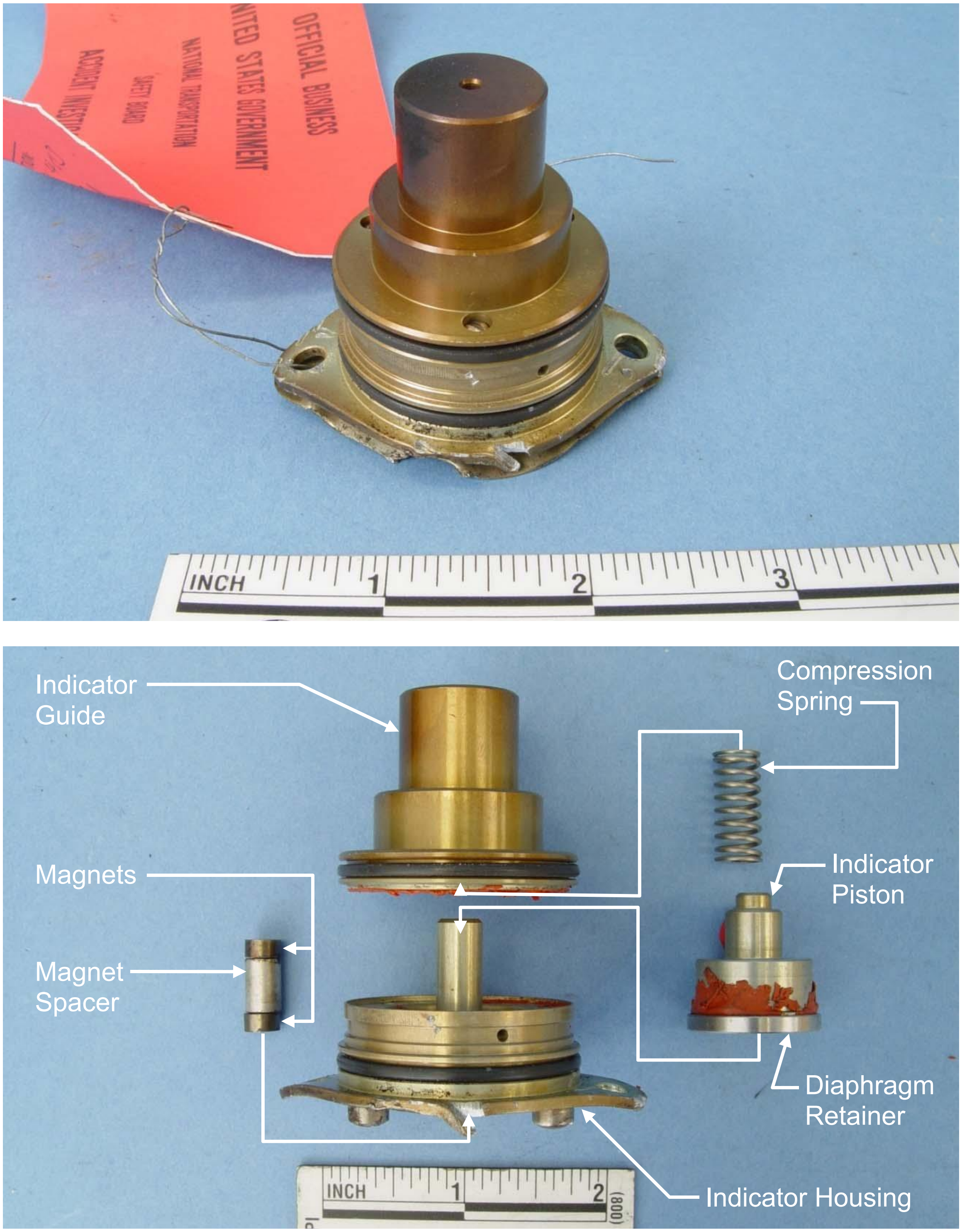


Figure 10: Graph of the location of material transfer marks on the left boost pump volute housing. The view of the housing is from the top as oriented on the aircraft.



a) b)

Figure 11: a) Fuel filter bypass indicator as received; b) exploded view of bypass indicator. Disassembly was done after radiography.

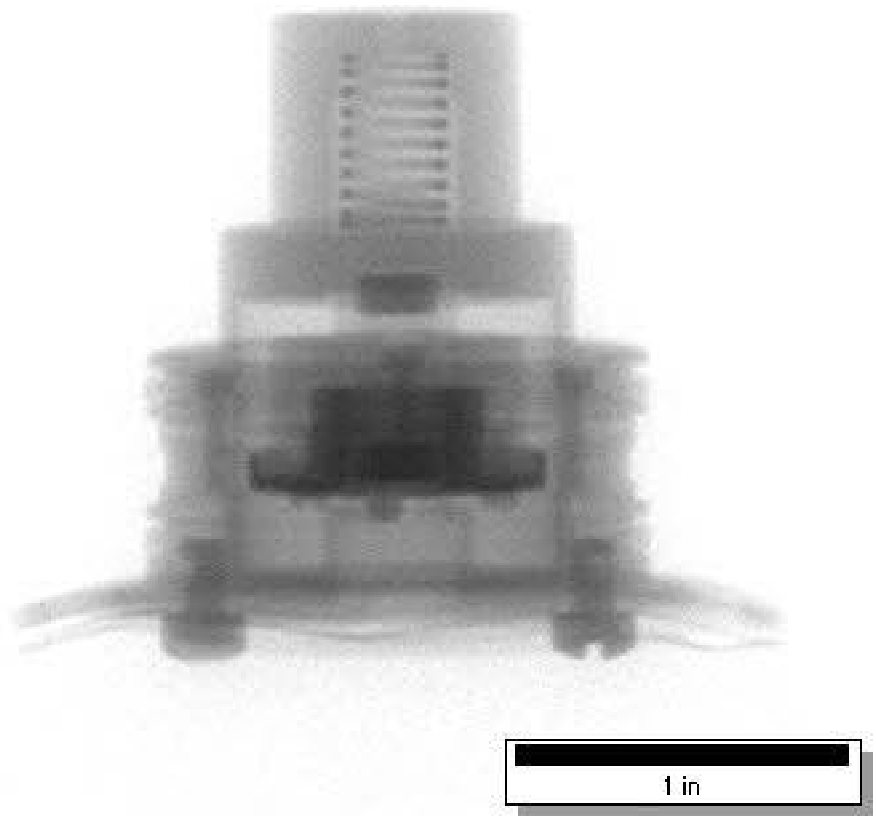


Figure 12: Radiograph of the fuel filter bypass indicator.

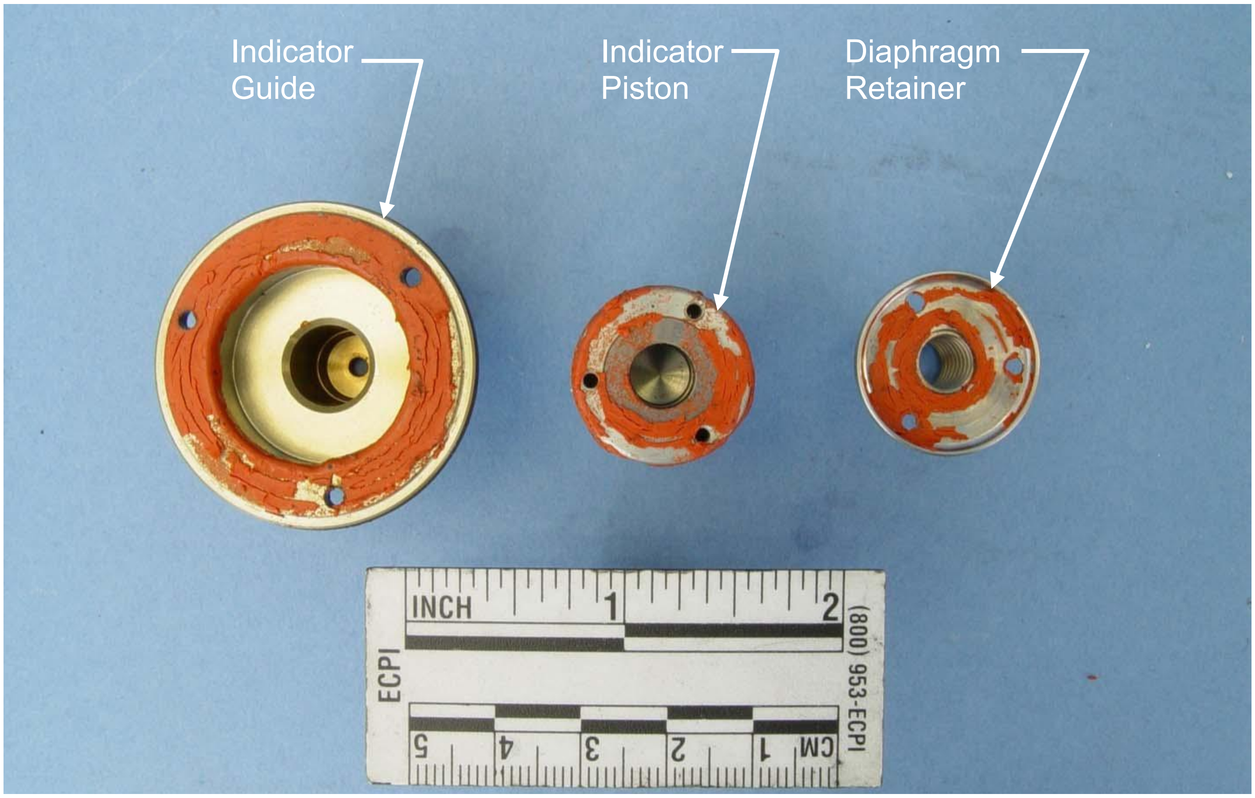


Figure 13: Photograph showing the condition of the elastomer rolling diaphragm.

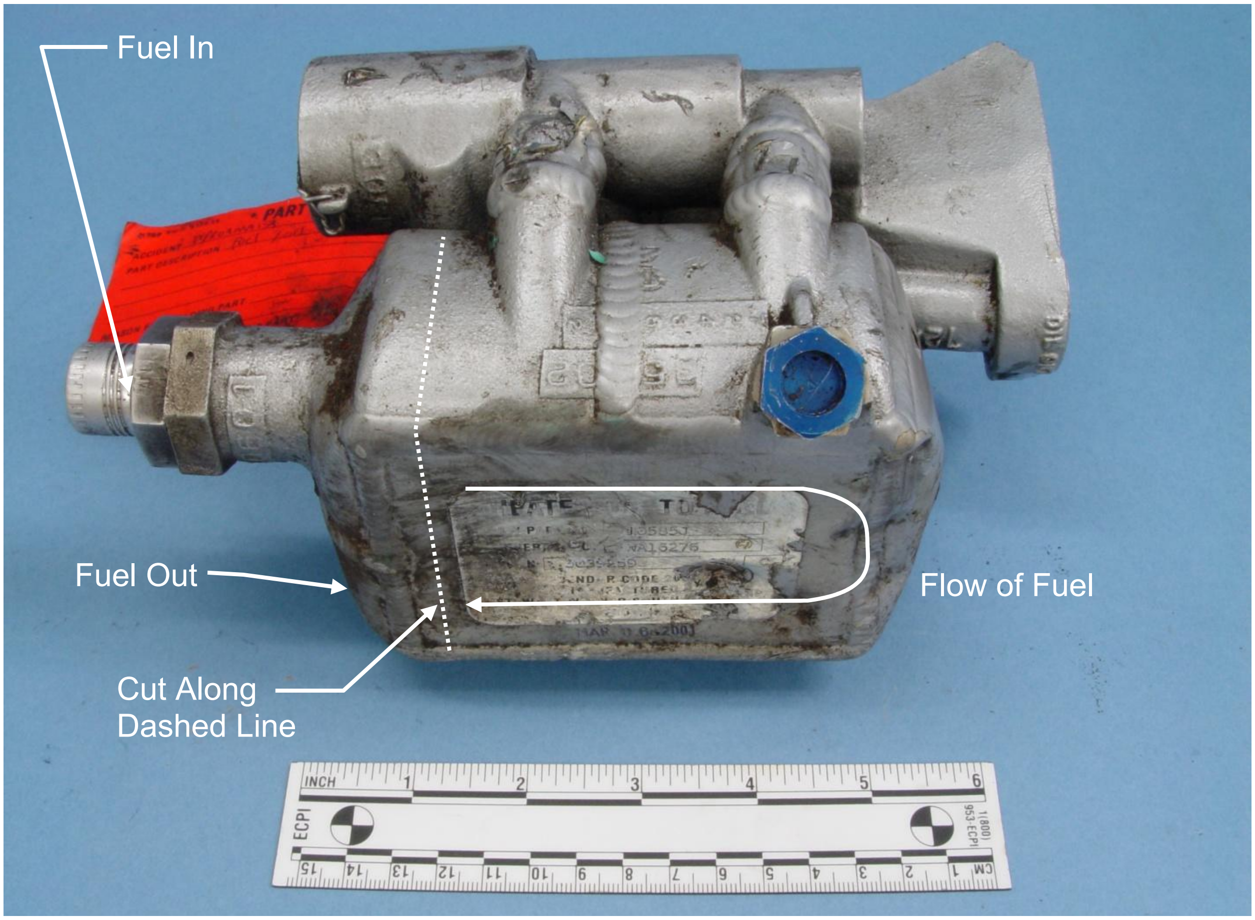


Figure 14: Fuel oil heat exchanger as received.

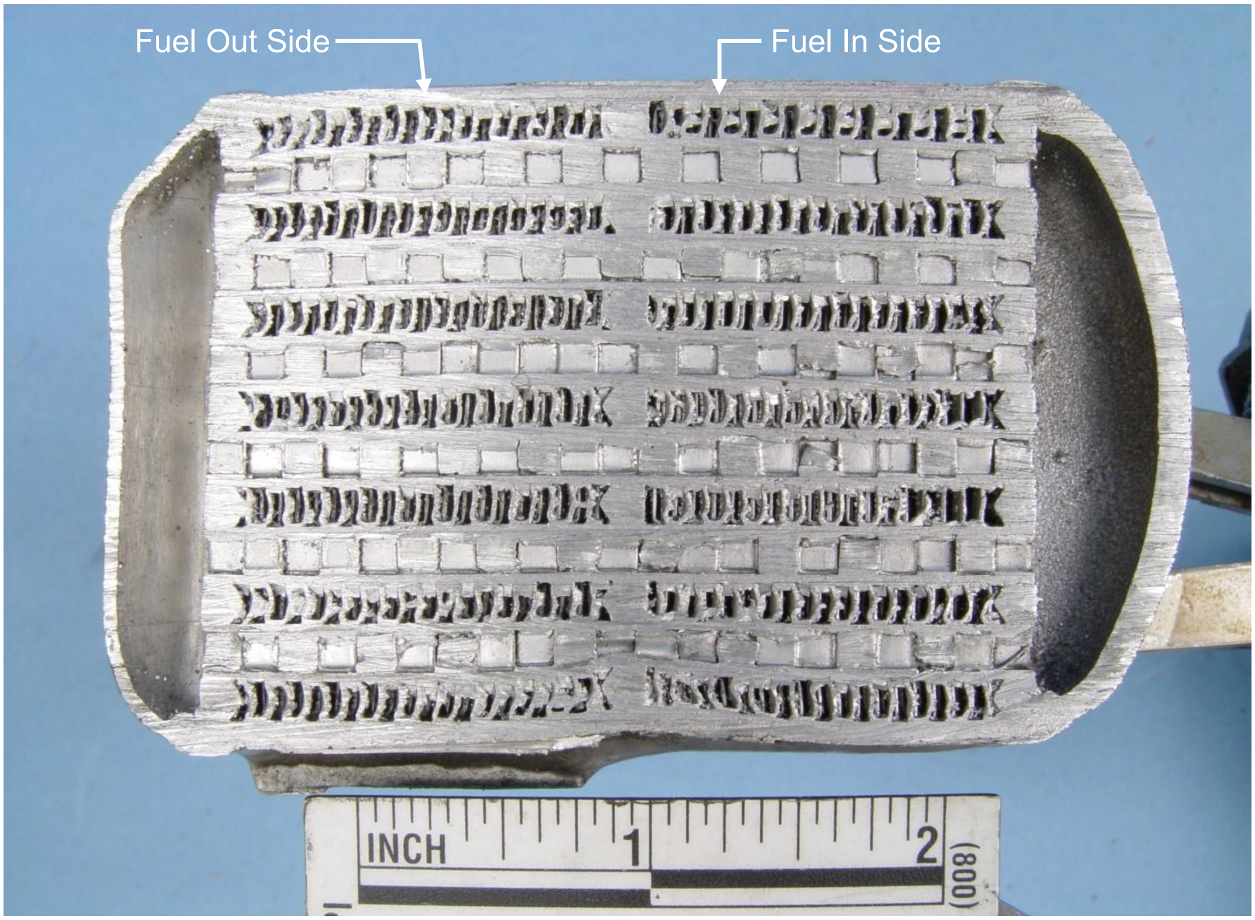
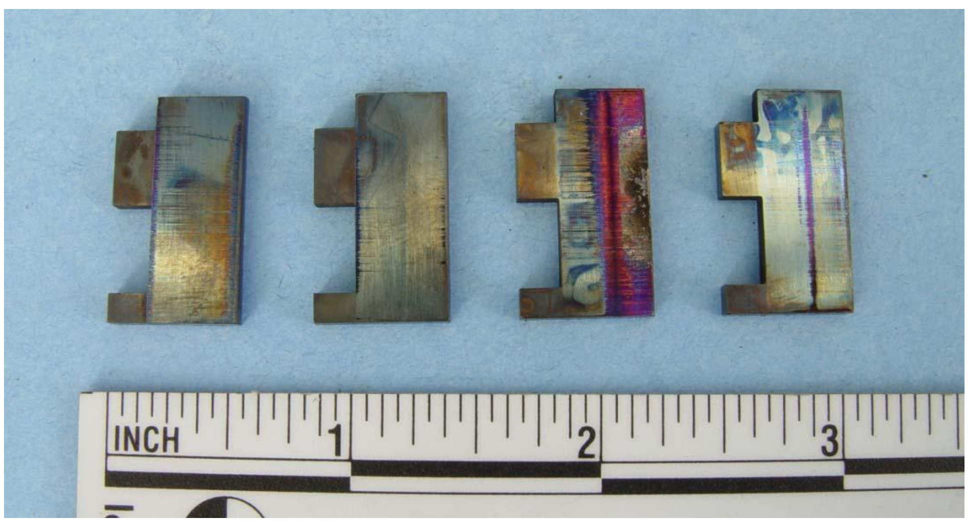


Figure 15: Cross section of the fuel oil heat exchanger approximately 0.5 inch inside the welded seam looking back at the fuel and out ports. Fuel flows out of the page on the fuel in side and into the page on the fuel out side.

Figure 16: Low-pressure engine-driven fuel pump as received.

a)



b)

Figure 17: Low-pressure fuel pump components showed typical wear marks and exposure to heat; a) pump offset cylinder, and b) vanes.