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

December 15, 1993

METALLURGIST'S FACTUAL REPORT — Report No 94-34

A. ACCIDENT

Place	: Provincetown, Massachusetts
Date	: August 2, 1993
Vehicle	: Piper PA-28-181, N2093
NTSB No.	: NYC 93-F-A140
Investigator	: Al Yurman (ASI-NYC)

B. COMPONENTS EXAMINED

Pieces of the right wing including 3 pieces of the main spar and two from the aft attachment, 5 pieces total. Aircraft s/n 28-7990103 reported total time 11,600 hours.

C. DETAILS OF THE EXAMINATION

The right wing components included three pieces from the inboard end of the main spar. The main spar was fractured through both the upper and lower spar caps and through portions of the spar web. The spar pieces are shown in figure 1 displayed in their approximate original positions with the mating cap fractures denoted by arrows "F". Both spar caps were transversely fractured at positions near the outboard ends of the fuselage carry-through structure, denoted by arrows "S" in figure 1. A schematic of the wing spar and carry-through structure area is presented as figure 2 with the path of the spar separation depicted by the red section lines. The spar was a riveted assembly composed of extruded aluminum upper and lower spar caps with riveted aluminum sheet webbing and gussets. At the inboard ends, the spar caps are bolted to upper and lower "C" channels which act as the main wing to fuselage attachments and fuselage carry-through structure.

The upper spar cap was fractured just past the outboard end of the upper carry-through, while the lower cap fractured through the most outboard pair of bolts connecting the spar and carry-through, as shown in figure 3. Both spars appeared to exhibit upward bending outboard, however the transition to the upward wing dihedral occurs at this location and masks the amount of actual deformation. Magnified optical examinations of the upper spar cap and sheet metal fractures disclosed evidence typical of overstress separations with the upper cap fracture typical of upward bending of the wing. In contrast, indications of preexisting fatigue cracking was uncovered on the lower spar break.

The lower spar break had a small area of fatigue on the fracture surface near the forward bolt, see bracket "C" in figure 3. The fatigue zone was approximately 0.3 inches wide and had penetrated about 0.2 inches into the spar cap. The fatigue zone was slightly aft and outboard of the forward bolt hole but the fatigue extension had not penetrated the bore surface. The remainder of the lower spar fracture displayed surface features typical of an overstress separation. Closer optical examinations after disassembly of the structure established that the fatigue had initiated on the lower surface of the spar cap at a location approximately 0.073 inches from the edge of the bolt hole. The fatigue had progressed upward and aft away from the bolt hole. Scanning electron microscope (SEM) examination of the outboard fracture face, after it was cut from the remaining spar, uncovered two distinct fatigue origins in close proximity to each other on the surface of the spar in the areas denoted by arrows "O" in figure 4. Further viewing established that the fatigue progressed upward and aft generally avoiding the hole to the fatigue terminus, indicated by arrowheads in figure 4. Beyond the terminus, the fracture morphology was completely ductile dimples typical of an overstress fracture in ductile aluminum alloys.

When removed from the carry-through channel, the lower surface of the spar was partially covered by green and yellow primer paint. Removal of loose paint by ultrasonic agitation in acetone uncovered many areas of randomly oriented surface scratches (see figure 5) as if the surface had been lightly sanded prior to assembly. As shown in the left view of figure 6, the fatigue origin, arrows "O", were located at the boundary of a faint polished area around the bolt hole (depicted by the dashed line). Light fretting and wear were also found immediately adjacent to the hole within this polished area. The wear area is indicated in figure 6 by the solid black line.

Several cracks, visible as irregular dark lines at the unlabeled arrows in figure 6, were present in the lower spar surface roughly paralleling the fatigue zone. Four cracks were located near the forward outboard hole and five smaller cracks were found near the aft bolt hole. The largest crack, at the forward hole measured 0.13 inches long.

Energy dispersive x-ray spectra acquired during SEM examination of the spar cap were consistent with a 2024 aluminum alloy. Hardness and electrical conductivity measurements on the lower spar cap were 73.9 to 76.4 HRB and 30.5 % IACS[1], respectively. These measurements were typical of a 2024 alloy heat treated to the T3 condition[2]. Longitudinal metallographic sections were cut from the outboard fracture face, one through the fatigue origin area and a second through one of the previously noted cracks near the forward bolt hole. Etching the prepared sections with Keller's Reagent[3], revealed a microstructure typical of extruded 2024-T3 with a layer of enlarged grains adjacent to the as-extruded surfaces. No apparent abnormalities were noted in either section. The fatigue

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[1] IACS, International Annealed Copper Standard

[2] Solution heat treated, cold worked and naturally aged to a stable condition.

[3] A solution of hydrofluoric, hydrochloric and nitric acids in water.

area and the crack both exhibited transgranular paths typical of fatigue progression through aluminum alloys, as shown in figure 7. The crack had only extended about 0.049 inches from the surface in this section.

The PA-28-181 maintenance manual lists the fastener hardware to connect the wing spars to the fuselage carry-through structure. For the lower spar cap, AN176-13A[4] or NAS464-P6-LA13[5] bolts are to be installed with a combination of AN960-616[6] and Piper 96352-3 washers and MS21042-6[7] nuts. The placement order of the washers is also prescribed. Inspections during disassembly indicated that the washers on the received spar sections were in the prescribed order. The loosening torque for the ten lower spar cap to fuselage carry-through assembly bolts exceeded 300 inch-pounds except for the two at the fracture location where the nuts loosened at about 150 inch-pounds each. The maintenance manual lists the installation torque as 360 to 390 inch-pounds and also notes that the tightening torque is to be applied through the nuts on the lower spar cap and through the bolt heads on the upper spar cap. Rotational damaged to the under-nut washers indicated that the nuts were tightened on the received lower spar cap. The bolt heads were marked with an "X" in a triangle and the letters "CS". In accordance with MIL-HDBK-131A[8], the triangle "X" marking denotes aircraft, close tolerance, alloy steel, machine bolts AN173 through AN186. The AN specification allows the bolt manufacturer to also place an identification mark on the head. Both the maintenance manual and Piper service letter No. 997 specify the use of MS21042 nuts on all of the main spar wing attachment bolts. MS21042 describes a self-locking ring based nut with a reduced hexagon and reduced height. The received nuts (see figure 8) were not marked with a part number or other identification and do not match this description in detail dimensions or style but rather appeared to more closely match one of the allowed configurations for a MS21046 nut.

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[4] Air Force - Navy Aeronautical Standard, 1.453 inch long, undrilled, 0.375-24 UNF thread bolt.

[5] National Aerospace Standard bolt of similar dimensions.

[6] Air Force - Navy Aeronautical Standard, flat washer, steel for 3/8 inch bolts or screws.

[7] Military Standard, Self Locking Nut, Ring Base, Non-Corrosion Resistant Steel.

[8] Military Standardization Handbook "Identification Markings for Fasteners", 15 September 1966.

The fuselage and wing lugs of the wing aft attachment fitting were received cut from the aircraft structure. As shown in the upper view of figure 9, the lugs did not appear to be damaged. The Maintenance Manual shows that for this s/n aircraft, the two lugs are connected by an AN5-7A bolt through the holes in each fitting. The investigator was not lugs during assembly. Matching paint and wear patterns on the faying surfaces of each lug, as depected in the lower view of figure 9, indicated that the lug surfaces had been in direct contact with each other with the bolt holes aligned. Visual inspections also showed that the holes were approximately round showing no appreciable deformation.

Joe Epperson

Joe Epperson
Senior Metallurgist

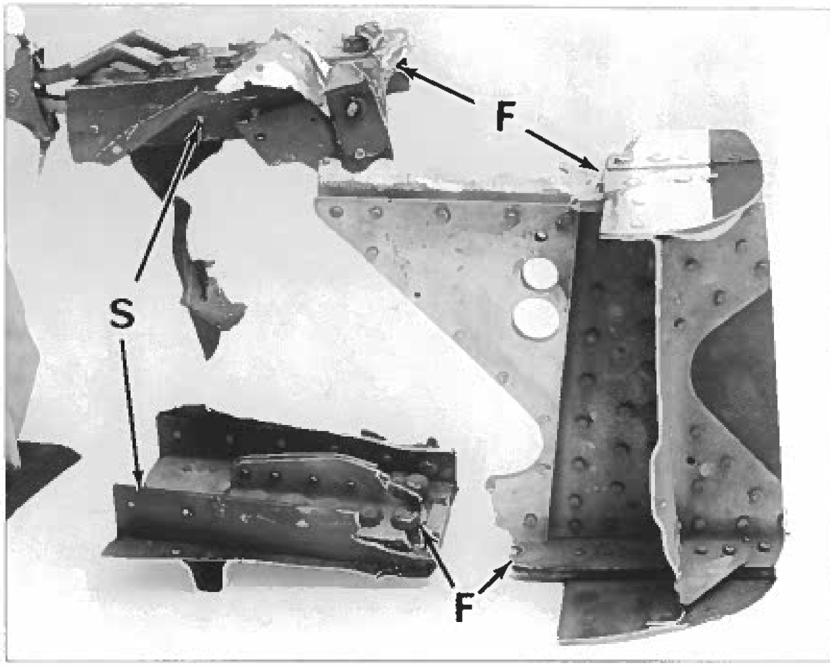


Figure 1: An overall view of the as-received right wing main spar structure with the mating spar cap fractures denoted by arrows "F". View looking forward.

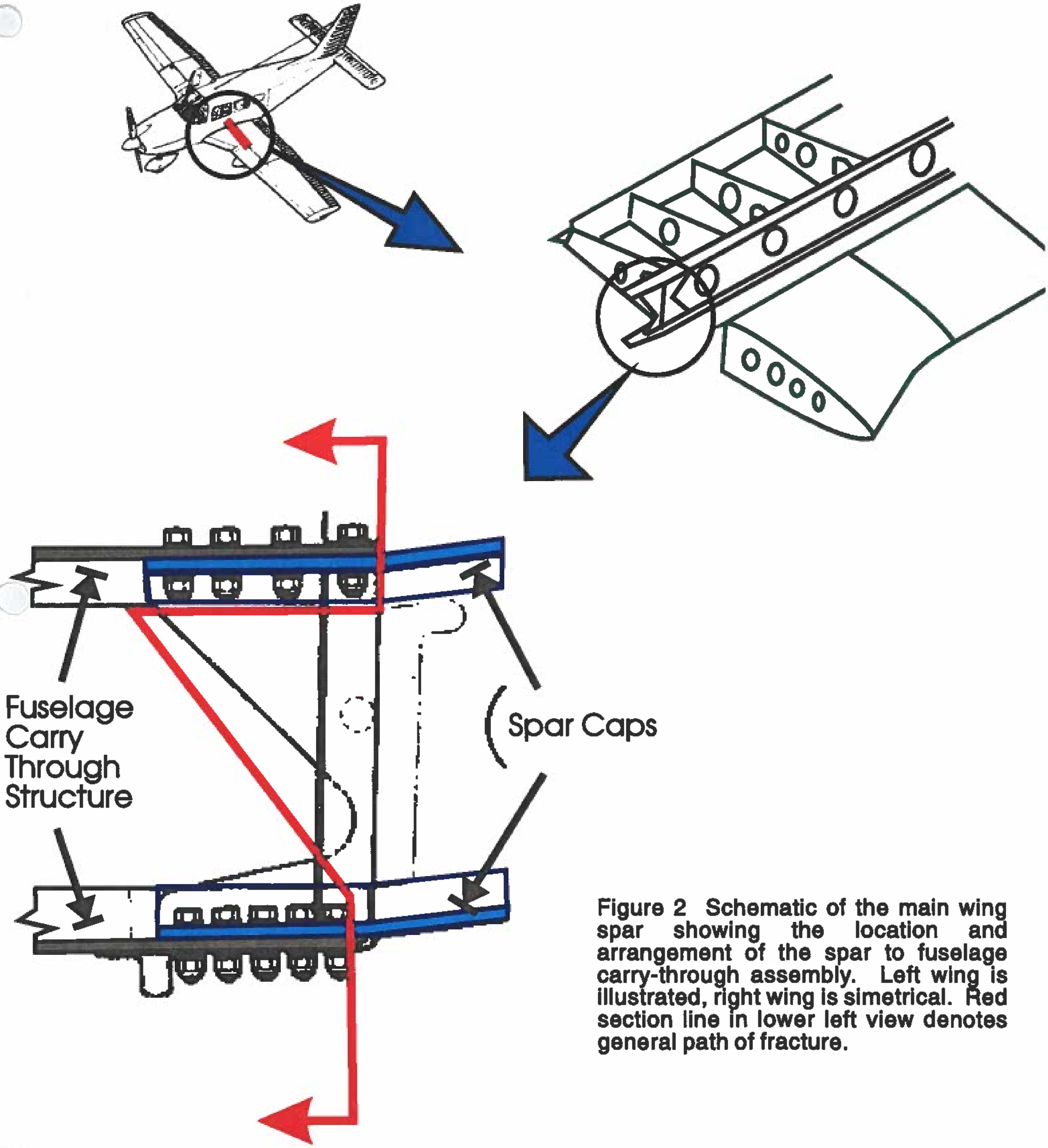


Figure 2 Schematic of the main wing spar showing the location and arrangement of the spar to fuselage carry-through assembly. Left wing is illustrated, right wing is simetrical. Red section line in lower left view denotes general path of fracture.

Figure 3: A 2X view looking generally inboard onto the lower spar cap inboard fracture face. The area of fatigue is indicated by bracket "C". Note its proximity to the bolt.

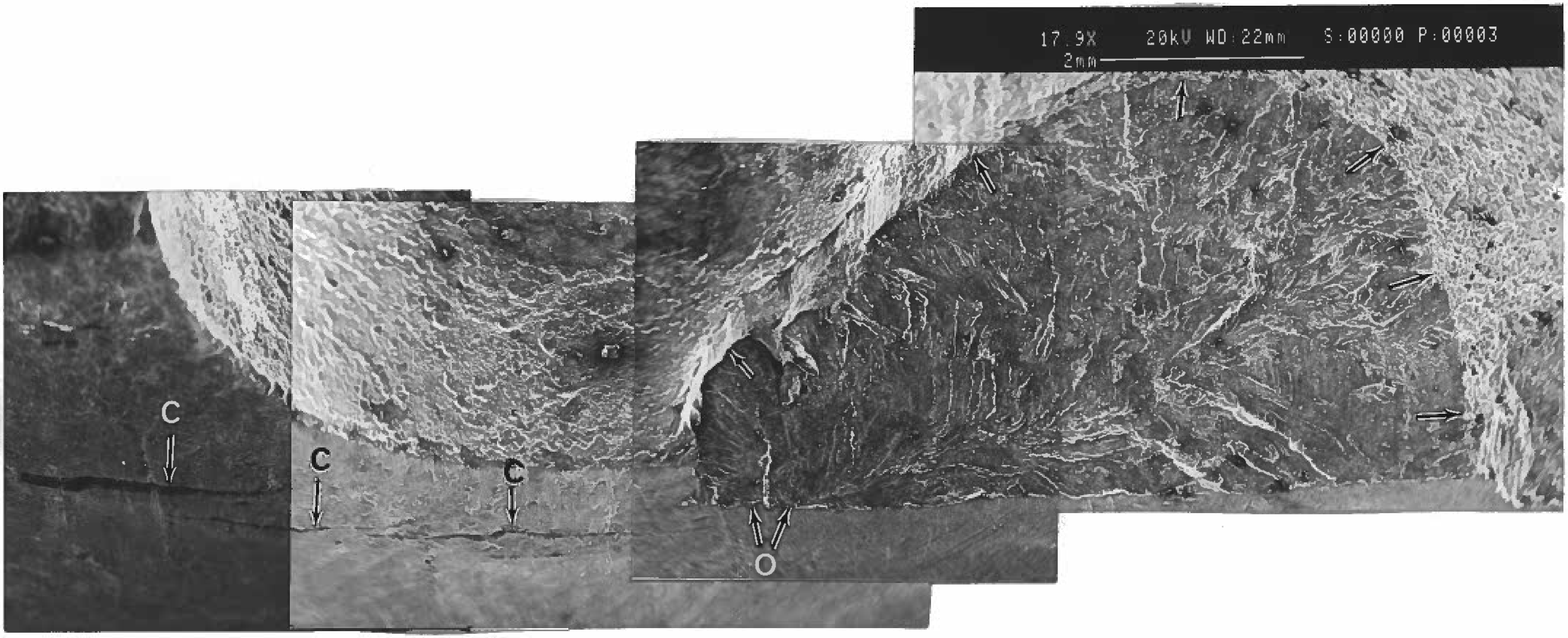


Figure 4: A SEM montage of the fatigue region and lower surface of the spar at 17.9X on the outboard fracture half. Fatigue origins are at arrows "o" with the fatigue terminus at the unlabeled arrows. View looking outboard and slightly up with aircraft forward at left.

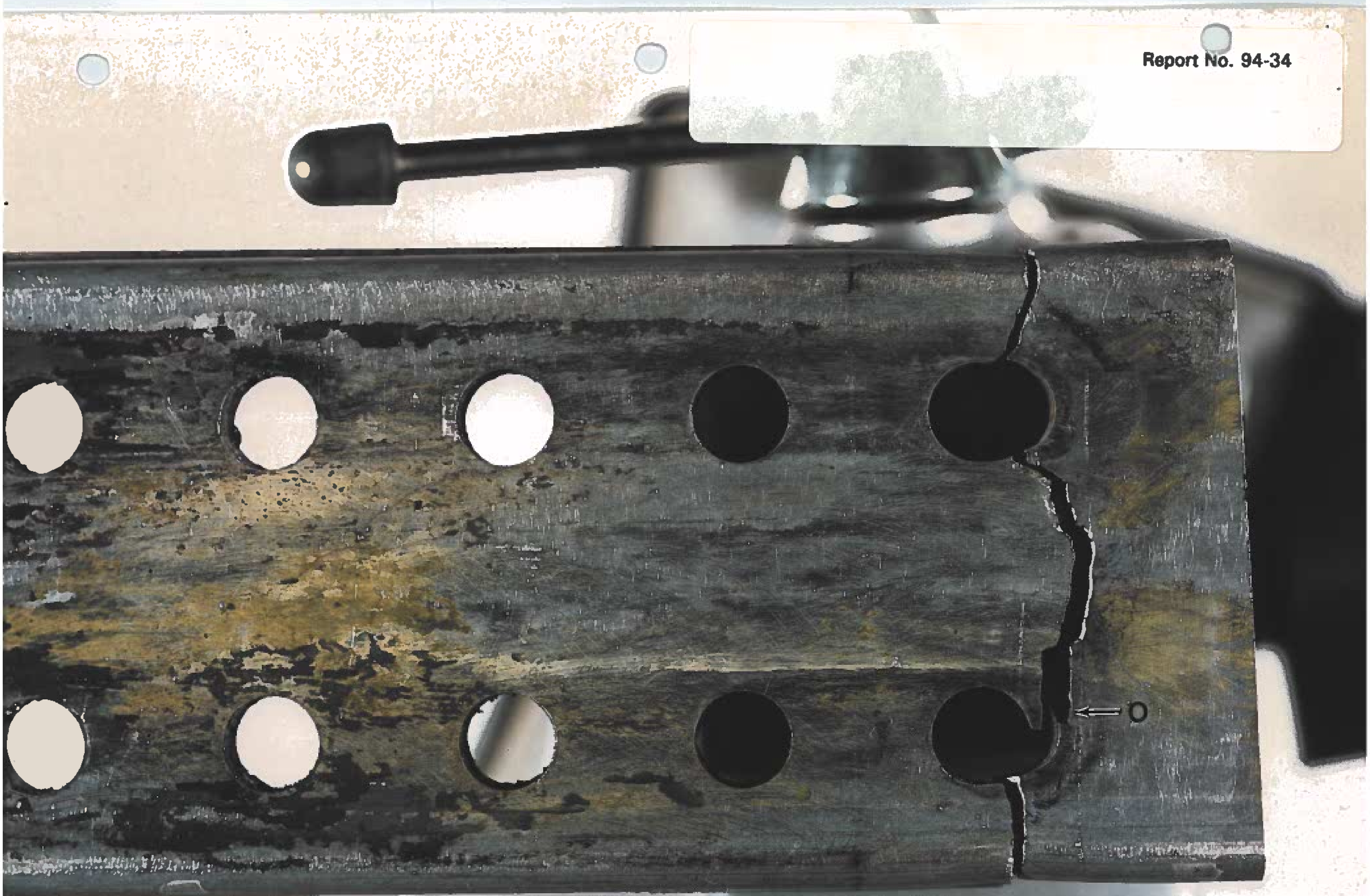
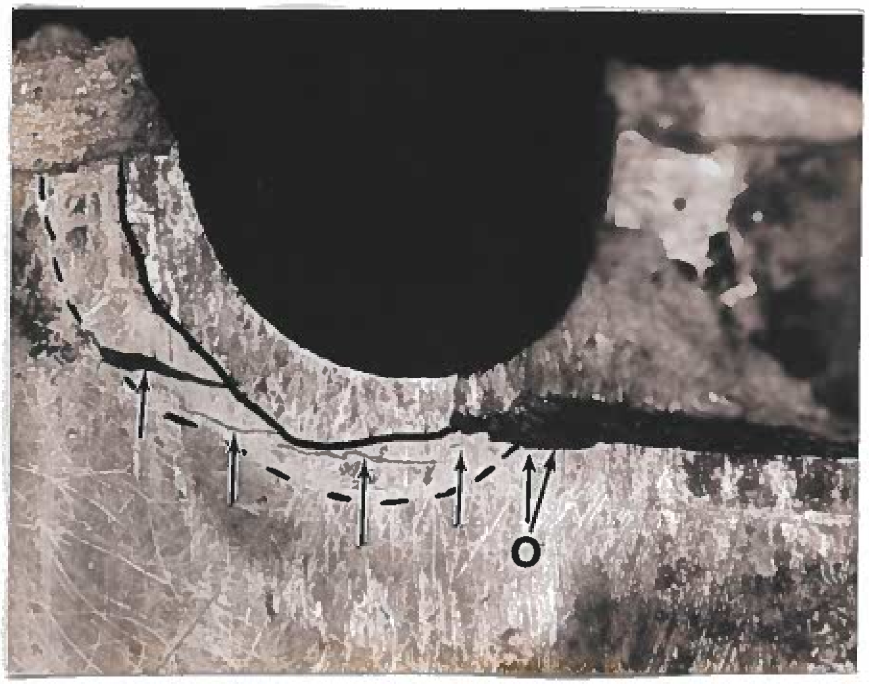


Figure 5: A 2X photograph showing the lower surface of the spar cap at the fracture and bolt location. Fatigue initiation location denoted by arrow "O".



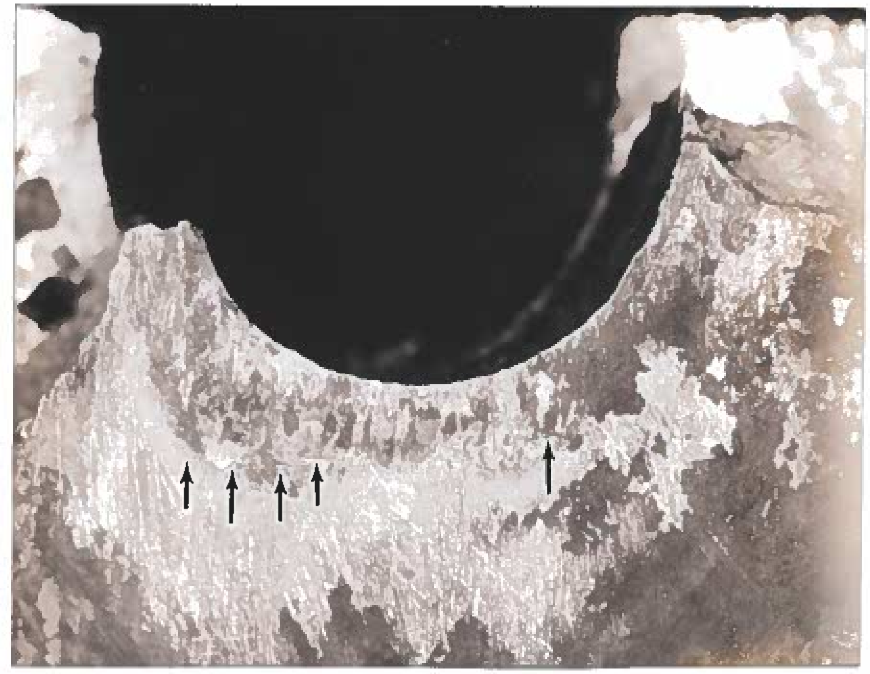
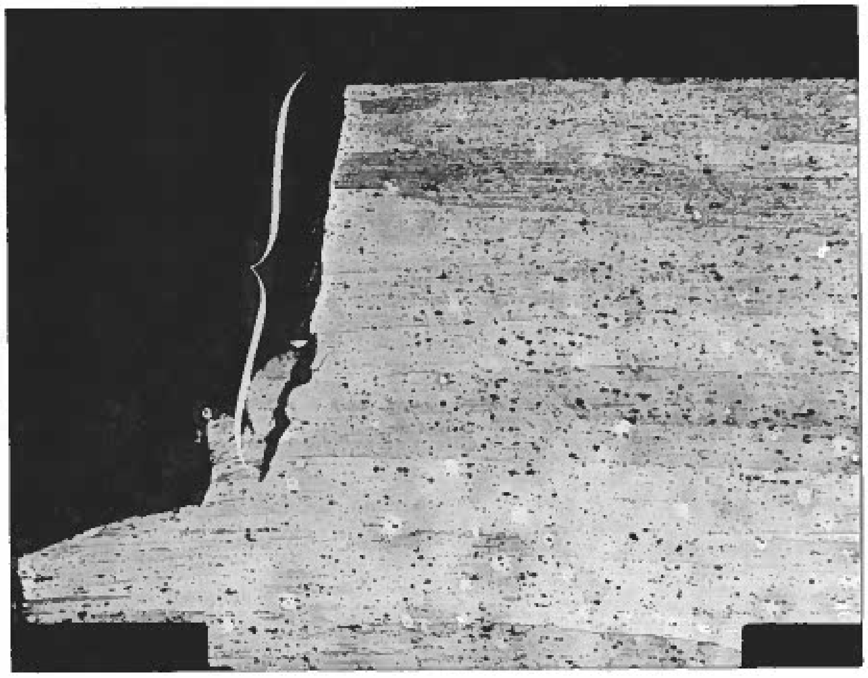


Figure 6: 7.5X views of the lower spar cap surface adjacent to and outboard of the two outboard spar attachment bolts. The left view, of the forward bolt, shows the fatigue origin locations, arrows "o" and areas of polishing (dashed line) and fretting (solid line) surrounding the bolt hole. Unlabeled arrow in both views denote cracks. See also arrows "c" in figure 4.



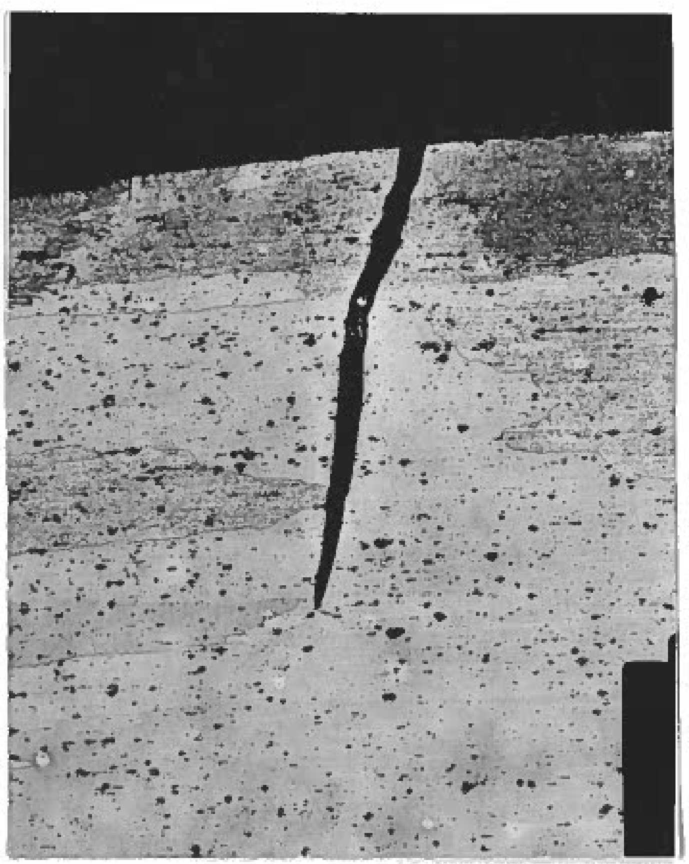
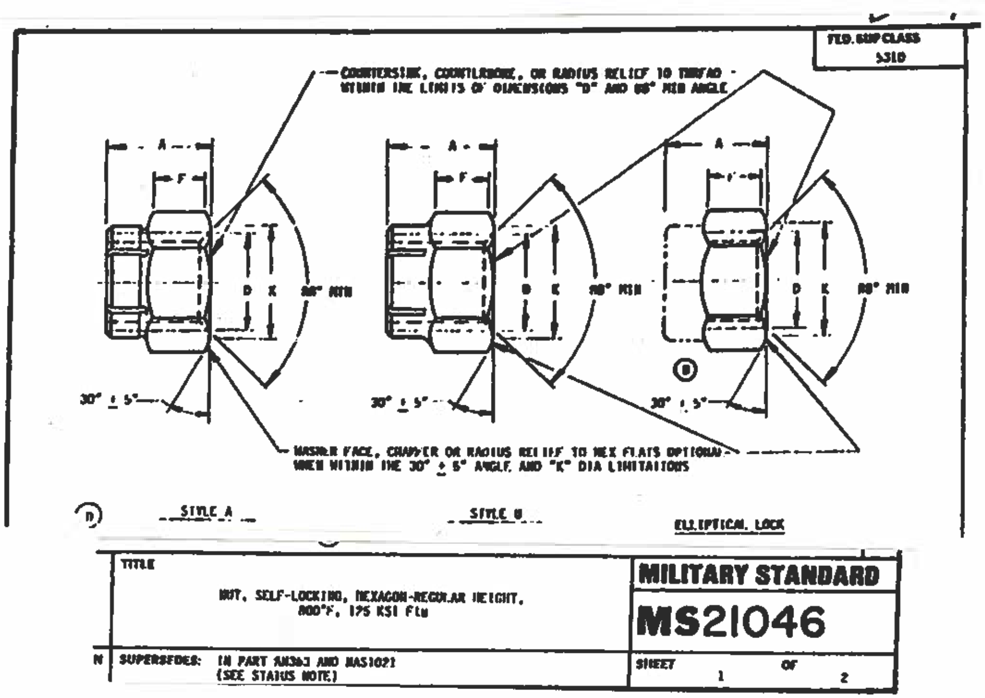
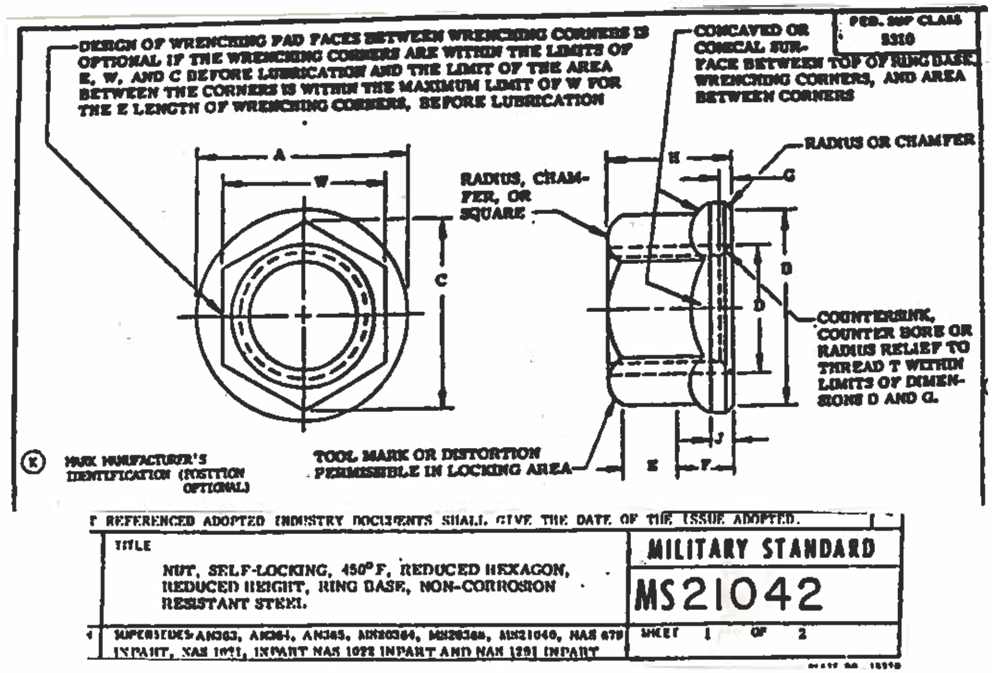


Figure 7: Metallographic sections through the fatigue origin (top at 32X) and one of the cracks (left at 50X). Fatigue region denoted by bracket in upper view. Keller's Etch





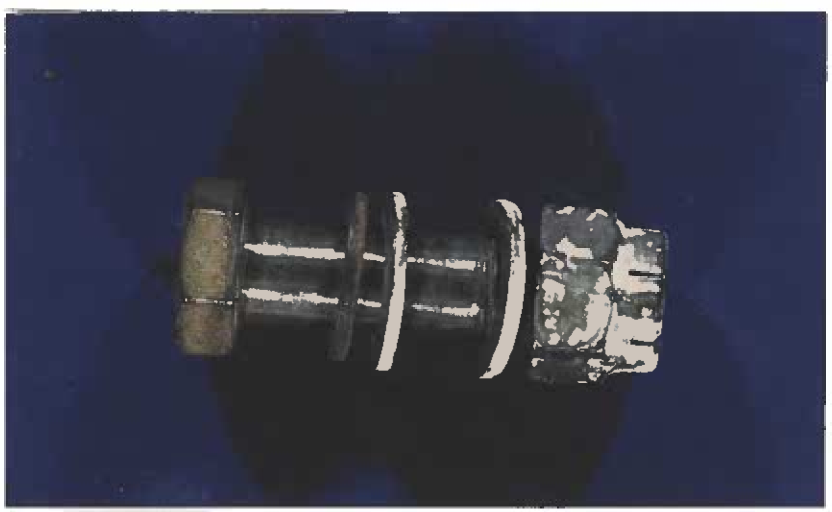


Figure 8: A 1.5X view (left) of a typical main spar attachment bolts. Compare the nut to the MS illustrations above.

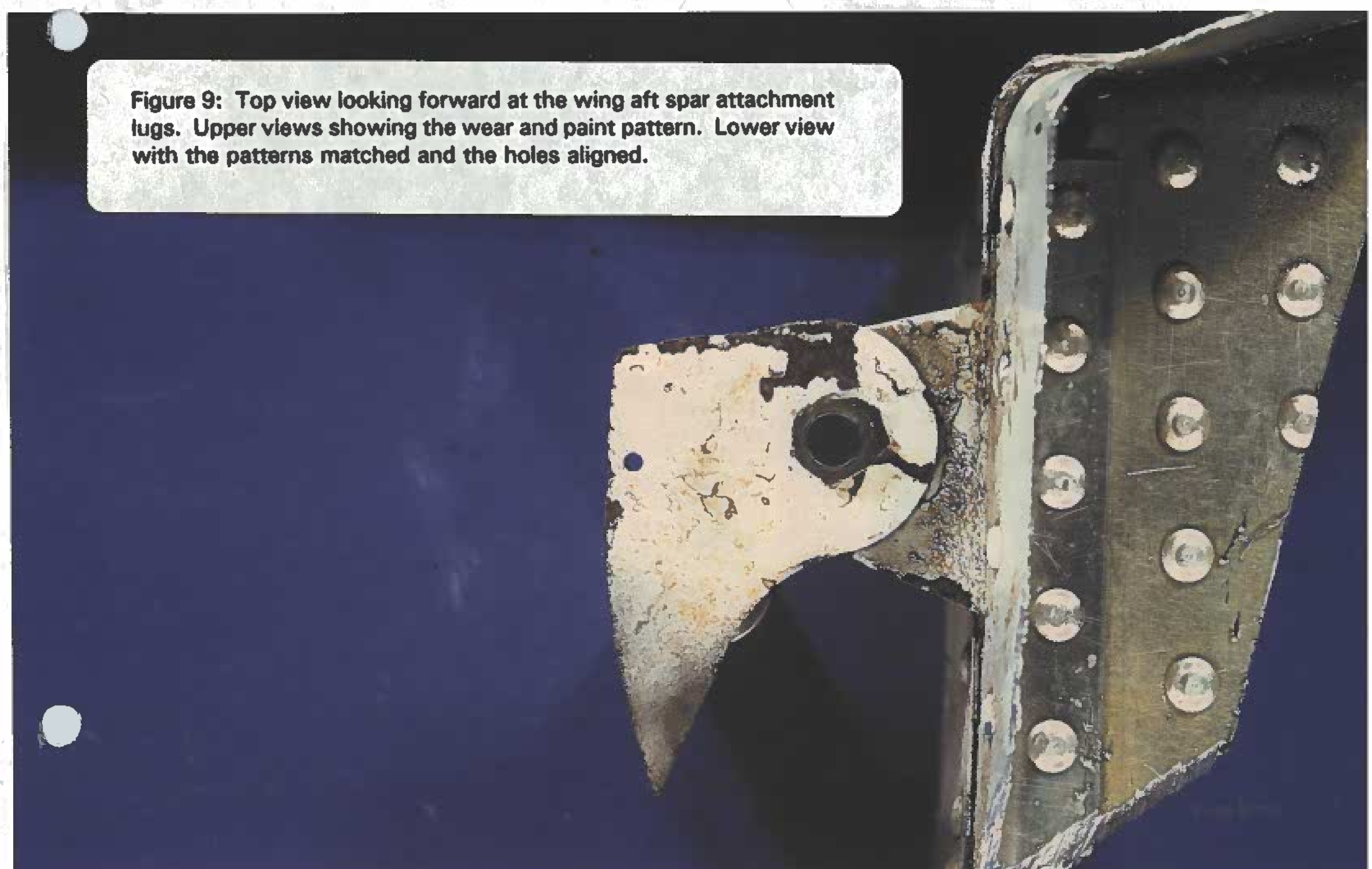


Figure 9: Top view looking forward at the wing aft spar attachment lugs. Upper views showing the wear and paint pattern. Lower view with the patterns matched and the holes aligned.