National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594

DCA22MA193

MATERIALS LABORATORY

Factual Report 23-019 Actuator – Accident

June 6, 2023

(This page intentionally left blank)

A. ACCIDENT INFORMATION

Location: Freeland, Washington
Date: September 4, 2022
Vehicle: de Havilland Aircraft DHC-3 Otter, N725TH
Investigator: Adam Huray

B. COMPONENTS EXAMINED

Horizontal stabilizer trim actuator assembly with separated eye bolt assembly (also referred to in the maintenance manual as the “top eye end and bearing assembly”).

C. EXAMINATION PARTICIPANTS

A group examination for the horizontal stabilizer trim actuator assembly with separated top eye bolt assembly was held between October 18 and 19, 2022 at the Safety Board’s Materials Laboratory, Washington, D.C. The following individuals participated in the examination:

Group Chair	Frank Zakar NTSB Washington, DC
Group Member	Adam Huray NTSB Washington, DC
Group Member	Mitch Mitchell FAA Washington, DC
Group Member	Bobbie L. Kroetch FAA Wichita, Kansas

Follow-up work continued and was completed after departure of the group members.

D. DETAILS OF THE EXAMINATION

1.0 As-received

Figure 1 shows a photograph of the as-received horizontal stabilizer trim actuator assembly, P/N C3CF290.[1] A part number was not marked on the submitted part. The top eye bolt assembly was separated from the barrel portion, that is, the actuator was found separated where the clamp nut threads into the barrel section. The top attachment bolt (without attaching hardware) that was used to attach the actuator to the horizontal stabilizer was also submitted and showed no evidence of damage.

1.1 Barrel

Examination of the as-received actuator assembly revealed no indication of a part number. The top end of the barrel at the outer surface contained a circumferential groove for a circular wire lock ring[2]. Figure 2 shows a photograph of an exemplar lock ring. A lock ring is used to prevent the clamp nut from unscrewing from the barrel. When a lock ring is installed on the barrel, the tang portion of the wire (the portion that is bent inward) must pass through the hole in the barrel and into a hole in the clamp nut (see figure 3). A lock ring was not attached to the groove portion of the barrel and a fragment of the lock ring was not found in the hole within the groove. The lock ring was not submitted and was not found during the investigation.

The diameter of the tang hole in the barrel (for the lock ring) was specified as 0.098 inch. The shank portion of a 0.098 inch nominal diameter drill bit was inserted into the tang hole. The drill bit easily fitted into the hole. The tang hole at the outer surface exhibited evidence of elongation deformation on both lateral sides (perpendicular to the length of the barrel). The groove contained circumferential gouge marks that extended as much as approximately 0.9 inches to either side of the tang hole (see figure 3). The groove in areas outside of the gouge marks exhibited light contact (polished) marks consistent with the size of a lock ring. Several longitudinal-like gouge marks were noted in the general area of the tang hole (see figure 4).

The inner threads at the top end of the barrel at one isolated location was covered with translucent red grease. The inner surface of the barrel in the area below the inner threads contained two bands that corresponded to the position of two ball bearing assemblies (see figure 5). The inner threads and areas corresponding to the location of the two ball bearing assemblies were cleaned with a cotton swab soaked with acetone. Stereo microscope examination of the upper barrel end revealed the

---

[1] The horizontal stabilizer trim actuator is also referred to as the trim jack assembly.

[2] The AN996-28 lock ring was specified as 0.08-inch nominal diameter; carbon steel per specification QQ-W-470 “Carbon Steel Spring Wire”; 282-312 KSI tensile strength; coated with cadmium or zinc.

two areas corresponding to the location of the duplex ball bearing assemblies exhibited light scouring marks that were oriented in the circumferential direction (see figure 6). The inner threads were intact and contained no evidence of sheared threads (stripped threads). The crest portions of the threads showed no evidence of the mating clamp nut threads having been pulled straight out of the barrel. The flank portion of the two outermost inner threads (adjacent to the open end of the barrel) in several areas showed evidence of minor galling[3] (see figure 7). The inner threads (root and crown portions) at several locations showed evidence of impact damage, consistent with an external object that entered the bore of the barrel when the clamp nut was not installed. The mating threads (on the clamp nut) could not be screwed (threaded) onto the barrel due to this damage.

The barrel portion of the actuator was specified as 2024-T4 anodized aluminum alloy. The material grade of the barrel portion was identified with an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer as grade 2024 aluminum alloy.

1.2 Top Eye Bolt Assembly

Figures 8 and 9 show photographs of the as-received top eye bolt assembly. The top eye bolt assembly contained an eye bolt portion, clamp nut, moisture seal (not part of the type design), duplex bearing assemblies, castellated nut, washer, and cotter pin. The grease (Zerk) fitting at the top of the eye bolt portion was missing. Duplex bearing assemblies are two matched bearing assemblies that are placed next to each other. In the as-received condition, the outer race of the two bearing assemblies could not be rotated by hand relative to the eye bolt.

1.3 Clamp Nut

The clamp nut showed no evidence of a part number. The external threads of the clamp nut were cleaned with a cotton swab soaked with acetone. Stereo microscope examination of the clamp nut revealed the external threads were intact and showed no evidence of sheared threads (stripped threads). The clamp nut in the area of the external threads contained a total of five drilled through-holes. For the purpose of this report, the rotational position of the drilled holes were measured when looking down at the center of the eye bolt and rotating clockwise relative to the square key slot (where the slot was arbitrarily assigned the zero degrees position), see figure 10. The drilled holes in the clamp nut were located in the 90, 100, 110, 230, and 310 degrees position relative to the slot (see figure 11). According to a representative from NW Seaplanes, NW Seaplanes did not drill any of the holes in the clamp nut.

[3] Galling is a form of wear caused by adhesion between sliding surfaces.

None of the holes contained a fragment of the lock ring or foreign material. Two of the five drilled through-holes (90 and 110 degrees) were unobstructed, and the remaining through-holes (100, 230, and 310 degrees) were obstructed by deformation in the wall that constricted (reduced) the diameter of the hole (see figures 12 through 15). The deformation was in the form of a flat bottom land that extended partially down into the hole and on one side of each respective hole. The flat bottom land at the 100 and 230 degrees position holes extended as deep as the root portion of the threads, whereas the flat bottom land in the hole at the 310 degrees position extended slightly below the root portion of the threads. The contour of the flat land appeared similar to the contour of a metal surface that was struck with a flat bottom tool punch.

The nominal diameter of the circular wire lock ring was specified as 0.08 inch. Per the engineering drawing C3 CF 290 for the assembly of the actuator, a 0.098 inch diameter hole should have been drilled into the clamp nut. The shank end of a 0.0755 inch diameter drill bit was inserted into the drilled holes within the clamp nut to determine whether the drill bit could be fully inserted into each respective hole. The drill bit simulated the diameter of the lock ring. The drill bit penetrated the holes at the 90 and 110 degrees positions. The end of the drill bit partially penetrated the holes at the 100, 230, and 310 degrees position, stopping at the flat bottom land of these respective holes.

The flank portion of the clamp nut threads were examined for evidence of gouge or scouring damage that may result if the tip end of the lock ring slides against the threads while the clamp nut is rotating. The flank portion of the clamp nut threads showed no evidence of circumferential gouge or scouring marks.

The clamp nut was specified as 4130 steel alloy. The material grade of the thread portion was identified with an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer as grade 4130 steel alloy.

1.4 Eye Bolt

Engineering drawing C3 CF 290 (for the actuator assembly) indicated the part number for the eye bolt is C3 CF 275-5.

The flat face of the eye bolt was marked part number "C3 CF 275 1". A representative from Viking indicated the last character "1" refers to the drawing revision/issue number at the time the part was manufactured. Revision "A" of the engineering drawing for the eye bolt indicated the drawing for P/N "C3 CF 275" was redrawn as P/N C3-CF-275-5. The engineering drawing change note does not explain the presence of the "1" in the observed part number.[4] The eye bolt was

[4] According to Viking, the part was originally drawn with no dash number. A "-1" part number never existed.

specified as 4130 steel alloy. The material grade of the eye bolt was identified by a portable alloy analyzer as grade 4130 steel alloy.

The top end of the eye bolt contains a hole for an attachment bolt. The engineering drawing for the eye bolt "C3-CF-275" specified the hole is to be between 0.5000 and 0.5005 inches. Two bushings are to be inserted into this hole. The outer bushing part number C3T13-3, is to be made from 4130 steel, outside diameter (OD) between 0.5006 and 0.5001 inch after plating, inside diameter (ID) between 0.4062 and 0.4067 inch. The inner bushing part number C3T12-3, is to be made from 4130 steel, outside diameter (OD) between 0.4058 and 0.4054 inch, inside diameter (ID) between 0.3130 and 0.3125 inch. Examination of the eyebolt revealed the hole appeared to contain two bushings. The outer bushing had a color consistent with steel. The inner bushing was identified by an Olympus Vanta X-ray fluorescence (XRF) portable alloy analyzer to be a copper alloy. The inner diameter of the inner bushing measured approximately 0.3125 inch, consistent with the ID of the specified bushing.

X-ray inspection of the upper eye bolt cross section revealed a channel extended between the flange on the top of the bolt shank and the bushing hole (see figure 20). According to a representative from Viking, a review of the engineering drawings history revealed the eye bolt never contained a channel that extended between the shank flange and bushing hole.

1.5 Grease Fitting

The grease fitting fractured from the eye bolt leaving a threaded fragment inside the hole for the grease fitting (see figure 8). The fractured grease fitting portion was not submitted and was not found during the investigation. The hole for the grease fitting and bottom side of the lower bearing were covered with red translucent grease. The outer threads of the clamp nut was covered with grease that appeared opaque and red (with certain portions having a brown appearance). The fracture face of the grease fitting, after cleaning with a cotton swap soaked with acetone, exhibited a rough texture on slant planes consistent with overstress separation.

1.6 Ball Bearing Assemblies

The de Havilland aircraft illustrated parts catalog for the "Fuselage – Controls Installation – Elevator Trim", revision 18 Dec 2019, indicated quantity two of part number "7202W-DB" "Bearing-Duplex (FAF)" bearings are to be installed on the eye bolt. A "duplex" bearing is comprised of two single-row bearings that are manufactured specially for use as a unit.[5] "FAF" indicates the bearing was made to the FAFNIR Bearing Company specification. "7202W" is the part number. The DB

---

[5] Timken Engineering Manual, 11-22 Order No. 10424, © 2022 The Timken Company, p95.

designation after the part number indicates the bearings are supplied in a set of two and for use in a back-to-back configuration. Appendix 1 shows illustrations of two common duplex bearing configurations.

The engineering drawing "C3 CF 290" for the "Assembly of the Tailplane Actuator" specifies to install "7202W-DB" duplex bearings and indicated that "it is important that the thrust faces of the bearings are mounted together".[6] On the same engineering drawing, a cross section of the duplex bearings are shown assembled in a back-to-back configuration. The engineering drawing bill of material further states that the bearings are to be assembled in a face-to-face configuration.[7]

The eye bolt assembly was disassembled to expose the ball bearing assemblies. The cotter pin at the threaded end of the eye bolt was intact and secured to the castellated nut. The cotter pin and the nut were disassembled from the threaded end of the eye bolt. The two bearing assemblies were removed from the shank portion of the eye bolt. The shank portion of the eye bolt did not show evidence of mechanical damage. One side of each bearing assembly on the outer race portion was marked with the characters "FAFNIR® 7202W THRUST 02L LOT# 0011477359. The marked side of the bearings were facing each other.

All portions of the two disassembled bearing assemblies (including the balls and cage) were covered with grease. The top side of the upper bearing was covered with opaque brown grease, whereas the remaining sides of the bearing assemblies were covered with translucent red grease. In the disassembled condition, the outer race of each bearing assembly could not be rotated by hand relative to its respective inner race. The side faces of the bearing assemblies were sprayed with WD-40 lubricant/cleaner, after which the outer race of both bearing assemblies could partially be rotated by hand relative to the inner race, but the balls were binding at multiple locations as the outer race was rotated. The bearings were immersed in a glass beaker filled with trichloroethylene and ultrasonically cleaned for one hour, which removed the grease and exposed the cage and bearing elements.

Examination of each bearing assembly after cleaning revealed they were angular contact ball bearing assemblies. Stereo microscope examination of the bearing assembly revealed the outside surfaces exhibited evidence of minor general corrosion and the ball portions exhibited a smooth surface with no evidence of general corrosion. The bearings rotated freely without binding. The bearing assemblies were examined and it was determined that the bearings were found in a

---

[6] The de Havilland maintenance manual (section 2.27.4, revision 15, dated September 1959) also indicated the bearings must be re-assembled in a manner to "ensure that the thrust faces of the bearings are mounted together".
[7] This statement is in conflict with the rest of the drawing which specified to mount the bearings in a back-to-back (thrust faces together) configuration.

back-to-back configuration (DB) and, as indicated earlier, with the thrust (marked) faces of the bearings mounted together.

1.7 Moisture seal

A moisture seal assembly was installed between the inner face of the clamp nut and the larger diameter of the shank portion of the eye bolt. Figures 16 through 19 show the moisture seal in various stages of disassembly. It consisted of a circumferential metal enclosure that was installed against the inner face of the clamp nut. The inner diameter portion of the metal enclosure contained an elastomer seal that extended all around the inner diameter of the metal enclosure. The elastomer seal could not be removed from the metal enclosure and was bonded to the inner diameter portion of the enclosure. A circumferential spring seal made from steel was installed on the outer surface of the elastomer seal. A moisture seal assembly is not shown or listed in the de Havilland aircraft illustrated parts catalog, aircraft maintenance manual, or actuator assembly drawing. The moisture seal was installed after the airplane was delivered from the factory. According to the current operator of the airplane, the purpose of the moisture seal was to prevent environmental elements (moisture, water, dirt) from entering the lubricated portion of the bearings.

2.0 Measurements

2.1 Clamp Nut Thread Measurements

Visual examination of the clamp nut revealed the threads showed no evidence of wear damage. The engineering drawing for the clamp nut part number C3-CF-277 specified 1.5 inch-12NF3 threads. The major and minor diameters[8] of the external threads were measured with an optical comparator, OPG Optical Gaging Products Inc., model Opticom Qualifier 14B. The major and minor diameters were measured in one area of the clamp nut and are not an average of measurements from multiple locations of the clamp nut. The major and minor diameters of the external thread on the clamp nut measured approximately 1.499 inches and approximately 1.386 inches, respectively. The minor diameter on the internal threads of the barrel portion on the actuator measured approximately 1.402 inches. A screw thread pitch gauge set was utilized to measure the pitch and size of the threads. The inner threads on the barrel and outer threads on the clamp nut matched the threads that corresponded to 12 NF size threads (12 threads per inch).

2.2 Extension of the Jackscrew

The actuator lower eye end assembly was actuated (rotated) by hand to determine the full travel distance of the jack-screw portion. During the initial travel,

---

[8] Major diameter is the largest diameter of the thread for a screw or nut, whereas the minor diameter is the smallest diameter of the threads for a screw or nut.

there were some locations where the applied rotational force varied slightly, but no more than hand force was ever required to cause rotation. After the initial extension and retraction, the travel was generally smooth with little force required to rotate the jack screw. The travel distance was measured with a caliper, between the bottom end of the barrel and approximate center of the bolt hole, indicated by distance "D" in figure 1. Measurements were made for an actuator in the as-received, fully extended, and retracted position. The measured distance "D" for these positions measured 2.8 inches, 4 inches, and 1.6 inches, respectively. When measuring from the upper eye bolt to the lower eye bolt (center of bolt hole to center of bolt hole) these measurements corresponded to approximately 13.75 inches, 14.7 inches, and 12.4 inches, respectively. According to the de Havilland aircraft maintenance manual, the actuator should extend approximately 14.5 inches in the fully extended position and approximately 12.4 inches in the fully retracted position.

Submitted by:

Frank Zakar
Senior Metallurgist

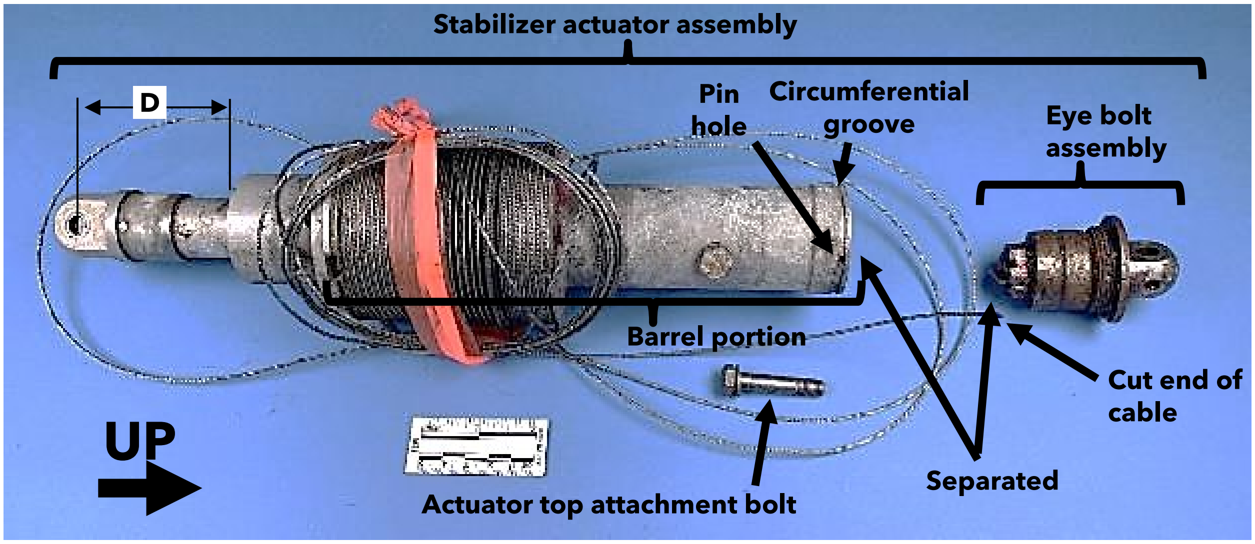


Figure 1. As-received horizontal stabilizer trim actuator assembly with the separated eye bolt assembly and actuator top attachment bolt. The eye bolt assembly is also referred to in the maintenance manual as the top eye end and bearing assembly.

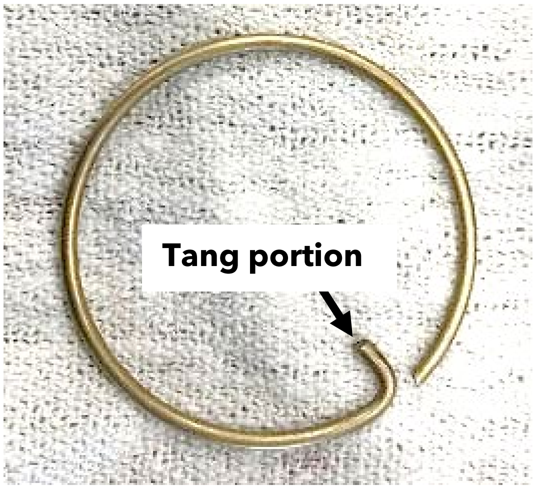


Figure 2. Exemplar lock ring that was not involved in the accident. One end of the lock ring is curved radially inward, referred to as the tang portion.

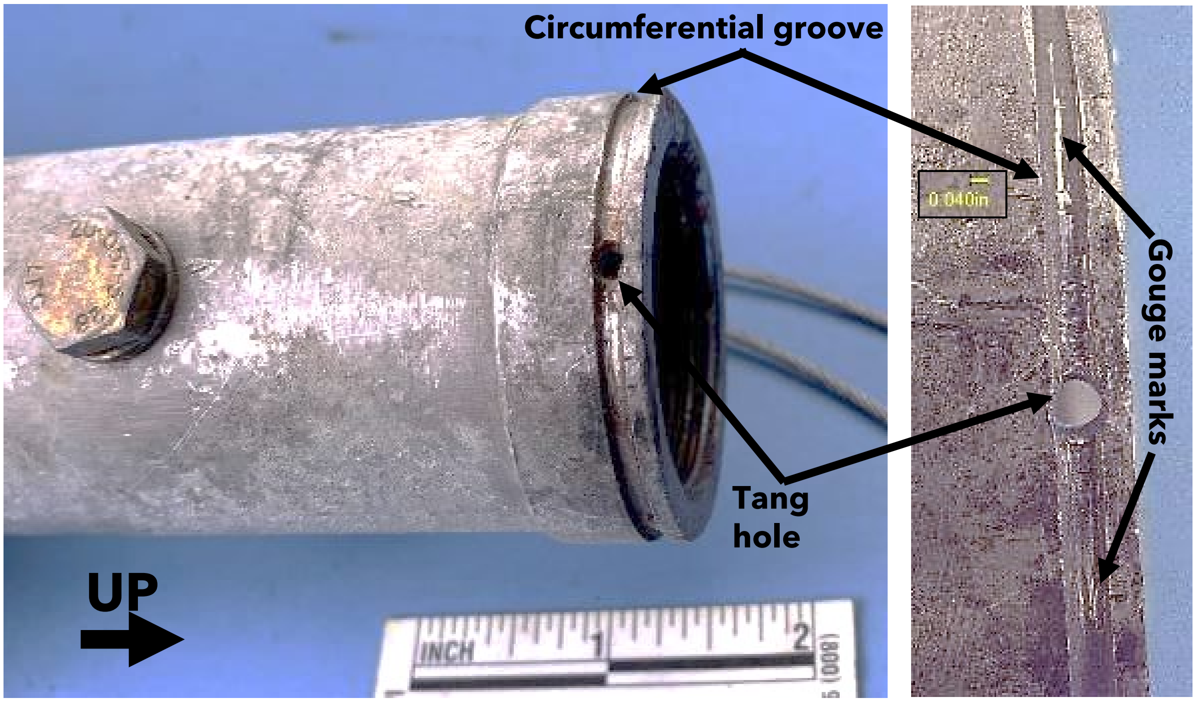


Figure 3. Oblique view of the top end of the barrel showing the circumferential groove for the lock ring and hole for lock ring (left image); and close-up view of gouge marks in the groove (right image).

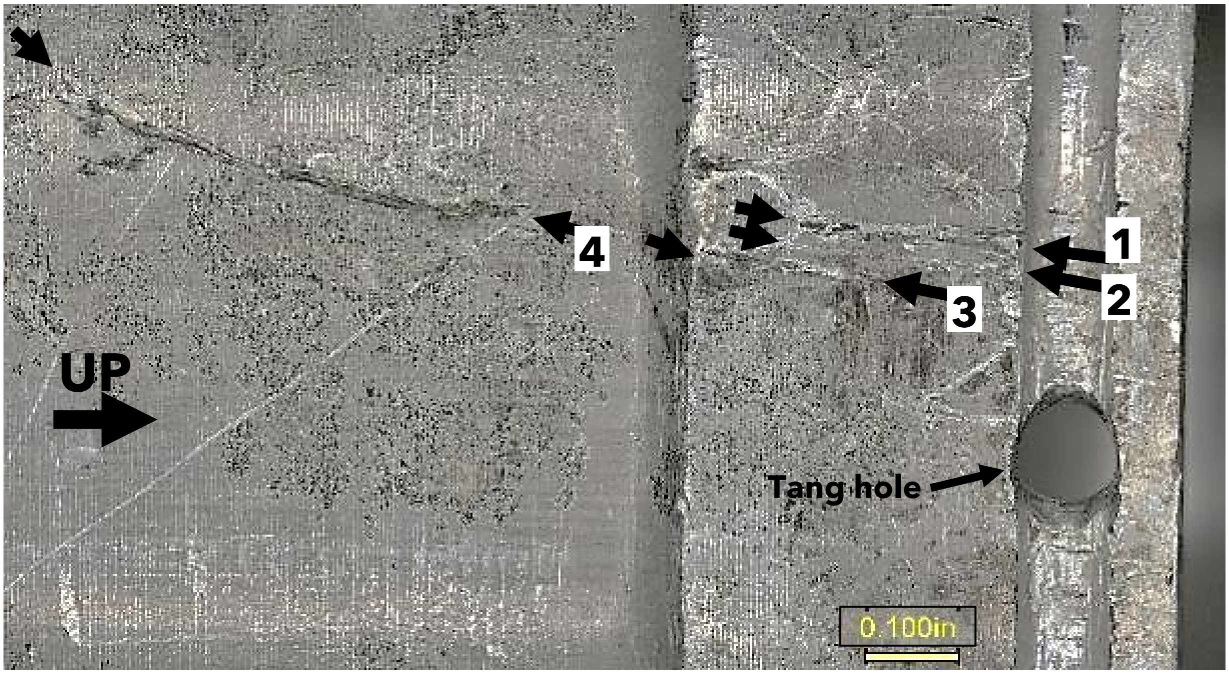


Figure 4. Side view of the barrel showing the longitudinal-like gouge marks that extended from the circumferential groove, in the areas between arrows “1” through “4”.

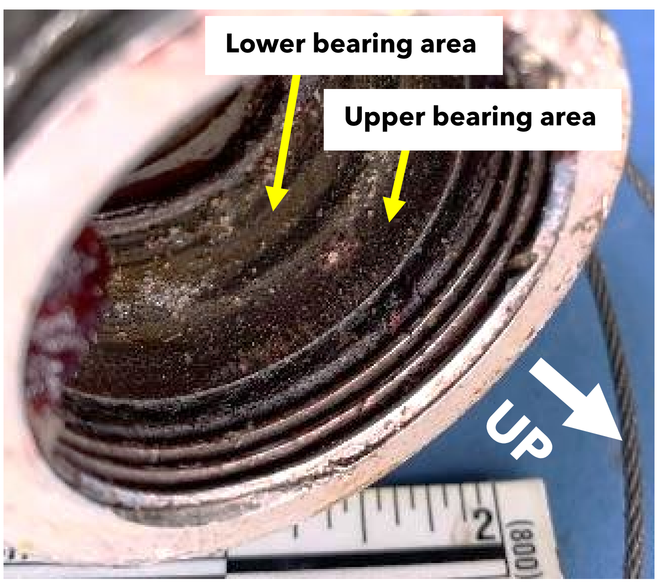


Figure 5. Inner threads at the upper end of the barrel portion in the as-received condition. Areas on the inner surface that corresponds to the locations of the two bearing assemblies are indicated in the photograph.

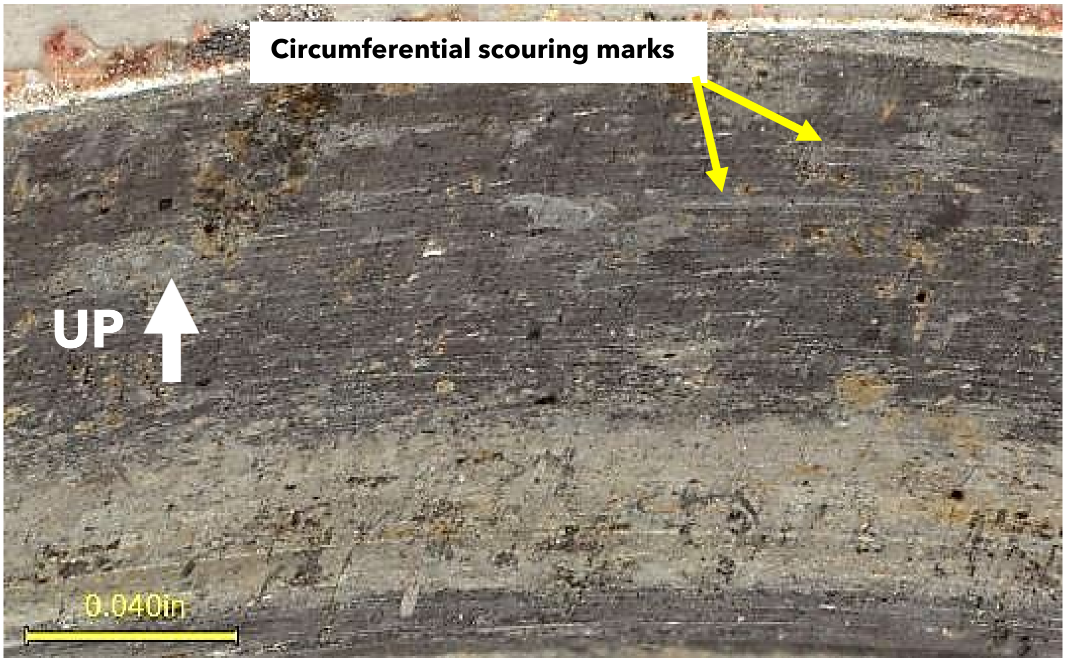


Figure 6. Inner surface of barrel showing circumferential scouring marks in the area that corresponded to the upper bearing assembly.

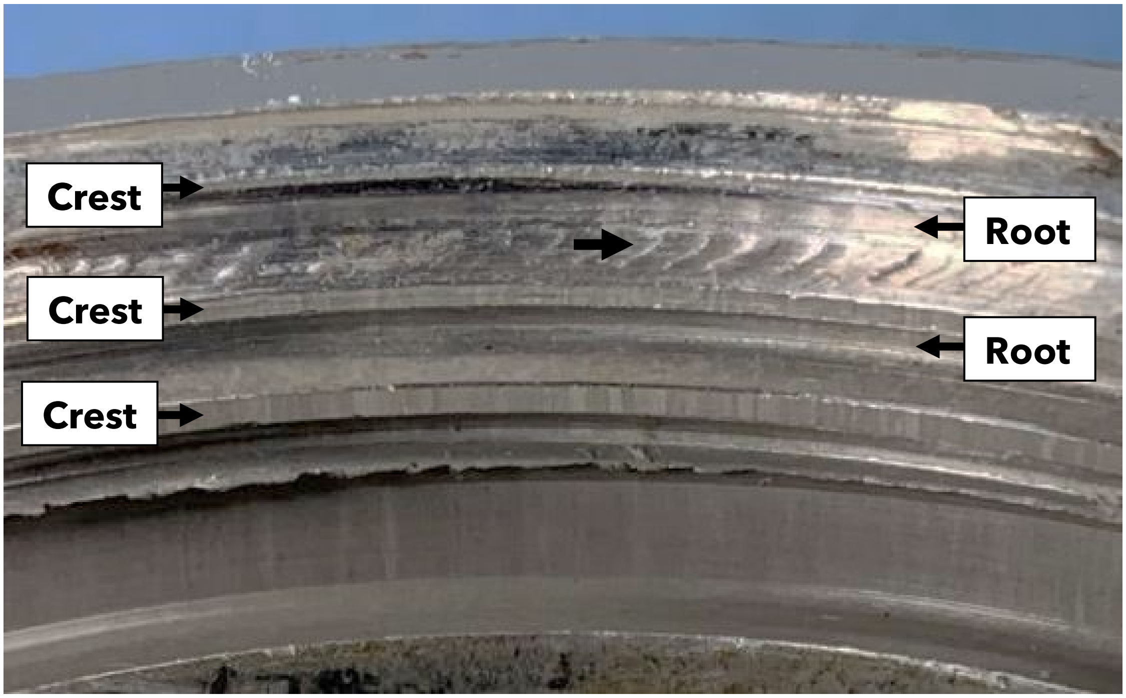


Figure 7. Inner threads at the upper end of the barrel portion, after cleaning the threads with a cotton swab soaked with acetone. The thread flank in the general area indicated by an arrow contained evidence of minor galling.

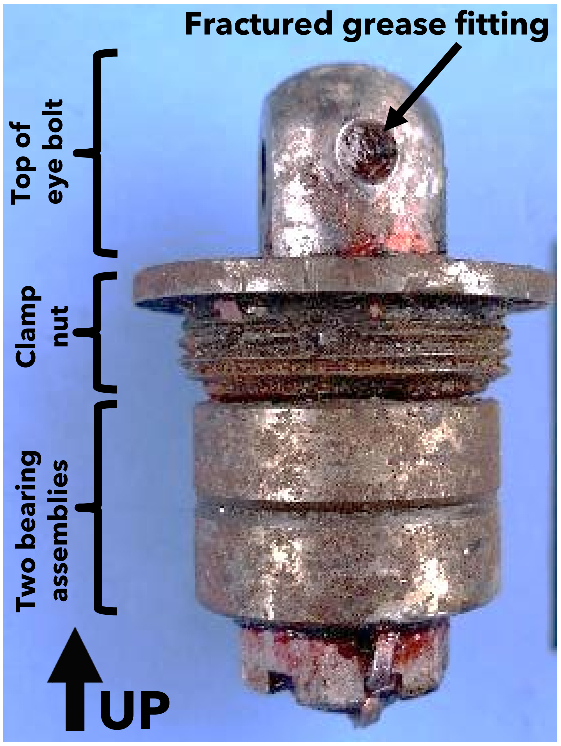


Figure 8. Side view of the as-received eye bolt assembly.

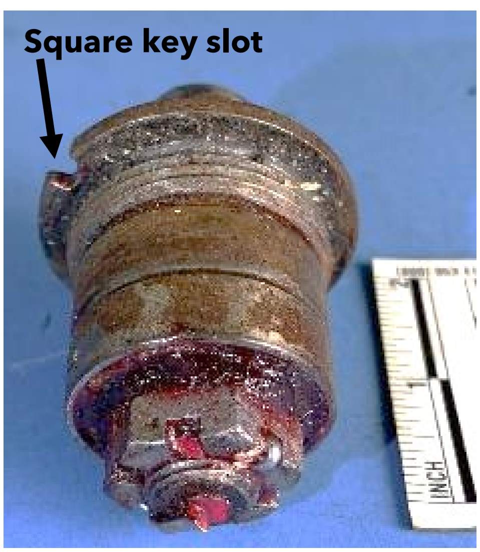


Figure 9. As-received eye bolt assembly showing the bottom end of roller bearing assembly that was covered with translucent red grease.

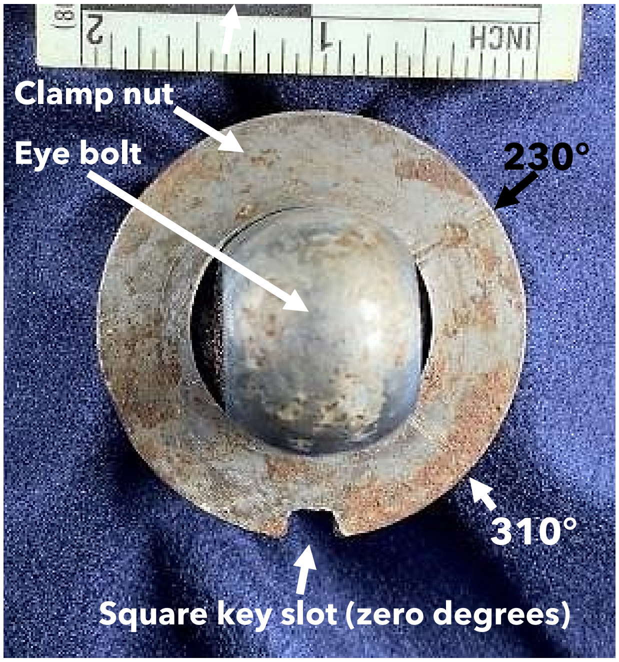
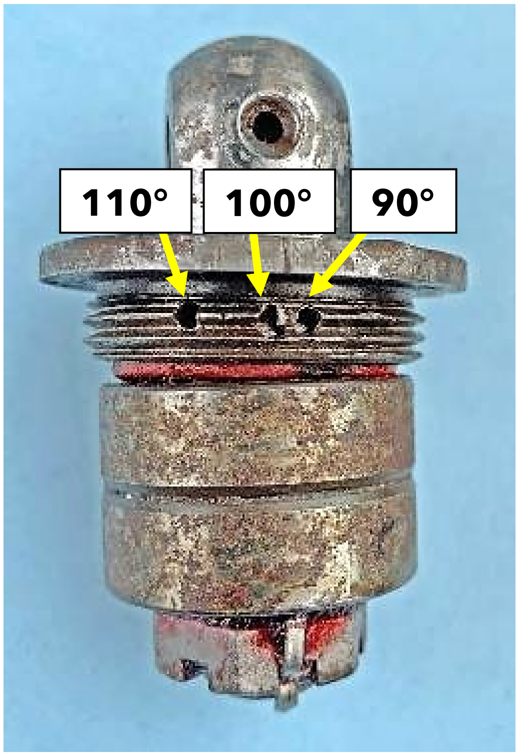
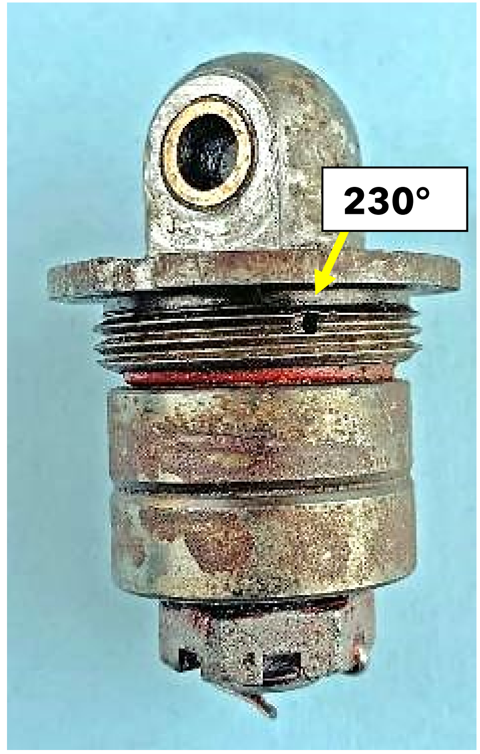


Figure 10. Top view of the eye bolt and clamp nut. For the purpose of this report, the position of the drilled holes in the clamp nut outer threads were measured when looking down at the center of the eye bolt and when rotating clockwise relative to the square key slot, where the slot is the arbitrary zero position. Radial scribe marks were found at approximately the 230 degrees and 310 degrees position that corresponded to the location of two of the five drilled holes in the nut clamp.





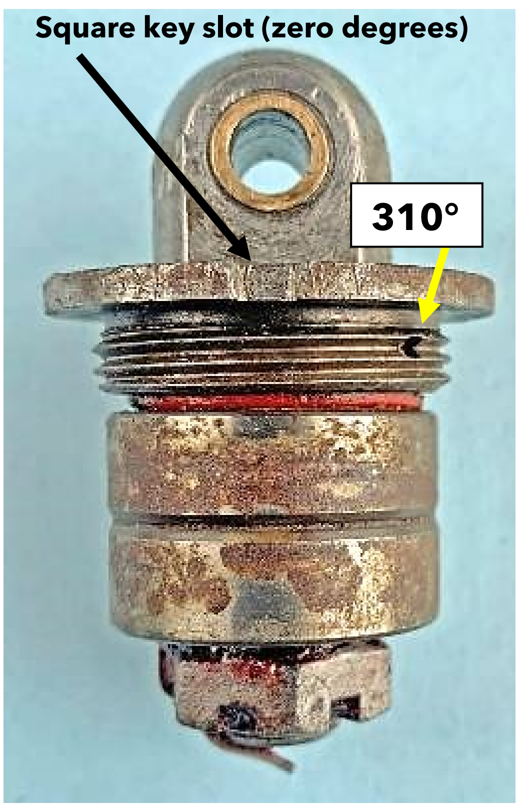


Figure 11. Side view of the eye bolt assembly, after cleaning the threads and threaded hole for the grease fitting with a cotton swab soaked with acetone, showing drilled through-holes in the outer threads of the clamp nut, at approximately the 90, 100, 110, 230, and 310 degrees position, relative to the square key slot; when looking down at the eye bolt and rotating clockwise. The square key slot is the zero degrees position.

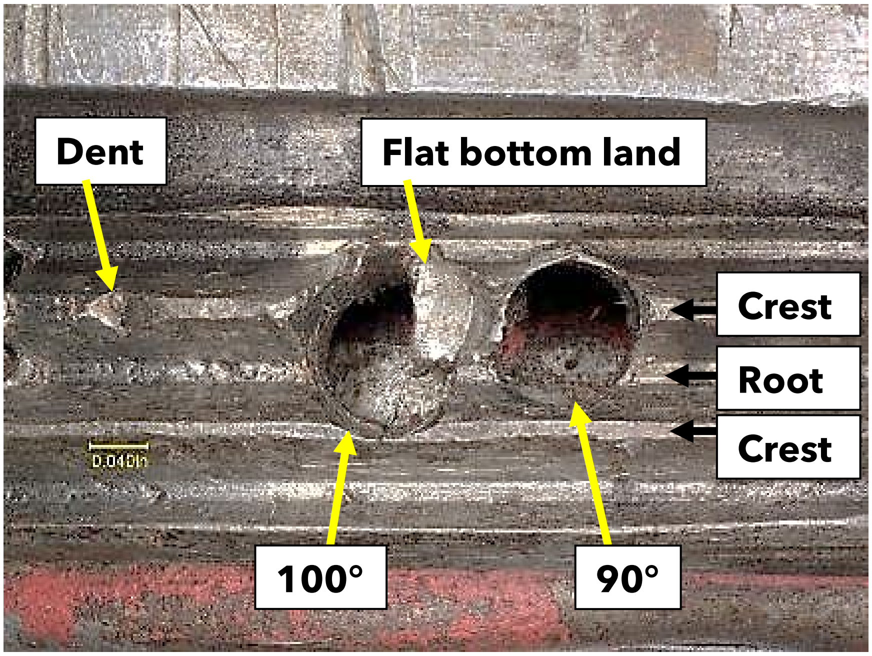


Figure 12. Side view of the clamp nut showing radial-oriented drilled through-holes in the outer threads, at approximately 100 and 90 degrees (left to right); after cleaning the threads with a cotton swab soaked with acetone. Metal enclosure for the moisture seal assembly is located under the drilled holes.

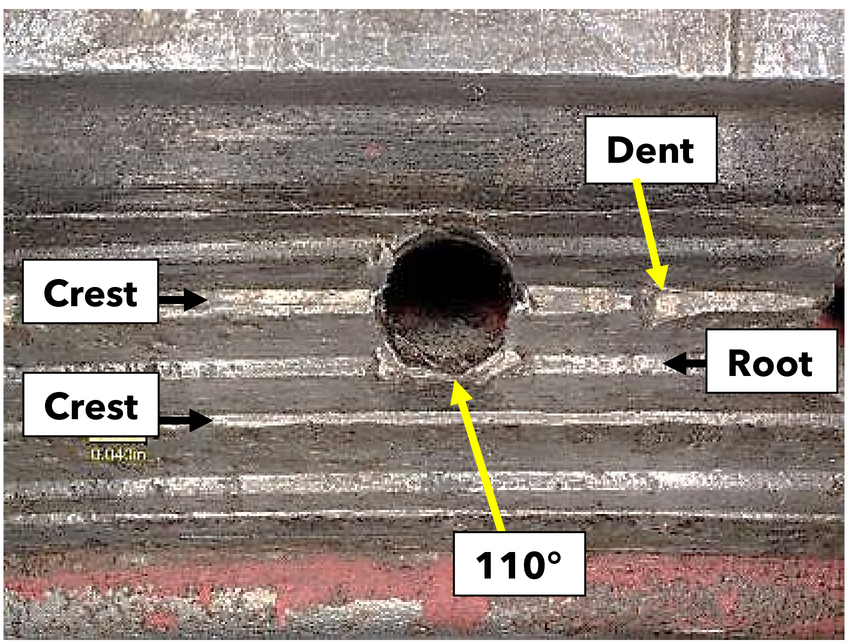


Figure 13. Side view of the clamp nut showing a radial-oriented drilled through-hole in the outer threads, at approximately 110 degrees; after cleaning the threads with a cotton swab soaked with acetone. Metal enclosure for the moisture seal assembly is located under the drilled holes.

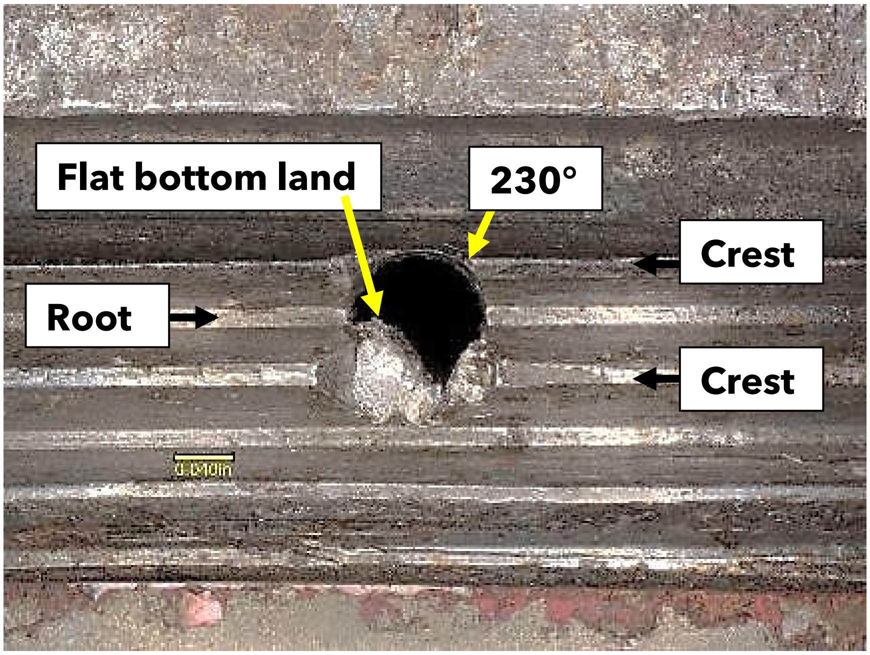


Figure 14. Side view of the clamp nut showing a radial-oriented drilled through-hole in the outer threads, at approximately 230 degrees; after cleaning the threads with a cotton swab soaked with acetone.

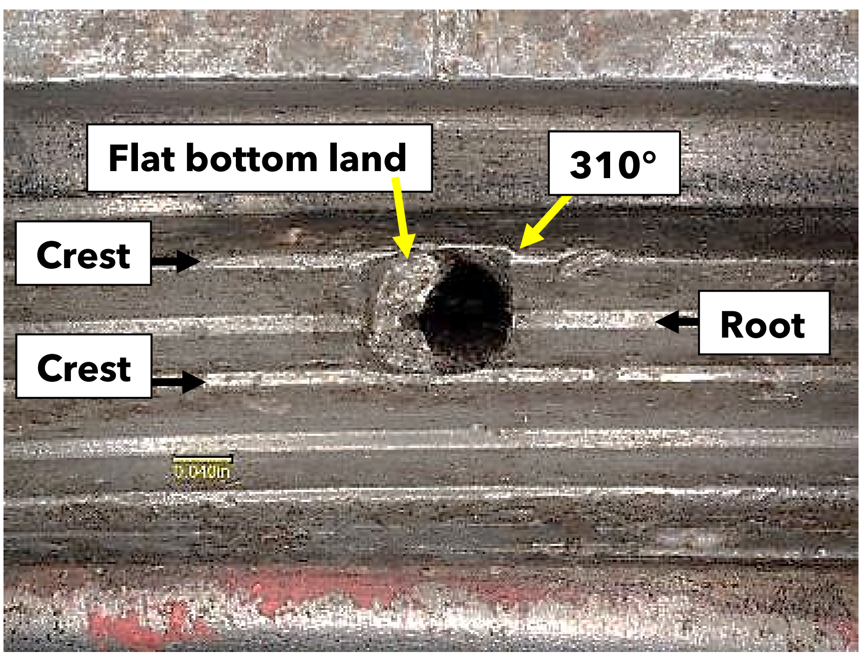


Figure 15. Side view of the clamp nut showing a radial-oriented drilled through-hole in the outer threads, at approximately 310 degrees; after cleaning the threads with a cotton swab soaked with acetone.

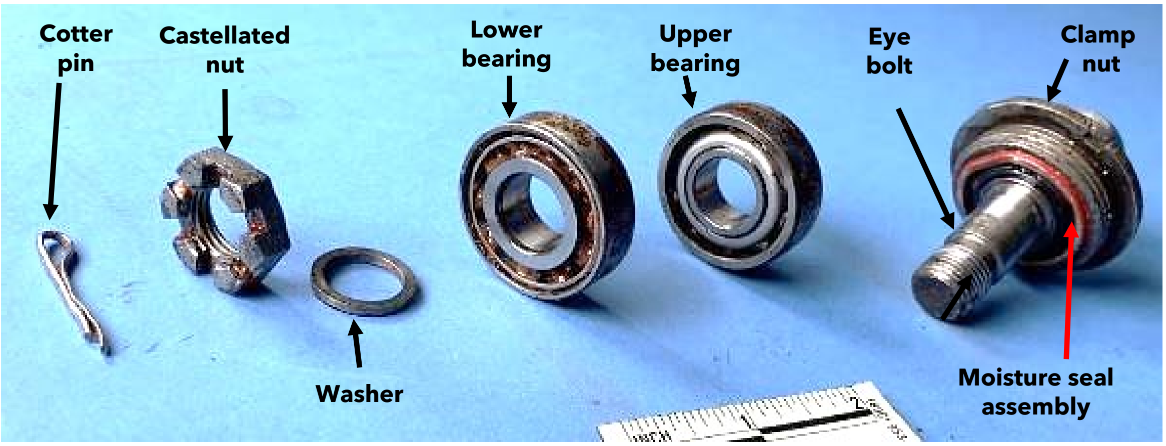


Figure 16. Disassembled pieces of the eye bolt assembly showing the cotter pin; castellated nut; washer; lower and upper bearing assemblies; eye bolt, moisture seal assembly, and clamp nut. (left to right).

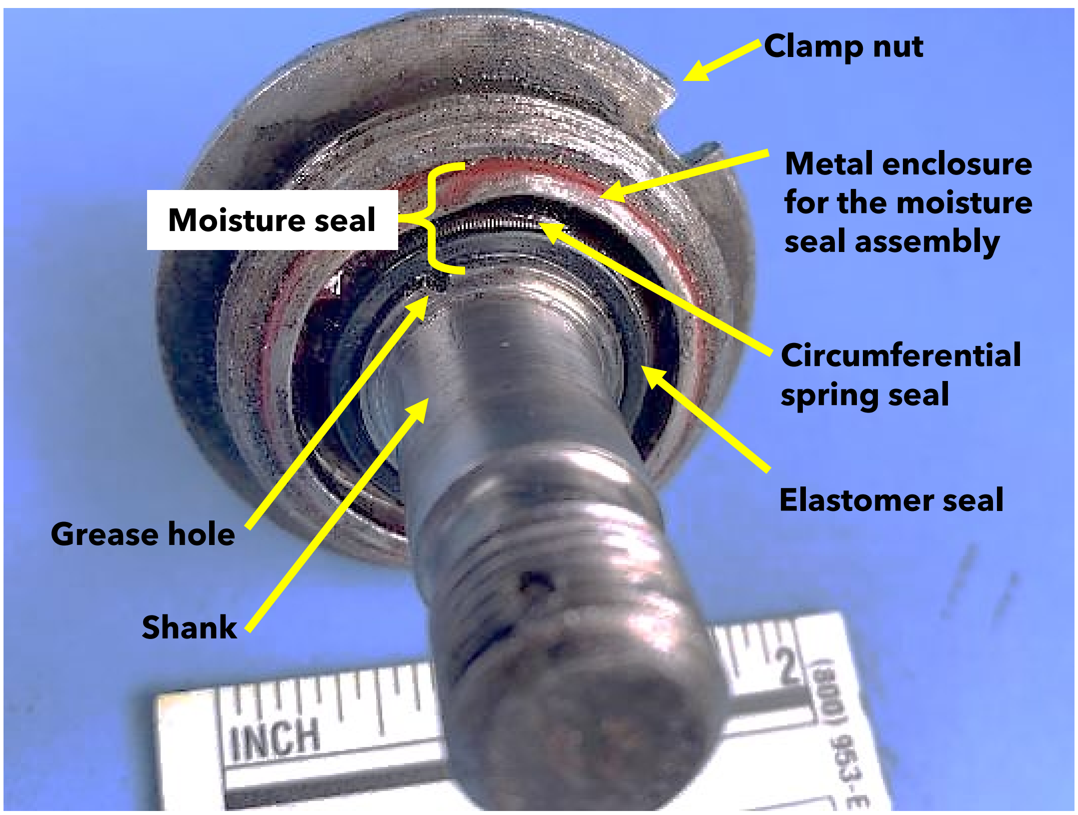


Figure 17. View looking up at the clamp nut showing the moisture seal assembly. It was installed between the inner diameter of the clamp nut and the larger diameter portion of the shank. It is composed of a circumferential metal enclosure, an elastomer seal and circumferential spring seal.

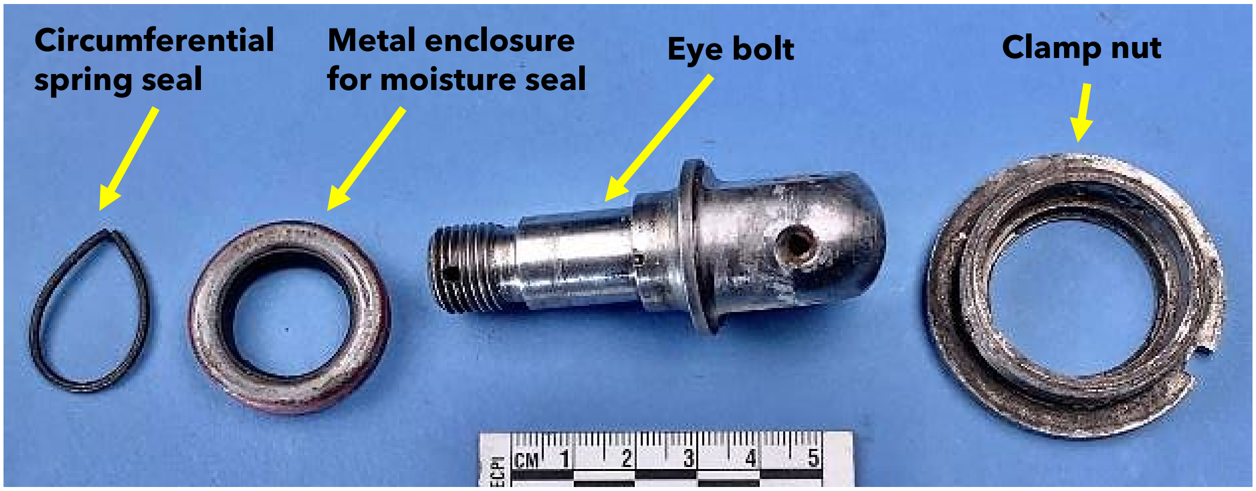


Figure 18. Disassembled pieces of the eye bolt assembly showing parts of the moisture seal (circumferential spring seal and metal enclosure), eye bolt, and clamp nut.

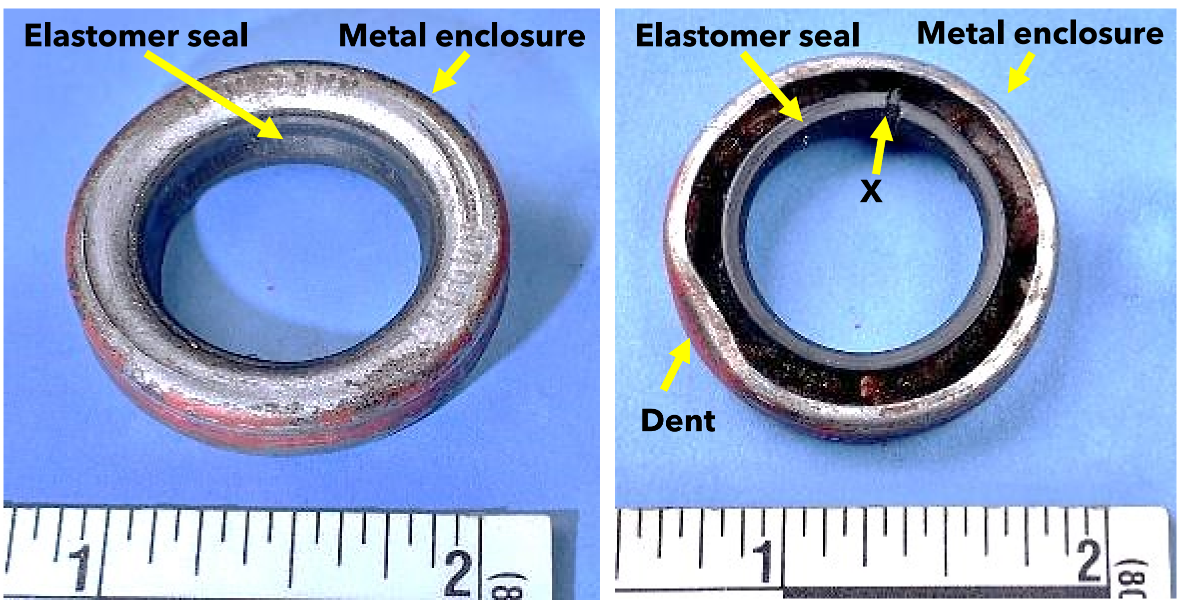


Figure 19. View of the disassembled moisture seal assembly. The metal enclosure portion was stamped "NATIONAL" and "180954". The elastomer seal was in the area indicated by arrow "x" and was cut by the NTSB Materials Laboratory to facilitate disassembly. The dent was present in the as-received condition.

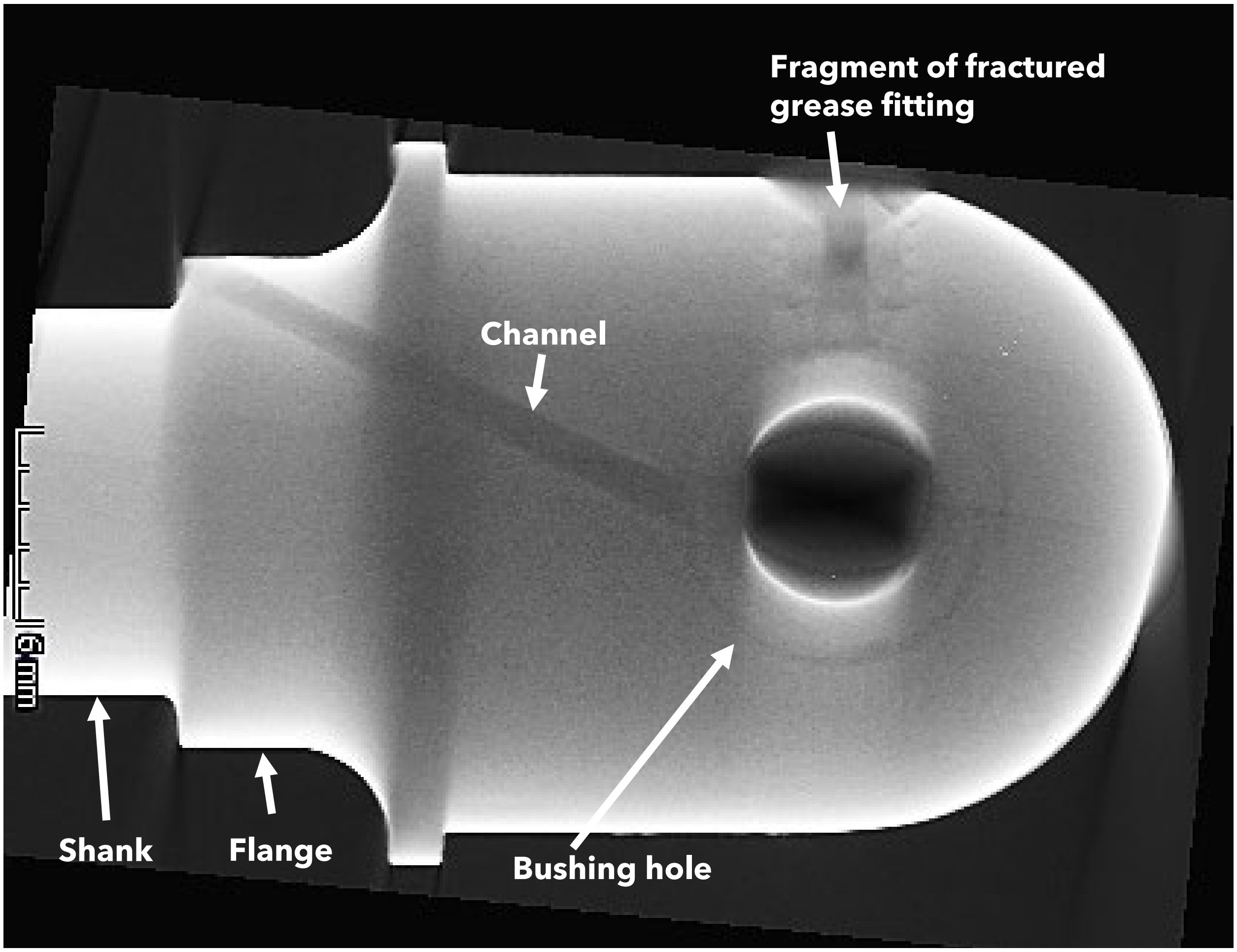
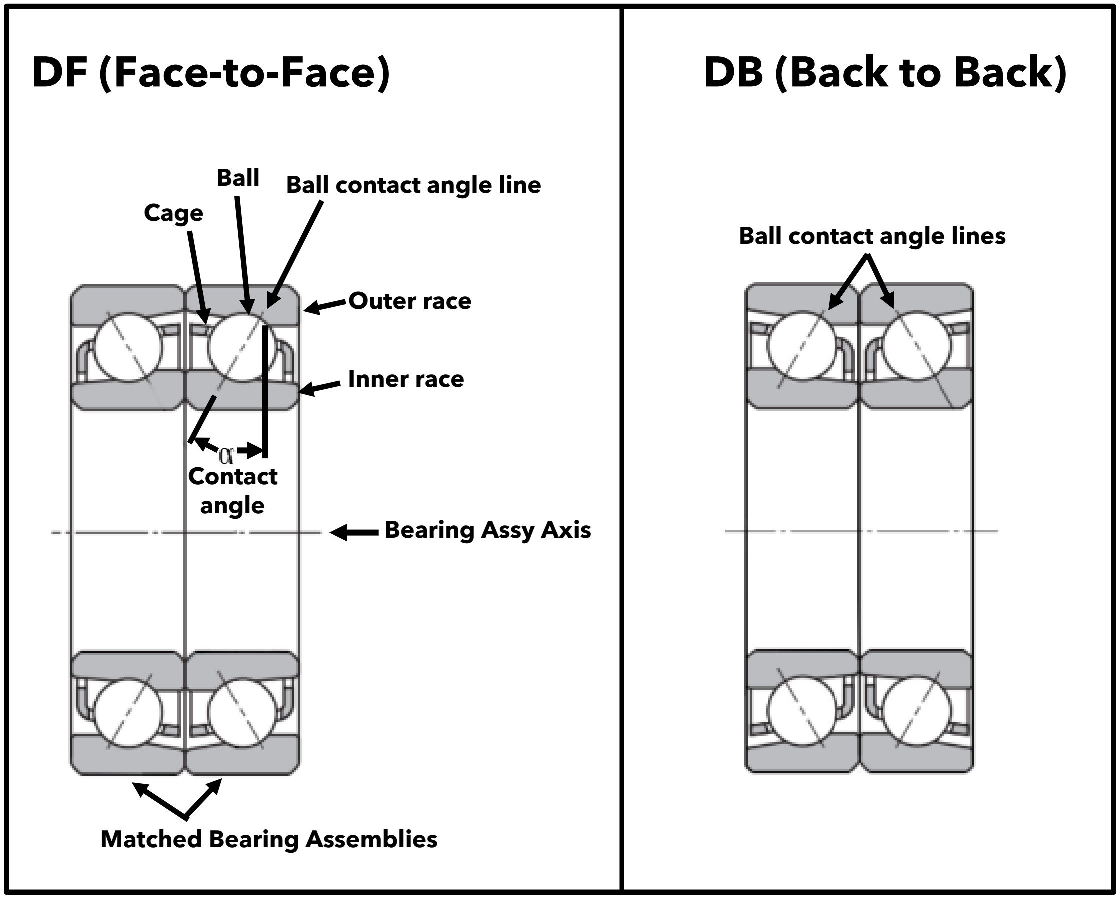


Figure 20. X-ray image of the eye bolt cross section showing a channel that extended between the flange on the top of the bolt shank and the bushing hole.

APPENDIX 1

Examples of Different Duplex Bearing Configurations



Appendix 1. In the face-to face duplex bearing configuration (also known as "DF" configuration), the two halves are placed next to each other so that the contact angles of the ball portions converge inwardly to the bearing axis inside of the bearing envelope. In a back-to-back duplex bearing configuration (also known as "DB configuration") the two halves of the bearing assemblies are placed next to each other so that contact angle lines of the ball portions diverge inwardly to the bearing axis inside the bearing envelope. The contact angle is the angle between a plane perpendicular to the ball bearing axis and a line joining the two points where the ball contacts the inner and outer raceways. The unlabeled diagram shown on this page was obtained from an NTN Bearing Corp of America catalog and labels were later added to identify various parts of the bearing. (Examples of bearing configurations can also be found in references such as "Timken Angular Contact Ball Bearing Catalog, 06-22 Order No. 11193; and Timken Engineering Manual, 11-22 Order No. 10424, © 2022 The Timken Company, p95).