NATIONAL TRANSPORTATION SAFETY BOARD

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

June 1, 2015

MATERIALS LABORATORY FACTUAL REPORT Report No. 15-059

A. ACCIDENT INFORMATION

Place	:	Bellevue, Tennessee
Date	:	February 3, 2014
Vehicle	:	Gulfstream Commander 690C, N840V
NTSB No.	:	ERA14FA112
Investigator	:	Luke Schiada, AS-ERA

B. COMPONENTS EXAMINED

Collins 332D-11T vertical gyro and unknown directional gyro.

C. DETAILS OF THE EXAMINATION

An overall view of the submitted gyros as received is shown in figure 1. Both components showed damage consistent with impact and exposure to fire. The cover from the vertical gyro was missing. A data plate was located on the base of the vertical gyro that indicated it was a Collins Avionics Divisions/Rockwell International Type 332D-11T vertical reference unit, Collins part number 622-4565-002, serial number 4661. No data plate was located on the turn gyro. According to installation drawings for the accident airplane, the airplane was to be equipped with one Collins 332D-11T gyro and two Sperry C-14 directional gyros.

1. Vertical Gyro

Components of the inner gimbal assembly that will be referenced throughout this report are illustrated in figure 2. The illustration in figure 2 is a representation of most of the components in the assembly to facilitate understanding of components referenced in this report. The rotor assembly includes the rotor, end caps, and bearings, and the stator assembly includes the stator shaft, winding, and core. The illustration is not to scale nor is it an exhaustive list of all components included in the assembly. For reference, right and left are as shown in figure 2, where the power leads exit the assembly at the left end of the stator shaft. The direction of rotor rotation under normal operation is clockwise as viewed looking at the right face of the inner gimbal assembly.

Views of the vertical gyro with the inner gimbal assembly rotated in different positions are shown in figures 1 and 3. The stator shaft was displaced toward the left end of the inner gimbal assembly such that the right end plug was disengaged from the threads of the housing cover toward the interior of the inner gimbal assembly, and the left end plug was disengaged from the threads and was located to the exterior of the housing.

The inner gimbal assembly was removed from the rest of the unit, and then the housing cap was unscrewed from the housing. Figure 4 shows the inner gimbal assembly after it was disassembled from the rest of the unit and after the housing cover was removed to show the rotor assembly. As indicated in figure 4, a bearing ball fell out of the inner gimbal assembly as it was disassembled.

Next, the rotor assembly with the stator assembly was removed from the housing. Initial attempts to remove the left end plug were unsuccessful as the end plug was frozen on the left preload sleeve and could not be easily removed from the left preload sleeve. In comparison, the right end plug was easily disassembled from the assembly by removing the screw and lock washer from the right end of the stator shaft followed by removal of the right end plug by hand. It was noted that the threads in the inner gimbal housing for attaching the left end plug were sheared, and the inner gimbal housing had radial cracks intersecting the center threads. As a result, the left end plug fit through the threaded hole of the housing without being removed from the left preload sleeve. Two more bearing balls were recovered after the rotor assembly was removed from the inner gimbal housing.

After the rotor was disassembled from the housing, several measurements of the rotor and housing were made. The outer diameter of the rotor was 2.000 inches, and its axial length was 1.655 inches. The inner diameter of the inner gimbal housing was 2.112 inches, and the axial length of the cylindrical portion of the housing between the left and right interior faces was approximately 1.745 inches. The inner diameter of intact threads in the housing cover measured 0.602 inch, and the inner diameter of sheared threads at the left end of the housing measured between 0.623 inch and 0.625 inch. By comparison, the outer diameter of the end plugs measured 0.621 inch.

Figure 5 shows the rotor assembly after it was removed from the gimbal housing. The rotor end cap at the left end of the assembly was displaced from the rotor end surface. The axial distance of the displacement was between 0.047 inch and 0.068 inch. The rotor end cap at the opposite end of the rotor was not displaced, positioned tight against the rotor. Circumferential scoring was observed on the outer diameter of the rotor near the left end of the rotor as indicated with a bracket in figure 5.

Grooves were observed around the outer diameter of the inner gimbal housing interior surface at the left end of the housing as indicated in figure 6. The rounded shape of the groove was consistent with contact with a sliding or rolling bearing ball under load, and the bearing balls recovered during disassembly of the inner gimbal assembly fit into the observed grooves. The location of these grooves corresponded to the location of the circumferential scoring marks on the rotor. Grooves consistent with rolling or sliding bearing ball contact under load were also observed around the outer edge of the interior face of the inner gimbal housing cover as indicated in figure 7.

Impact marks corresponding to the outer circumference of the rotor were observed on the left face of the interior of the inner gimbal housing (see figure 8). Additional circumferential marks were observed on the end faces of the housing and cover. However other marks had less depth and appeared to have disturbed the oxides on the surfaces as compared to the impact marks noted in figure 8.

The inner gimbal housing was sectioned longitudinally to facilitate an examination of the rotor impact marks shown in figure 8 using a scanning electron microscope (SEM). A view of typical features observed within the area of impact is shown in figure 8. Multiple contact marks corresponding to the edge of the rotor were observed within the region indicated with a bracket in the lower image in figure 8. Most of the deformation associated with the impact marks was radially inward and outward, but marks within the impact areas were oriented circumferentially. The surface appeared oxidized, but some of the fine features had deformation patterns consistent with contact with an object rotating clockwise relative to the surface, which is the direction of rotation of the rotor under normal operation.

Views of threads in the inner gimbal housing cover are shown in figure 9. The end plug attachment threads within the cover were intact. In contrast, the threads at the left end of the inner gimbal housing were sheared as shown in figure 10.

Turning to the rotor assembly, bearing grease shields on the rotor bearings were stamped with the following characters, “BARDEN R3HSSX91 MADE IN USA”. According to the Barden Super Precision Ball Bearings Specialty Products catalog,[1] bearings of type R3H have 8 balls with a diameter of 3/32 inch. However, all balls were missing from the bearing races in both bearings on the rotor assembly. Figure 11 shows 3 bearing balls that were recovered from the inner gimbal assembly after the housing cover was removed and the rotor assembly was separated from the housing. The bearings had a dark appearance and the surfaces were damaged. One of the bearings had a flat face that had a smeared appearance consistent with sliding contact with another object.

Next, the stator assembly was disassembled from the rotor. The right grease shield for the right rotor bearing had a deformed inner diameter that was large enough that it slid off right end of the stator assembly over the right preload sleeve. Attempts to pry the right rotor end cap from the rotor were unsuccessful. However, the displaced left rotor end cap was pried from the rotor to allow the rotor to slide off the right end of the stator.

A view of the stator assembly with the rotor removed is shown in figure 12. Separation was observed between laminates of the core across 2 core segments at the left end of the core and similarly at 2 different segments at the right end of the core as indicated in figure 12. The stator shaft was bent in the area between the winding and the right bearing inner race, and the area of laminate separation at the left end of the core was located in the outside of the bend. Blue colored grease was present at the

[1] www.bardenbearings.com

right bearing, and additional bearing balls and cage pieces from the right bearing were recovered from within the rotor after it was removed from the stator assembly.

To further facilitate examination of the left bearing races, the left grease shield for the left bearing was cut from the stator assembly. The rotor end cap could then slide off the left end of the stator shaft over the left preload sleeve. The inner diameter of the right grease shield for the left bearing was also deformed sufficiently that it also slid off the left end of the stator shaft over the left preload sleeve.

Grease was cleaned from the surfaces of the right bearing inner race. The bearing inner race did not show evidence of heat distress as shown in the close view of the bearing inner race in figure 12. The ball wear pattern was located closer to the right shoulder than the left shoulder, consistent with a preloaded bearing. The right shoulder of the inner race had an impression on the shoulder edge that spiraled onto the shoulder and around to the right face of the bearing race. In addition, the right shoulder had ball impressions at 5 locations around 1/3 of the circumference. A bearing ball imprint was observed on the corner of the preload sleeve as shown in figure 12.

Multiple bearing ball contact areas were observed around the circumference on the right shoulder of the outer race of the right bearing. Contact grooves spiraling from the right shoulder toward the right face of the bearing outer race were also observed along with metal transfer consistent with heavy sliding contact. The left shoulder of the outer race was free of ball contact marks.

The left rotor bearing had more heat damage. However, no evidence of ball skidding was observed. Coked oil was present on the bearing races and the bearing races had a slight blue tint.

The left rotor bearing inner race had 2 impressions on the right shoulder of the inner race. The left shoulder of the inner race was rounded by ball contact around the circumference and included 2 locations that had relatively deeper impressions than the rest of the circumference.

The left bearing outer race had 8 equally-spaced brinell marks around the circumference on the right shoulder. Two of the marks are shown in the close view of the outer race in figure 13. Ball contact marks were also observed on the left shoulder at the location shown in figure 13.

2. Turn Gyro

The turn gyro was disassembled by removing the gyro assembly from the base and then removing the cover from the gyro gimbal assembly. An overall view of the gyro assembly with the cover removed is shown in figure 14. The frame supporting the rotor was fractured in two locations as indicated in figure 14.

The rotor was removed from the support frame, and the frame was removed from the rest of the assembly to facilitate examination of the frame interior surfaces for rotor contact marks. A sliding contact mark was observed at one corner of the frame at the location indicated in figure 14 corresponding to contact with the edge of the rotor. A closer view of the sliding contact mark is shown in figure 15.

Matthew R. Fox
Senior Materials Engineer

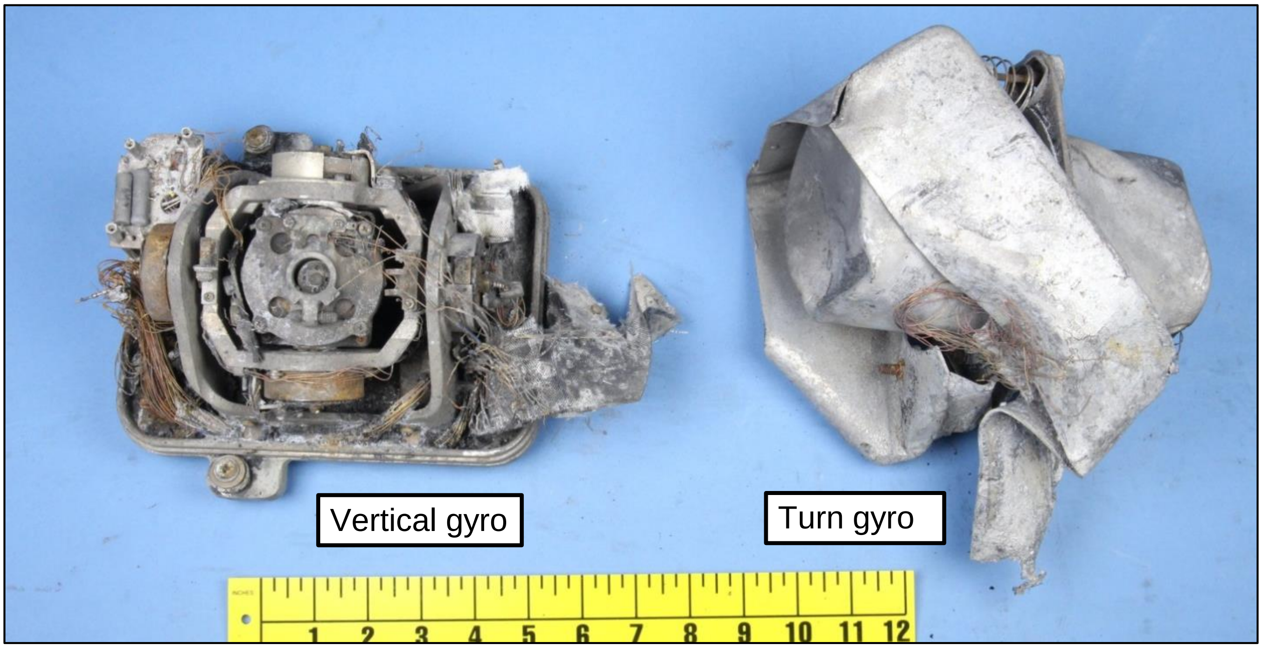


Figure 1. Overall view of the submitted gyros as received.

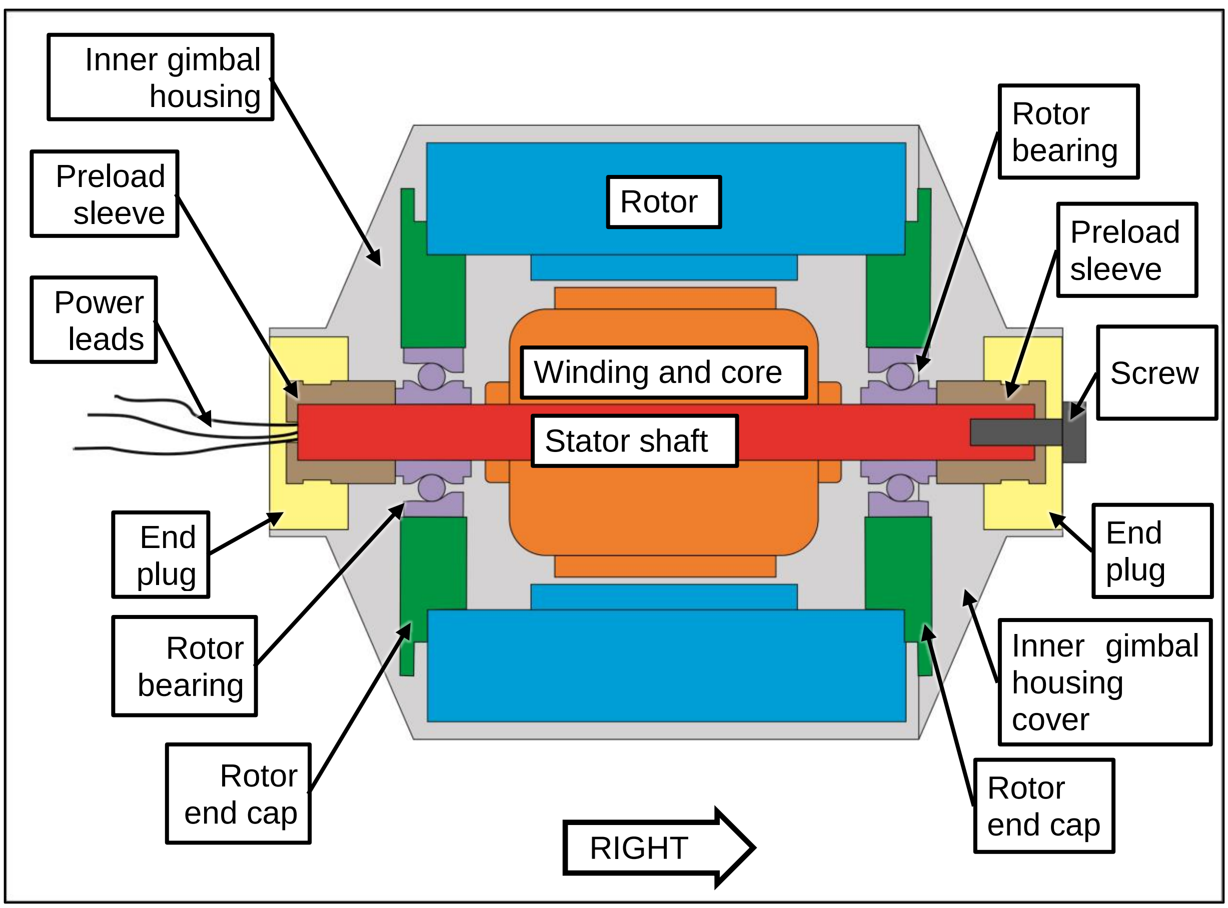


Figure 2. Illustration of a cross-section through the inner gimbal assembly from the vertical gyro showing components of the assembly.

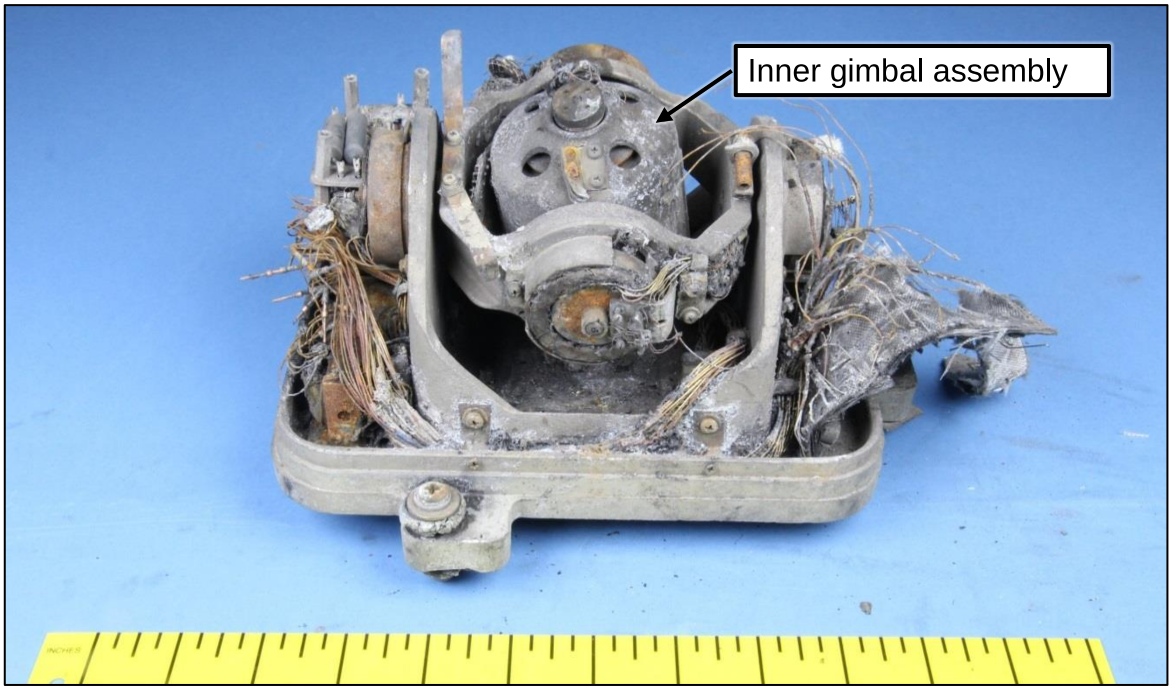


Figure 4. View of the vertical gyro with the inner gimbal assembly rotated approximately 180 degrees from the position shown in figure 1.

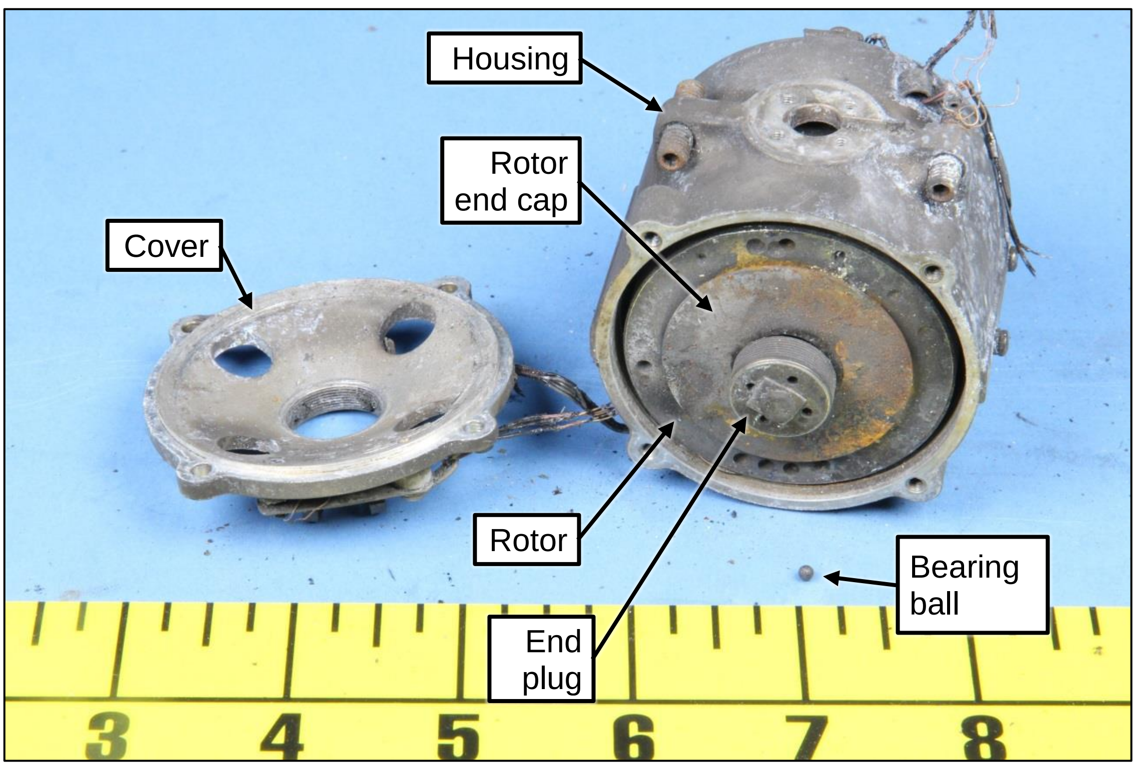


Figure 3. Inner gimbal assembly of the vertical gyro after removing the inner gimbal housing cover. A bearing ball that fell out when the cover was removed is also shown in the upper image.

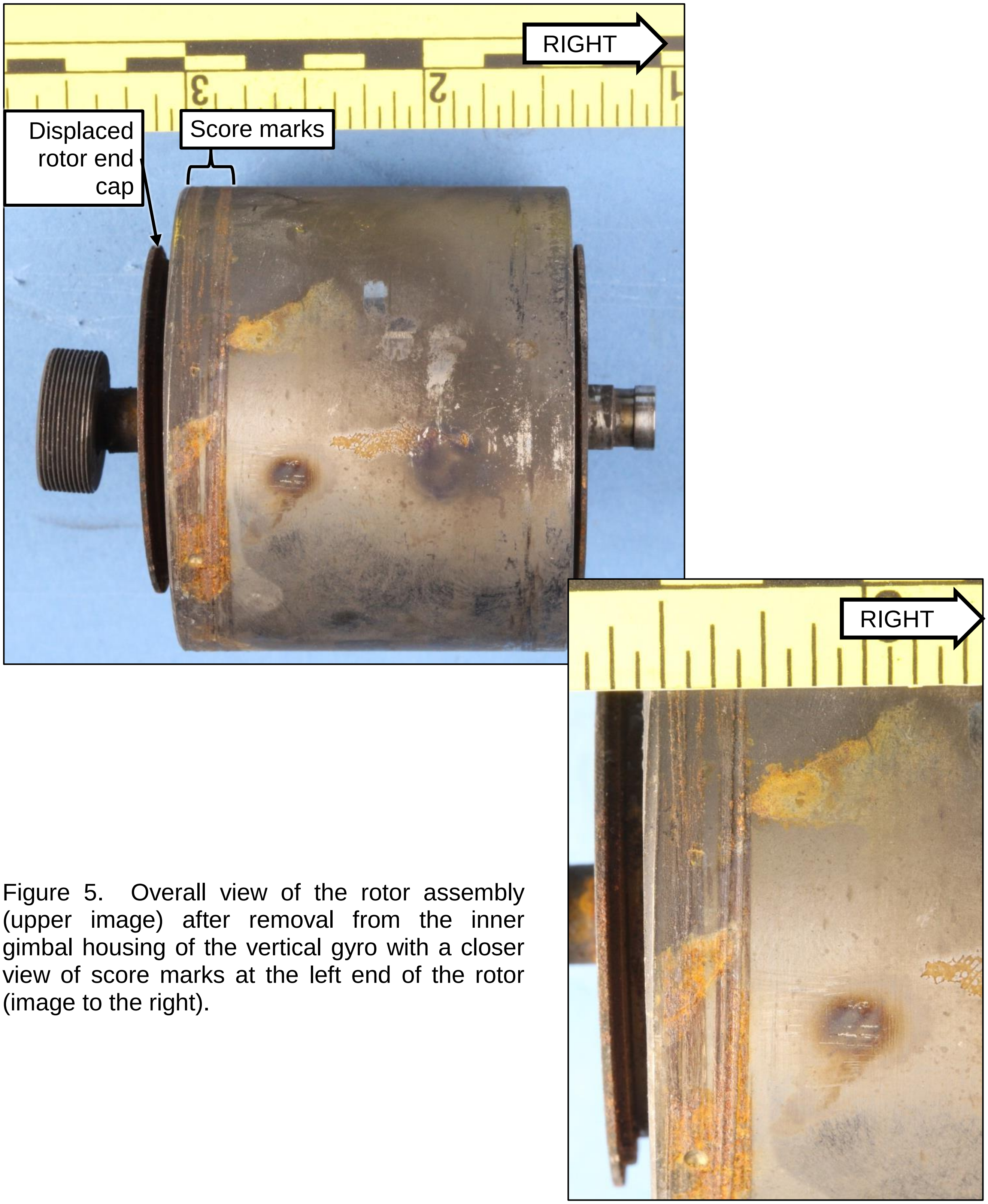


Figure 5. Overall view of the rotor assembly (upper image) after removal from the inner gimbal housing of the vertical gyro with a closer view of score marks at the left end of the rotor (image to the right).

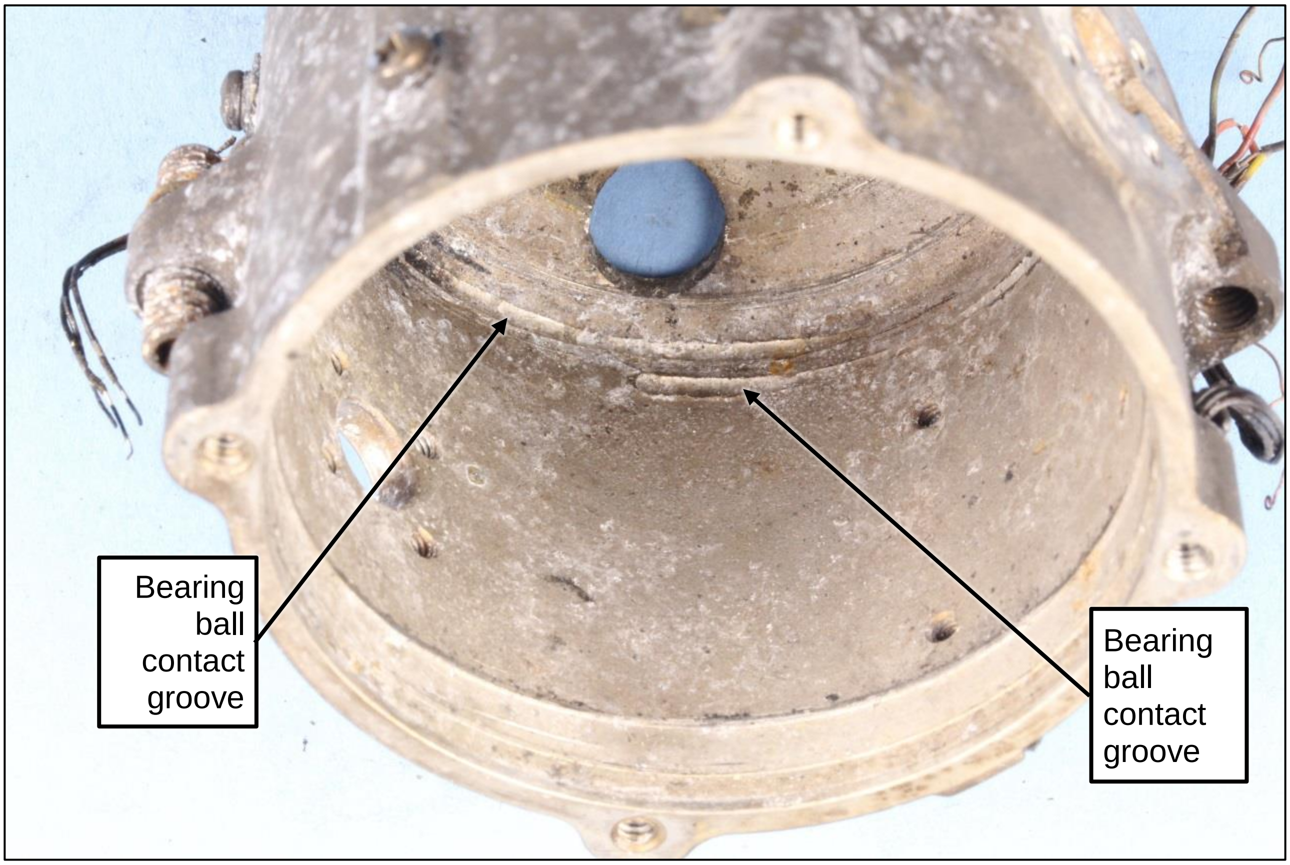
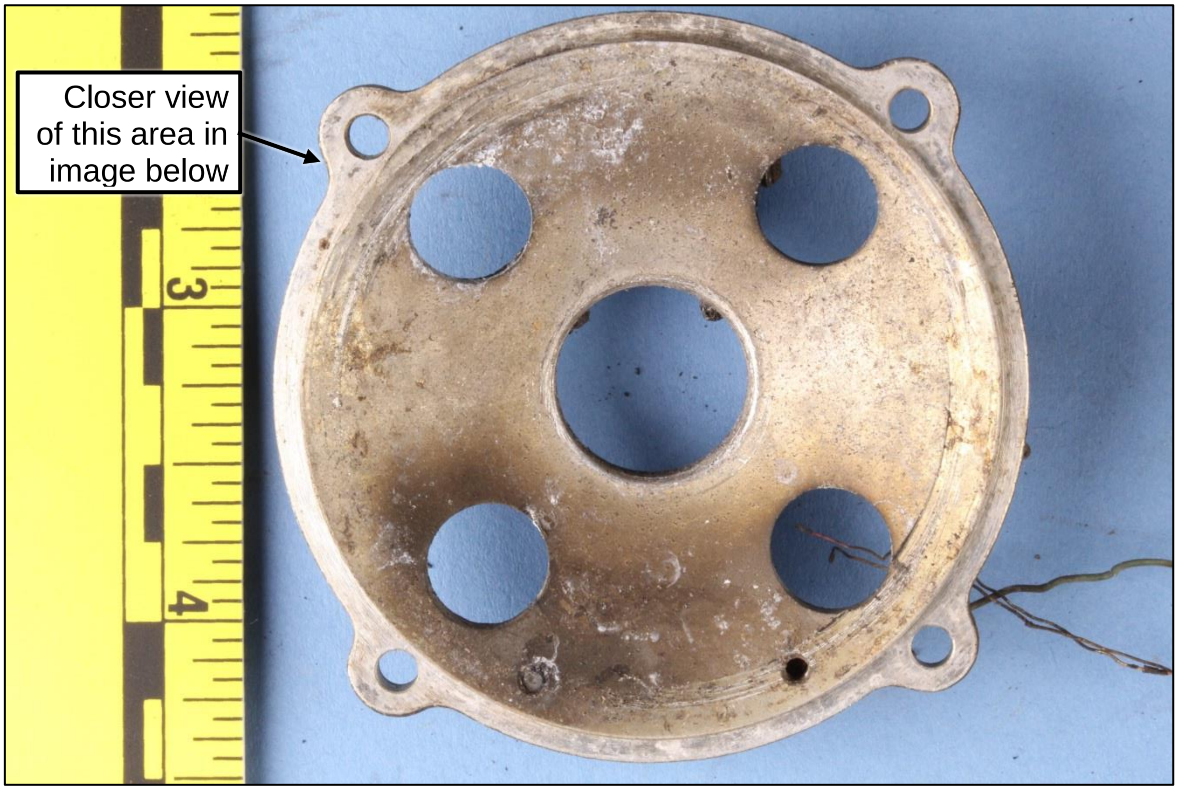


Figure 6. Interior surface of the inner gimbal housing showing bearing ball contact grooves near the left end of the housing.



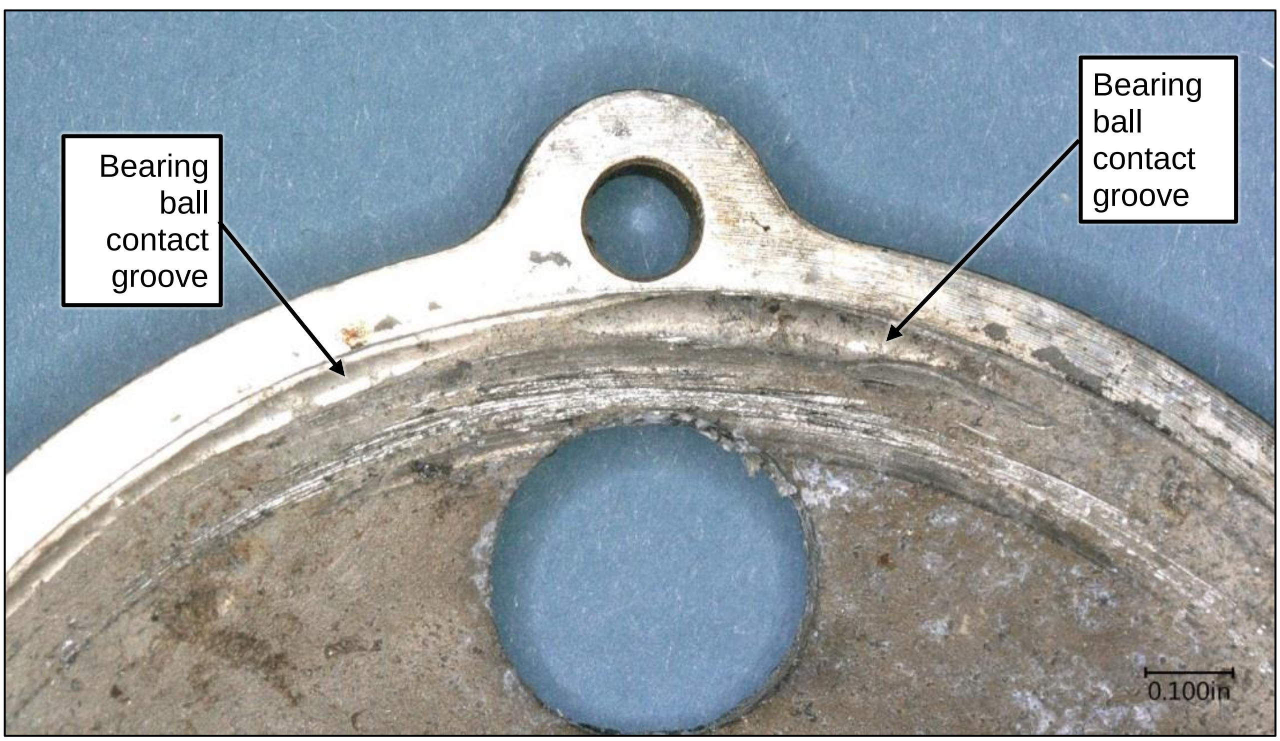
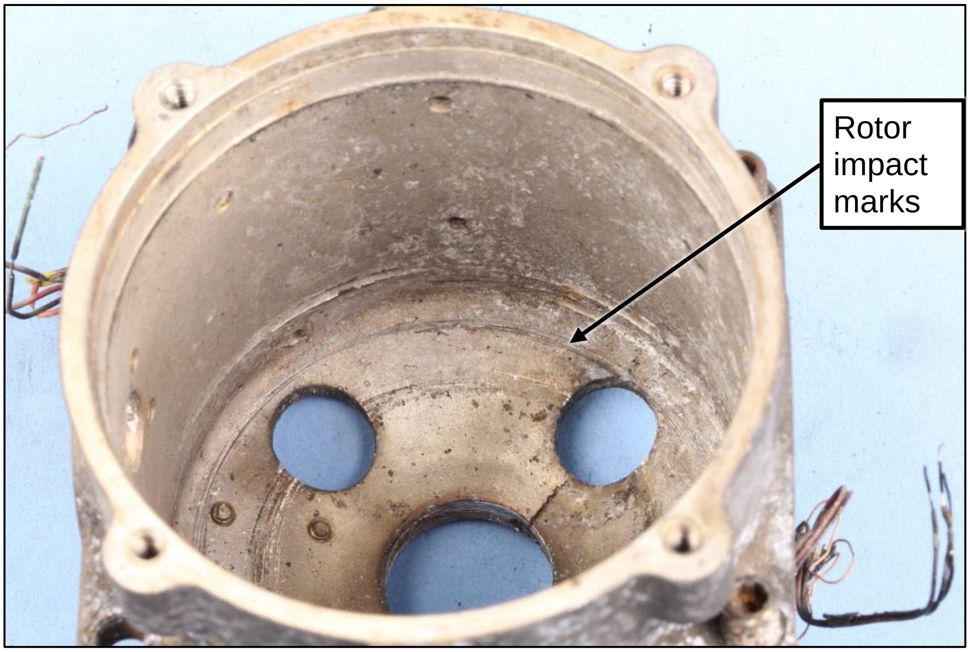


Figure 7. Views of the interior face of the inner gimbal housing cover showing grooves around the edges of the cover consistent with bearing ball contact.



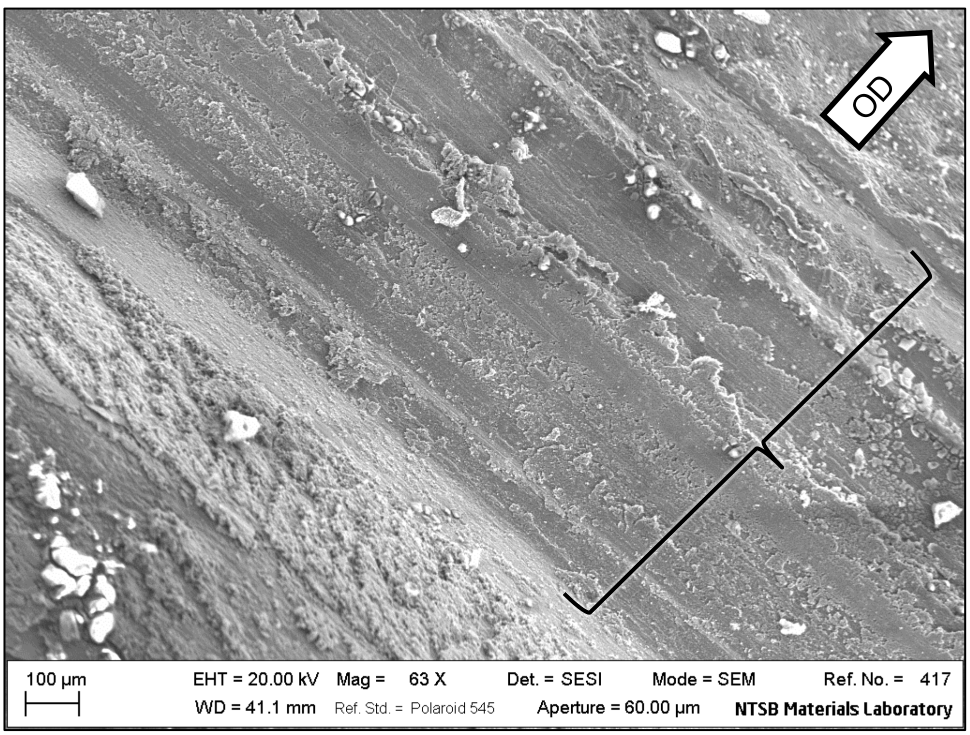


Figure 8. Impact marks on the inner gimbal housing corresponding to contact with the outer diameter edge of the rotor. Bracket in the SEM image (lower image) indicates area of multiple contacts.

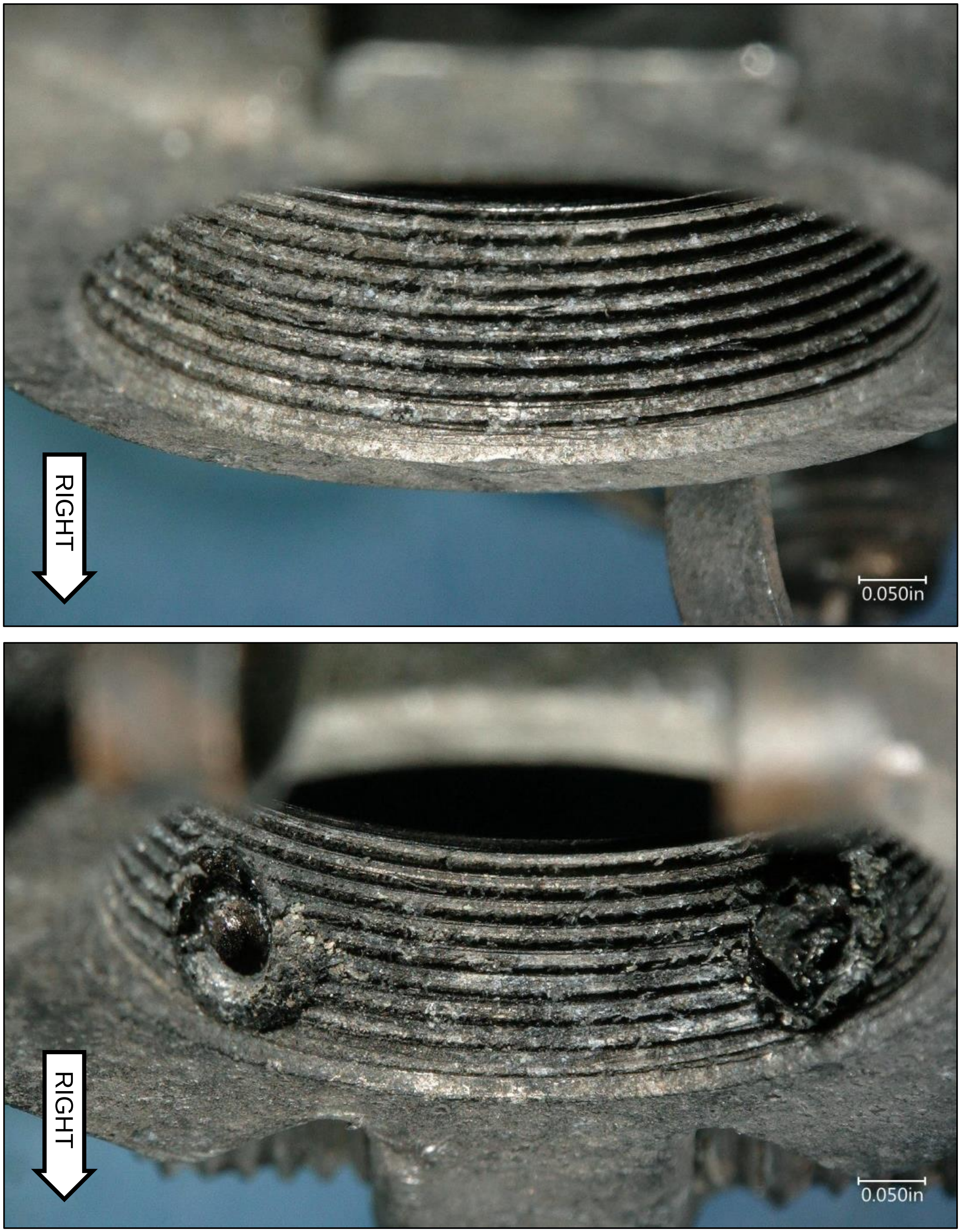


Figure 9. View of intact rotor plug attachment threads on the inner gimbal housing cover.

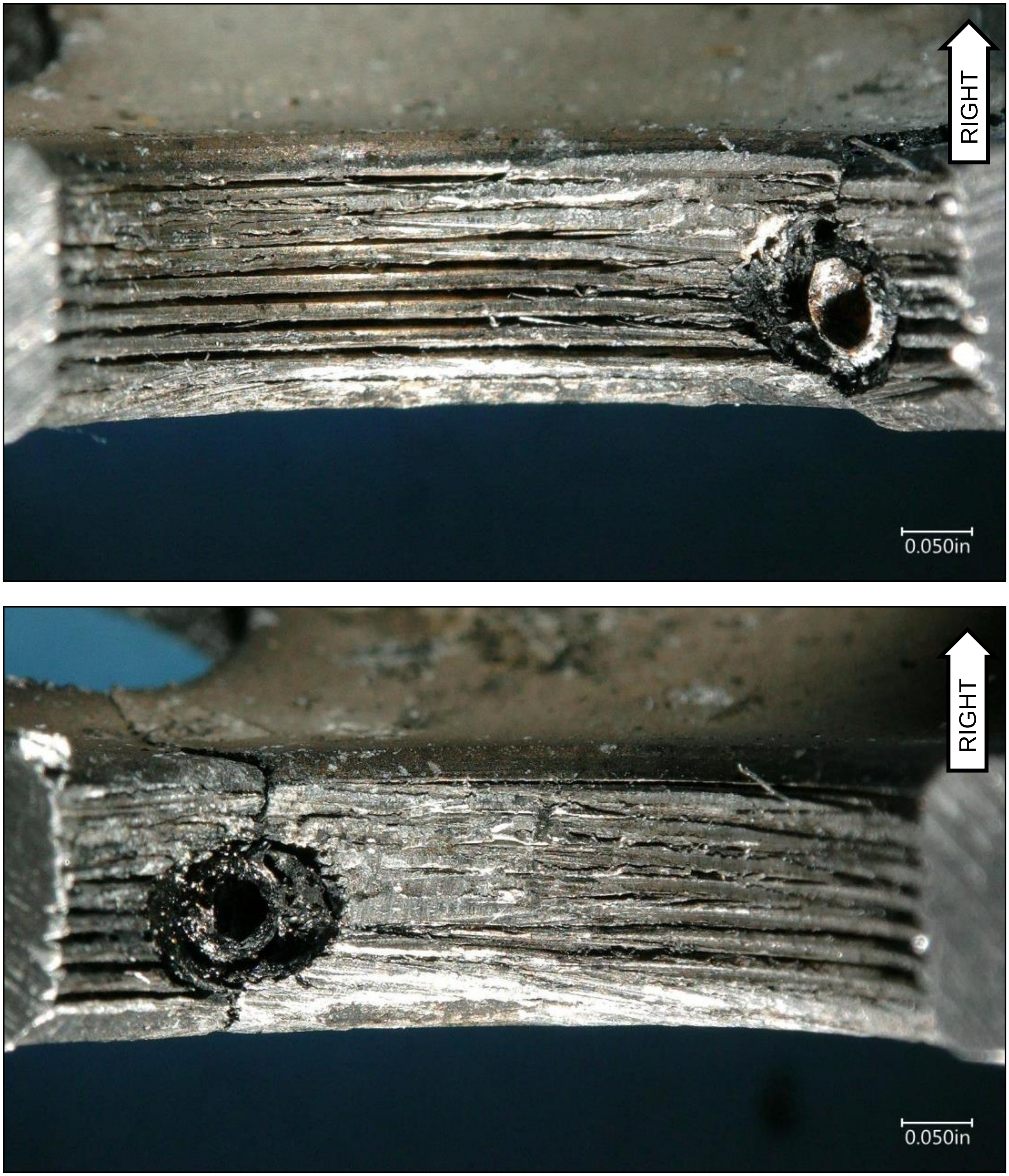
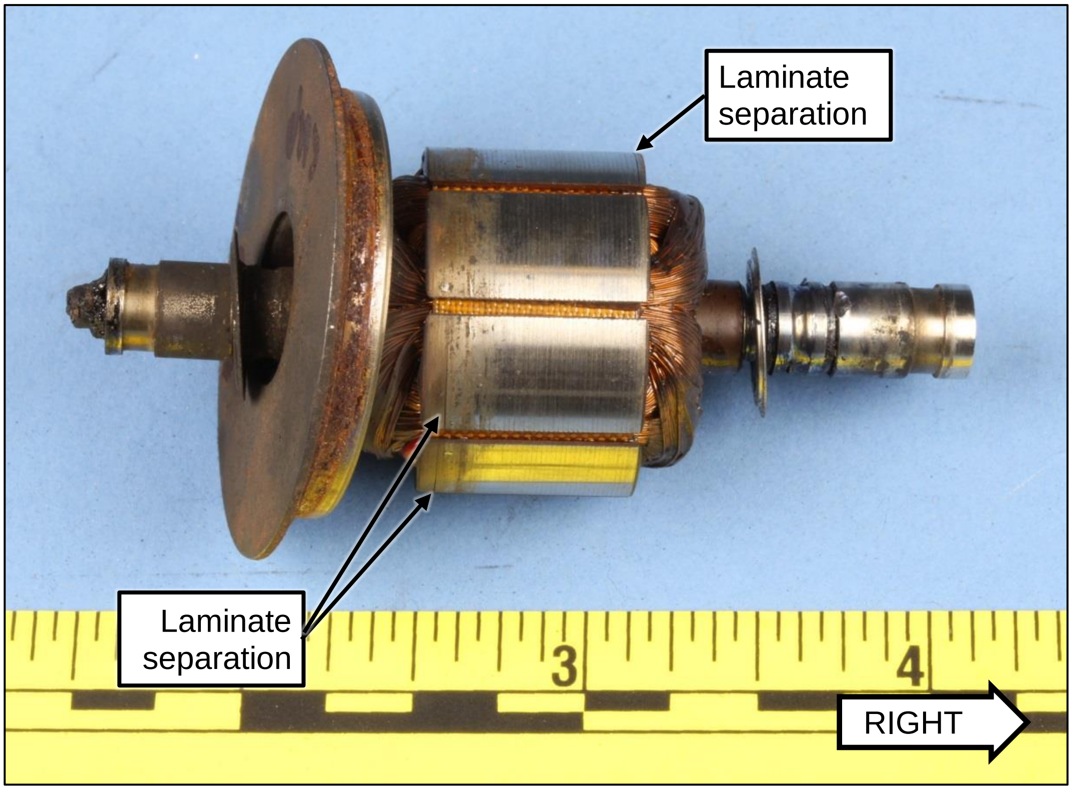


Figure 10. Thread damage on the rotor plug attachment threads of the inner gimbal housing.

Figure 11. Close view of bearing balls that fell out when disassembling the inner gimbal cover and the rotor assembly from the inner gimbal housing.



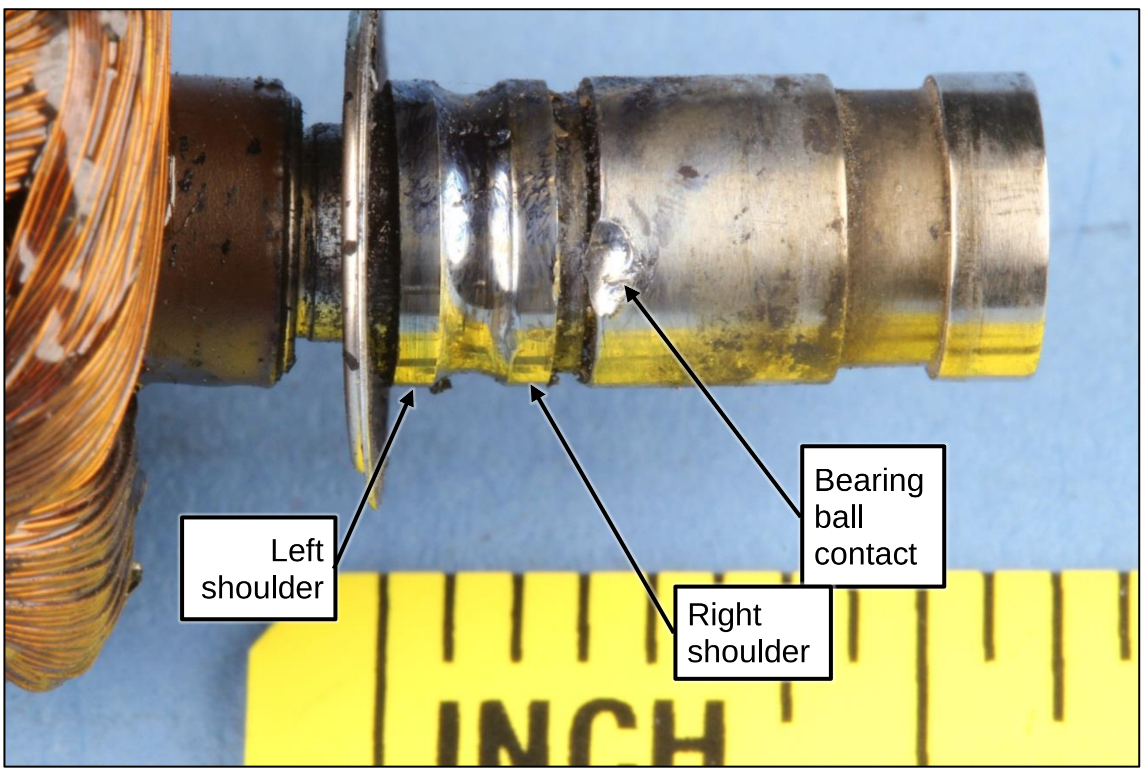


Figure 12. Overall view of the stator assembly (upper image) after removal from the rotor with a closer view of the bearing inner race and preload sleeve at the right end of the stator shaft (lower image).

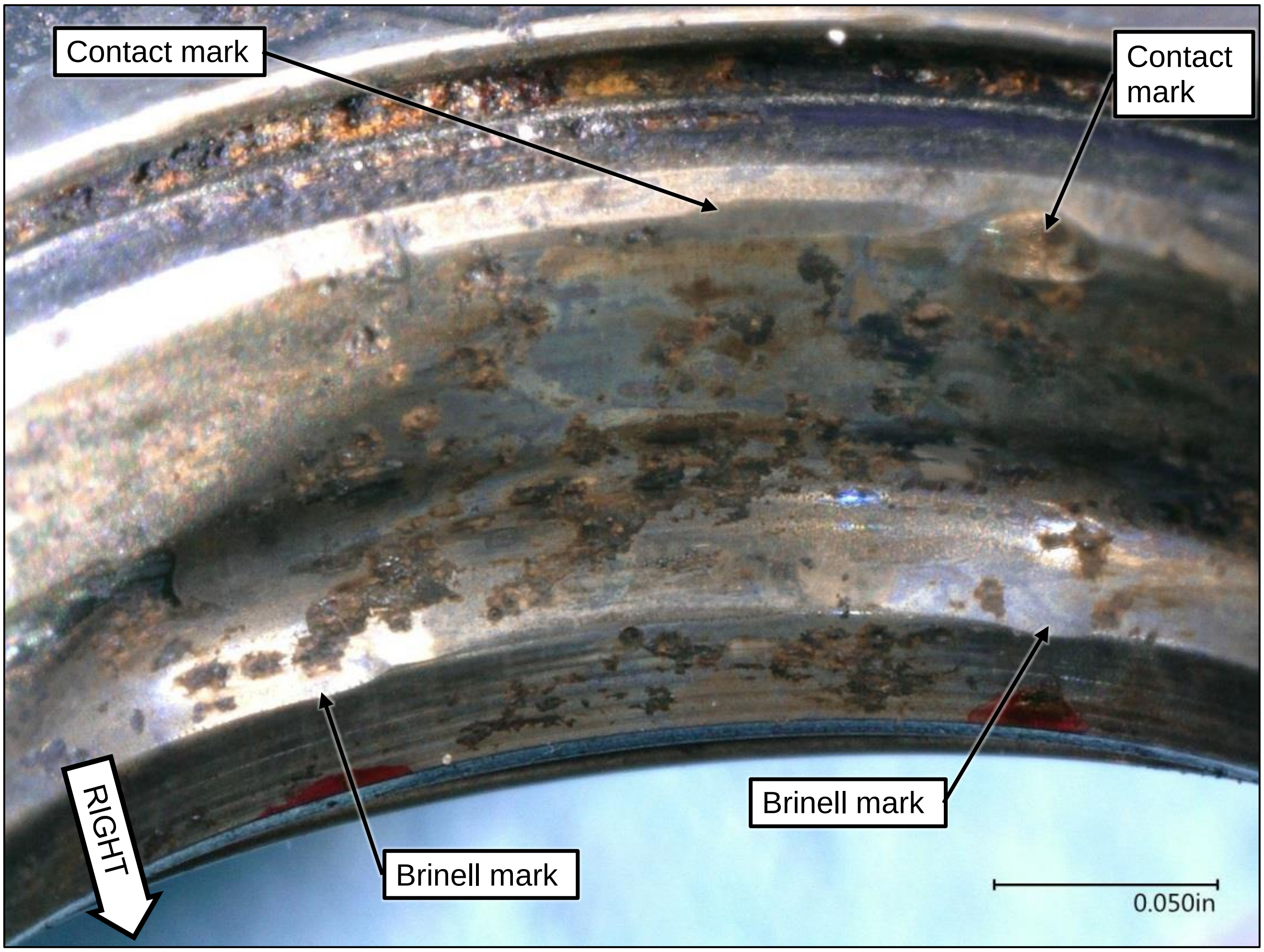


Figure 13. Close view of the left bearing outer race. Two of the eight equally-spaced brinell marks observed on the outer race are indicated.

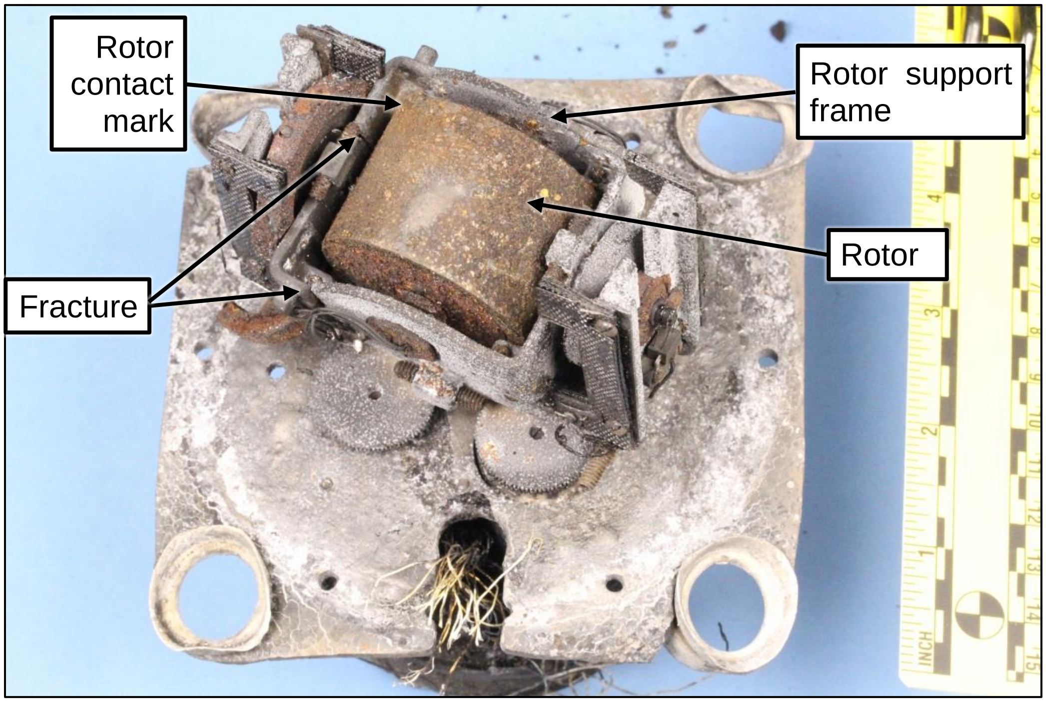


Figure 14. Overall view of the turn gyro after the gyro assembly was separated from the base and after the cover was removed.

Figure 15. Sliding contact mark on the rotor support frame corresponding to contact with the edge of the rotor at the location indicated in the previous figure.