NATIONAL TRANSPORTATION SAFETY BOARD

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

June 12, 2012

MATERIALS LABORATORY FACTUAL REPORT Report No. 12-042

A. ACCIDENT INFORMATION

Place	:	Las Vegas, Nevada
Date	:	December 17, 2011
Vehicle	:	Eurocopter AS350-B2, N37SH
NTSB No.	:	DCA12MA020
Investigator	:	Tom Jacky AS-40

B. COMPONENTS EXAMINED

Main Rotor Fore-Aft Servo with Input Rod and Linkage
Used Nuts and Bolts from N351VM and N340SH
New Exemplar Input Tube and Fastening Hardware

C. DETAILS OF THE EXAMINATION

The as-received fore-aft servo, s/n BX264 is displayed in the upper view of figure 1 with the upper end (servo side) of the input rod shown in the middle view along with an exemplar rod. The upper end of the input rod was reportedly found disconnected from the servo in the wreckage of the helicopter. None of the fastening hardware was located in the wreckage. The lower end of the fore-aft servo input rod was found attached to its linkage (not shown). The input rod was also separated near the middle. The input rod supplies the servo with commands from the pilot and connects to the servo at the clevis area as denoted in the upper view of figure 1.

The illustrated parts catalog for the AS350B2 lists the input rod to fore-aft servo fastening hardware as;

bolt	p/n 22731BC060020M,
washer	p/n 2311AF060LE
castelated nut	p/n ASNA0045-060BCL and
pin, split	p/n 23310AA015015L

Figure 2 shows the normal arrangement of fastening hardware between the input rod (rod end fitting only shown) and the servo clevis using exemplar hardware. The bolt has a 6 mm diameter shank with a 20 mm grip length and drilled 1.0 threads per millimeter threads. The washer has an approximate 12 mm outer diameter and is placed under the nut for assembly. The nut is castellated (slotted) with a full-circle nylon locking element in the castellations. The split pin engages the nut slots and the hole drilled in bolt threads. All components are specified to be cadmium plated steel.

The bolt specification, NF L22-731, lists the bolt material as 35 NC 6 alloy steel. The Standard Practices Manual[1] lists the ultimate tensile strength of the 35 NC 6 alloy steel as 880 MPa to 1080 MPa (128 kpsi to 156 kpsi).

Per the Eurocopter Standard Practices Manual[2] the nut is installed on the bolt and torqued to the minimum specification. The bolt is further tightened (up to the maximum specified) until the hole in the bolt threads aligns with a slot on the nut. The split pin is then inserted through the nut and bolt and the tails are bent 90 degrees or more. The aircraft Maintenance Manual[3] lists the bolt / nut installation torque as 0.2 to 0.7 daN-m (18 to 61 in-lbf).

Both the input rod and servo were heavily sooted and discolored consistent with exposure to fire debris and elevated temperatures. Additionally, the paint on the input rod was mostly missing with the remaining paint completely charred. No indications of melting or incipient melting was noted on the aluminum tubular section The upper portion of the rod was heavily deformed and crushed nearly flat in the middle, as shown in the lower view of figure 1. The rod was fractured through the large diameter tubular section about 330 mm (13 inch) from the top locking nut. Magnified examinations of the fracture revealed slanted fractures and accompanying deformation consistent with a predominant tensile overstress separation with some bending deformation.

Figure 3 shows left and right side views of the input rod clevis area of the as-received servo. As can be seen in the upper view, the left side of the servo was partially covered by previously molten aluminum. The flow pattern of the aluminum indicates that it was deposited onto the servo while molten and then solidified in-place. The deposited aluminum covered the fastener hole in the left side tang of the input rod clevis. As-received the right side hole was unobstructed as shown in the lower view. However, the bore was partially covered with light tan-colored powdery deposits as found elsewhere on the exterior of the servo, as shown in figure 4. Minor dents and dings were visible in the lower edges of the clevis tangs as indicated by arrows in figure 4.

The previously molten aluminum was easily removed by hand from the left side clevis tang. The clevis area, including the bores, was then lightly wiped with a dry cloth to remove loosely adherent fire debris. The surfaces showed purple to stray colored patterns consistent with exposure to elevated temperatures. The cleaned outer surfaces of the clevis tangs are displayed in figure 5.

The clevis surfaces also showed faint concentric patterns around the fastener holes consistent with previous contact by fastening components. The outboard surface of the right side tang had a pattern about 9.3 mm (0.366 inch) in diameter consistent

[1] MTC.20.02.05.404, 2009.11.23, "JOINING Assembly by bolts and nuts", Table 1.
[2] MTC.20.02.05.404, 2009.11.23, "JOINING Assembly by bolts and nuts", section 1.5.1.2
[3] Eurocopter Maintenance Manual 67.30.15.402 Revision date 2011-07-13.

with the underside of the specified bolt head, shown as the upper view in figure 5. Two additional faint concentric rings were also noted on this surface; one about 11.5 mm (0.453 inch) in diameter and the other about 16 mm (0.630 inch) in diameter. The outboard face of the left side tang had an 11.8 mm (0.465 inch) diameter pattern around the hole consistent with the size of the specified washer, as shown in the lower view of figure 5. Contact patterns were also noted on the inside surfaces of the clevis tangs consistent with the contact area of the rod end fitting on the input rod. Similar contact patterns were also visible on the used exemplar servo.

Both holes in the tangs appeared round and undeformed, measuring approximately 6.1 mm (0.240 inch) in diameter. Close inspection of the bore revealed smooth surfaces without any significant markings.

X-ray fluorescence spectroscopy[4] of the clevis identified the material as a nickel iron alloy. Hardness measurements averaged 30 HRC.

The servo side (upper) rod end fitting for the input rod is displayed in figure 6. One side of the fitting was partially covered in what appeared to be blackened and previously molten plastic-like material as shown in the upper view of figure 6. The charred material was tenaciously attached to the surfaces and partially blocked the bolt hole through the center of the fitting. The other face of the fitting was partially covered in dirt-like material as shown in the lower view of figure 6. As-received, the bearing in the fitting would not swivel or rotate with finger pressure.

Magnified visual examinations of the bearing head of the rod end fitting did not find any significant contact marks dents or dings.

Fourier-Transform Infrared spectroscopic analysis[5] (FTIR) of the plastic-like material on the rod end fitting in figure 6 identified it as poly(lauryllactam), a semi-crystalline polyamide commonly known as Nylon 12, see figure 7.

[4] Thermo Scientific Niton XL3t-980 x-ray fluorescence (XRF) alloy analyzer
[5] Varian Model 610-IR Microscope

1. Exemplar Hardware

Two exemplar used nuts and bolts (6 mm) and several exemplar new nuts and a bolt were received for testing and examination, as shown in figure 8. One used exemplar was from an aircraft with 7,308.3 service hours and the other was from an aircraft with 16,415.2 service hours. It is unknown if the received bolts were original to the aircraft.

The Eurocopter Standard Practices Manual[6] lists minimum locking torques for nuts 10 mm and larger but not for smaller. Instead the manual states:

Prior to re-using the nuts:
- *- Make sure nylon lock is not excessively damaged.*
- *- Fit the nut by hand:*
    - *If nut can easily be tightened by hand, it is to be discarded*
    - *If nut is hard and cannot be tightened by hand, it may be re-used.*

In the laboratory, the used nuts could be easily and fully tightened or loosened on the accompanying bolts with finger pressure. Torque measurements found that the turning resistance of the nuts on the bolts was approximately 1 in-lbf or less in both directions.

For comparison of locking torques, the peak tightening (on) and peak loosening (off) torques were measured on four new test nuts (#1-#4). Measurements were made by fixing a calibrated[7] dial indicating torque wrench in a fixture and tightening and loosening the new nut-bolt combination while recording the peak torque in each direction. The nuts were tightened with a socket wrench and appropriate sockets until all bolt threads were engaged by the test nut. The nuts were loosened until the locking portions of the nuts disengaged. Turning of the nut was performed in steps of approximately 90 degree each. The tightening–loosening (on-off) cycle was repeated at least 10 times for the four test nuts. The individual test results are presented in the following table along with the averaged readings of all nuts for each on-off cycle. For the number 3 test nut, torque measurements were also made after 15 and 20 on-off cycles.

The averaged torque data for each on-off cycle are presented in figure 8. As shown, the first application of the nut resulted in the highest resistance torque with generally equal or lower torque values with successive on-off cycles. For the majority of valid instances, the tightening torque values were equal to or higher than the loosening torques for a particular nut.

[6] MTC.20.02.05.404, 2009.11.23, “JOINING Assembly by bolts and nuts”, section 1.4.2 “Criteria for re-using dual locking nuts”.
[7] Calibration was performed by testing the torque wrench with a know weight suspended at a measured distance and comparing the dial indication to the calculated value.

Turning Resistance Torque Measurements (inch-pounds)										
Cycle	#1 On	#1 Off	#2 On	#2 Off	#3 On	#3 Off	#4 On	#4 Off	Avg On	Avg Off
1	5.0	4.0	3.5	4.0	4.0	4.0	5.5	4.5	4.50	4.13
2	7.0*	4.0	3.0	2.5	4.0	3.0	3.0	3.0	3.33	3.13
3	4.0	5.0	3.0	2.0	3.0	2.5	4.5	3.0	3.63	3.13
4	4.5	3.0	3.0	2.0	3.0	2.5	3.5	3.5	3.50	2.75
5	3.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	2.88	2.75
6	3.5	2.5	3.0	2.0	3.0	3.0	3.0	2.5	3.13	2.50
7	3.5	5.5*	2.0	2.0	2.5	2.0	3.0	2.5	2.75	2.17
8	4.0	3.5	2.0	1.5	2.5	2.0	3.0	1.5	2.88	2.13
9	4.5	3.5	3.0	2.0	2.0	2.5	3.0	2.0	3.13	2.50
10	4.0	2.0	2.0	2.0	2.0	2.0	3.0	2.5	2.75	2.13
11	2.5	2.0								
12	2.0	2.0								
13	2.5	2.0								
14	2.0	2.0								
15							3.0	3.0		
16										
17										
18										
19										
20							3.0	3.0		
*** Not used in average due to testing fault.**										

To test the installation procedures, a test setup using the accident clevis with new fastening hardware, rod end fitting, bolt and nuts was constructed. New nuts were tightened onto the new bolt to the minimum specified torque 18 in-lbf. The nuts were then further tightened until the nearest slot aligned with the hole in the bolt threads and the peak torque recorded. This was two times for each nut. The used nut and bolt from N351VM were also tested.

For two of the new nuts, 50 in-lbf were required to align a nut slot with the bolt's hole after initial tightening. For the 3rd nut test nut the necessary alignment torque exceeded the maximum allowed torque of 61 in-lbf before a slot could be aligned with the hole. For the nut and bolt from N351VM, in one test the initial torque application of 18 in-lbf resulted in alignment of a slot and the hole without additional tightening rotation was needed. The second test only required an additional 9 in-lbf (total torque 27 in-lbf).

Joe Epperson
Senior Metallurgist

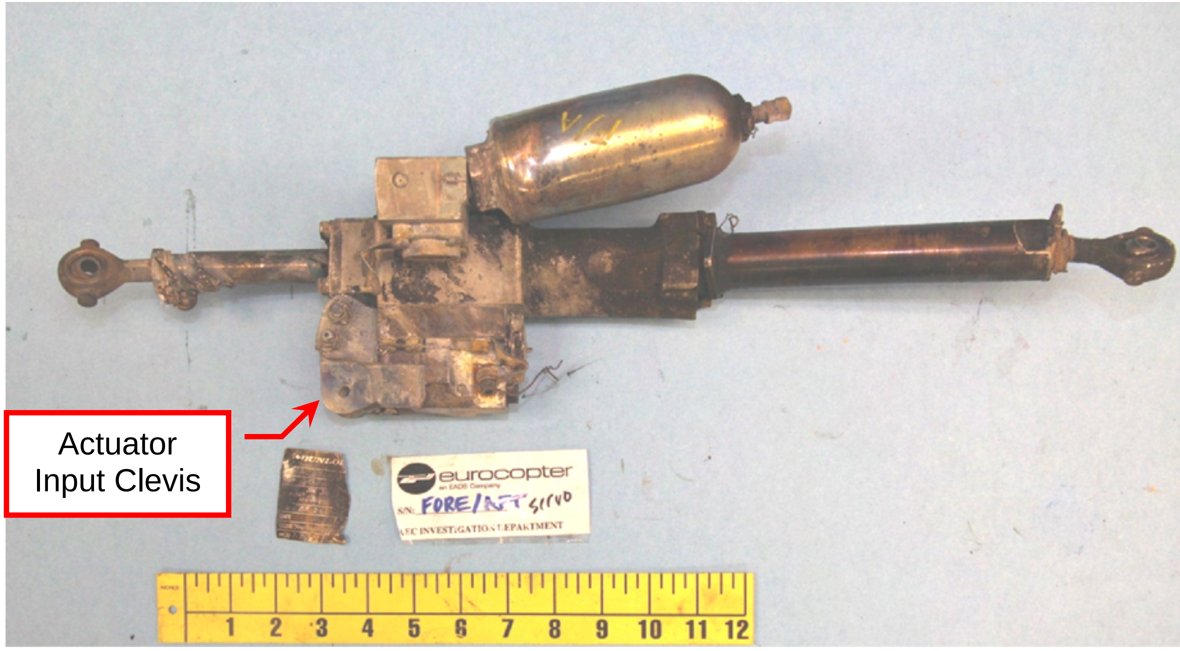


Figure 1. An overall view of the as-received fore / aft servo at top with the upper end of the input rod shown below next to an exemplar new input rod.

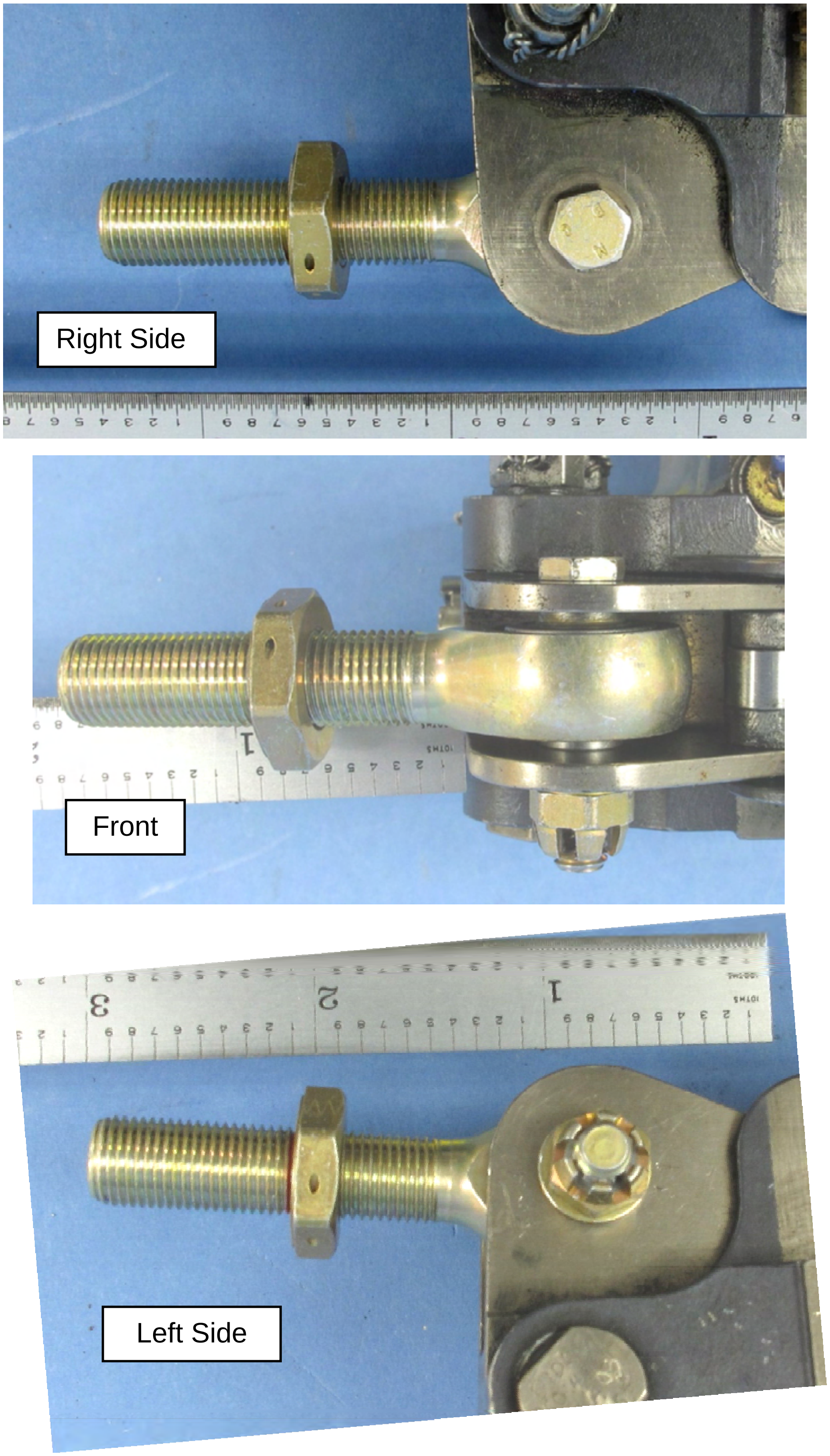


Figure 2. Three views typical arrangement of the input tube to the servo clevis using the accident clevis and exemplar hardware. Split pin not installed.

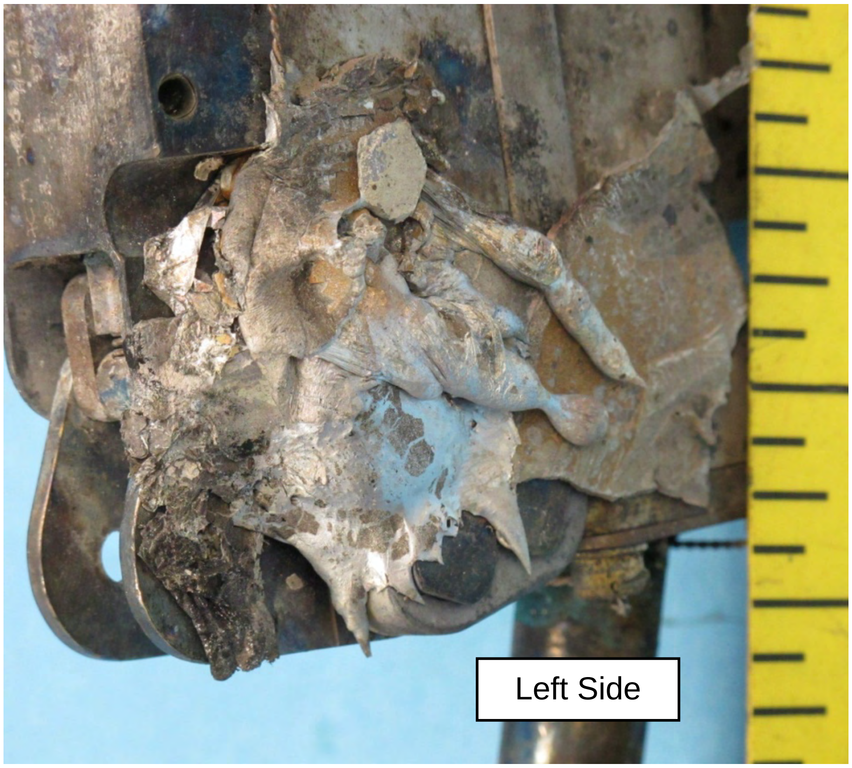
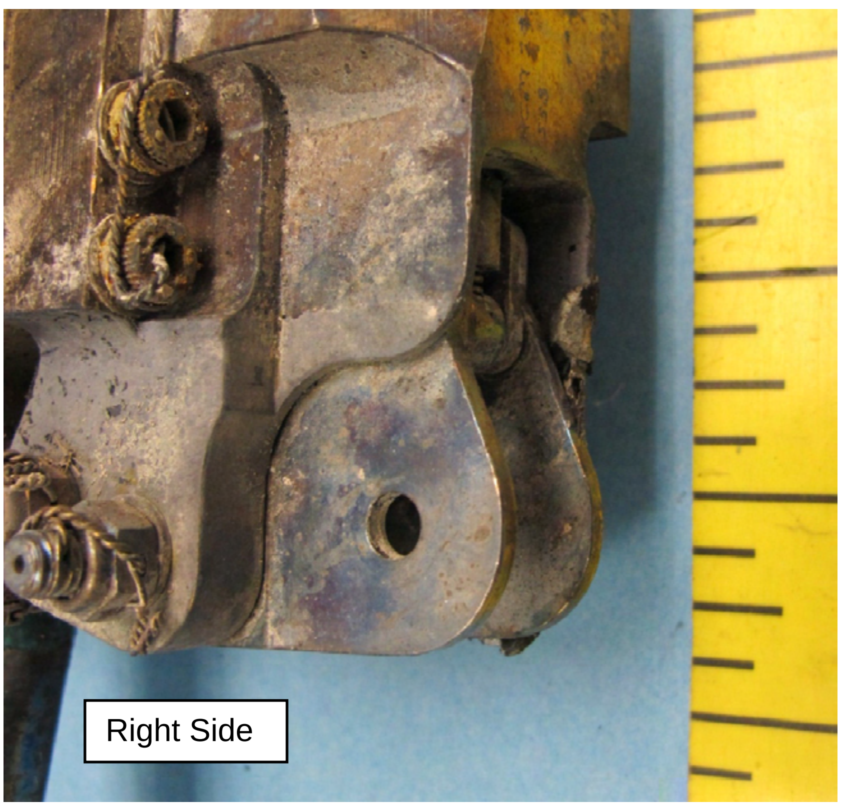


Figure 3. Images of the clevis are of the as-received fore/aft servo, left side at top, right side below.



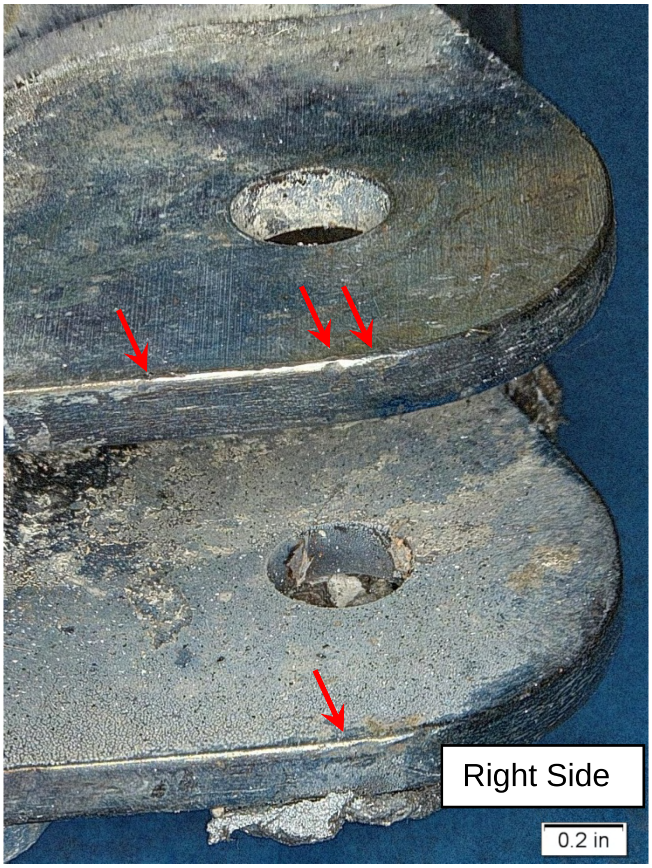


Figure 4. The left and right side clevis tangs showing powdery deposits in the bores. Minor dents in the lower edges of the tangs are denoted by arrows.

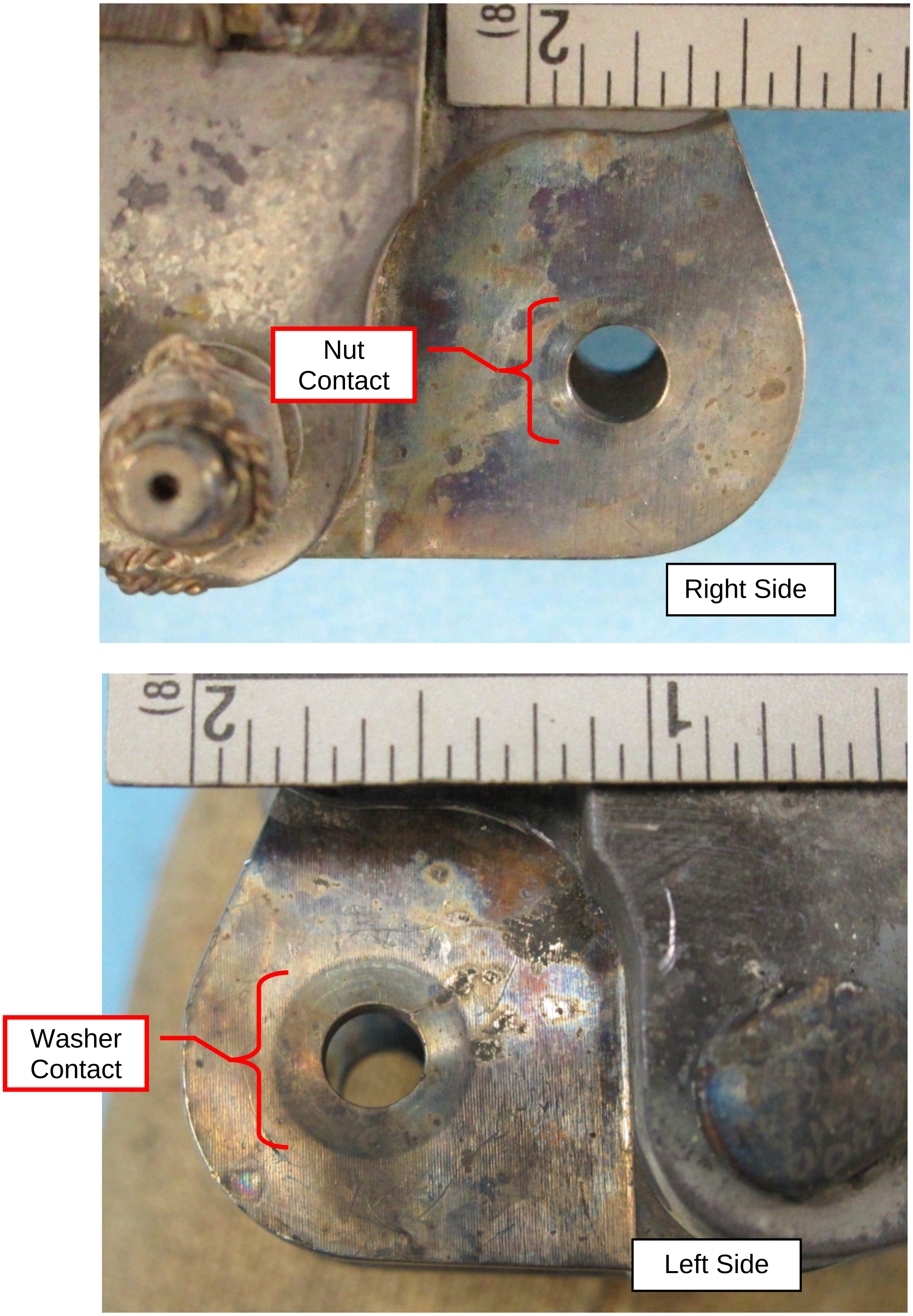


Figure 5. The outer surfaces of the cleaned clevis tangs showing the heat tinting (straw to purple colors) and contact patterns from fastening hardware, nut on right side and washer on left side.

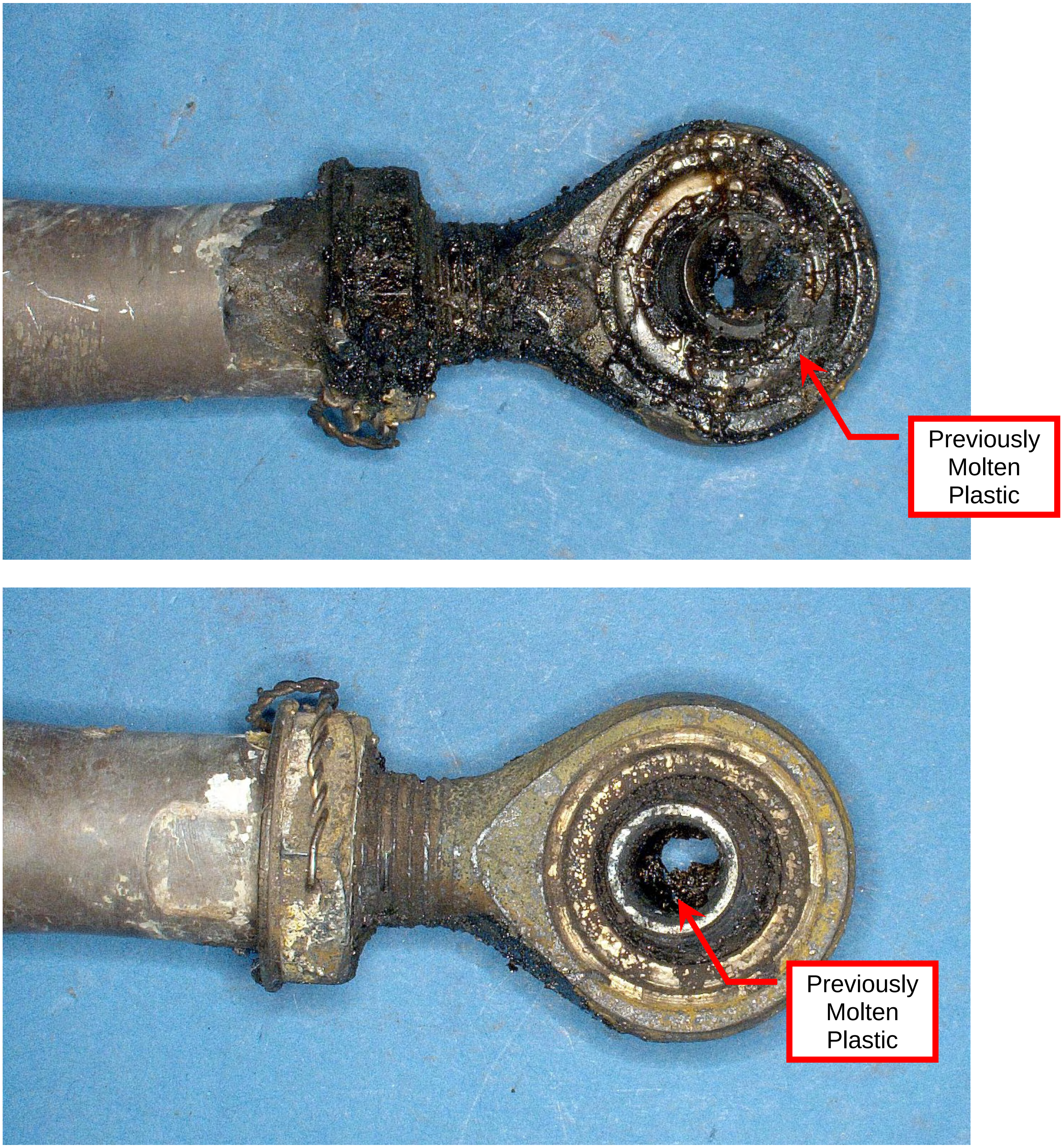


Figure 6. Both sides of the input rod upper rod end fitting showing the black previously molten Nylon 12 material on one side (top) partially blocking the bolt hole (bottom).

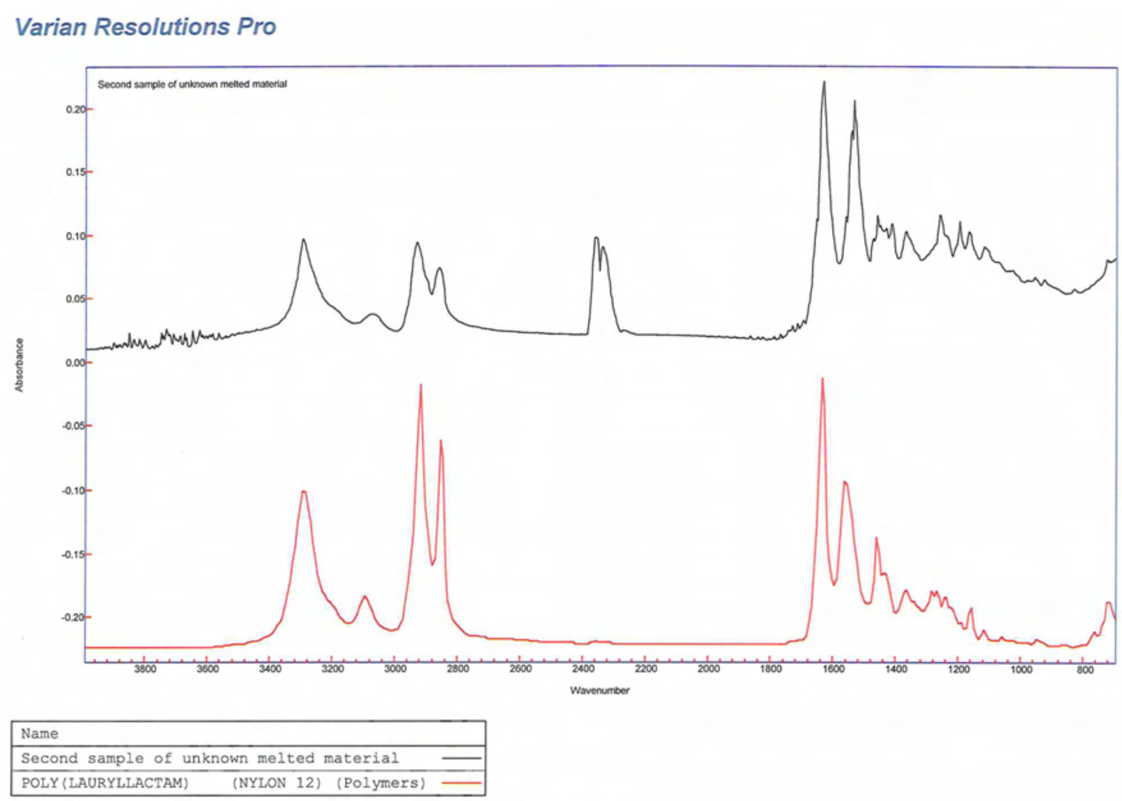


Figure 7. FTIR spectrum (upper black line) of the black material from the rod end fitting shown in the upper view of figure 6 compared to a standard spectrum for Nylon 12 (red line below).

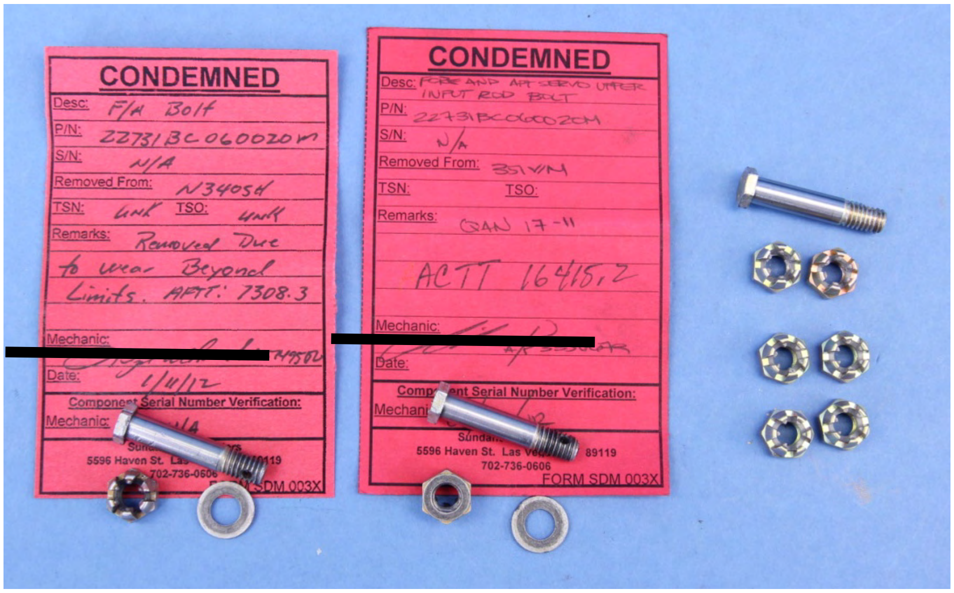


Figure 8. The exemplar hardware. Items removed from aircraft at left. New hardware at right.

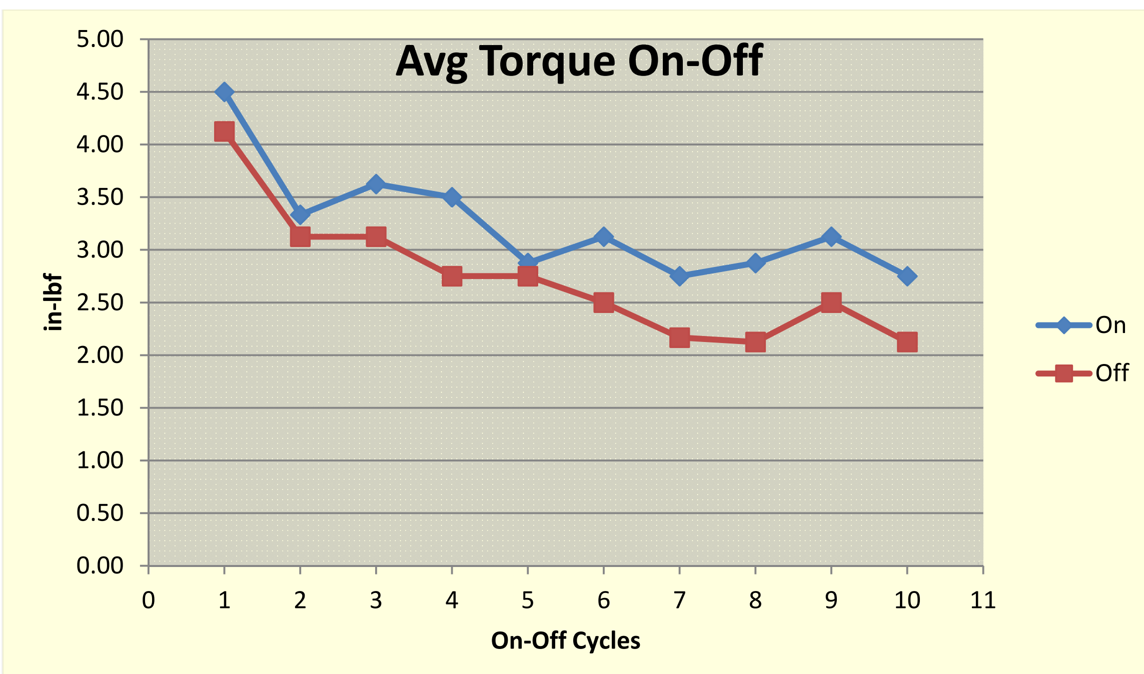


Figure 9. Chart of average peak torques for new nuts during on and off cycles.