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

October 21, 2020

MATERIALS LABORATORY FACTUAL REPORT Report No. 50-051

A. ACCIDENT INFORMATION

Place	:	Benbrook, Texas
Date	:	February 12, 2020
Vehicle	:	Cessna 560, N654CE
NTSB No.	:	CEN20LA082
Investigator	:	Michael Hodges, ASI-CEN

B. COMPONENTS EXAMINED

The following pieces from the right-side engine:

1) One piece of an upper cowl door;
2) One piece of a lower cowl door with piece of seal assembly;
3) 29 quarter-turn studs from the forward attachment flange;
4) 27 grommets and snap rings from the forward attachment flange;
5) Six quarter-turn stud receptacles from the forward attachment flange;

C. DETAILS OF THE EXAMINATION

1. Description of hardware and its operation

Pieces of an upper cowl door, lower cowl door, seal assembly, and quarter-turn fastener assemblies (also known as camlocks), used to secure the forward ends of the right-side engine cowl doors, were received by the NTSB Materials Laboratory for examination as shown below in figures 1a – d. The fastener system consisted of four components: a quarter-turn stud assembly, a grommet, a snap ring, and a receptacle. In the as-installed configuration, the grommets (see the exemplar in figure 2) were installed in a series of 32 dimpled holes along the forward edges of the two cowl doors and secured using snap rings on the inner side of the panels.[1] The stud assemblies (see also the exemplar in figure 2) consisted of a shank with a Phillips head at one end and cross-pin at the other. Captured between the head and the cross-pin were a spring and a spring cup. To insert the stud through the grommet, a tool was used to grab the rim of the spring cup and pull it against the underside of the stud head. One side of the cross-pin was passed through the grommet opening and the stud was tilted to pass the other side of the cross-pin through the opening. Once the tool was removed, the stud was captured in the grommet by the cross-pin on one end and the rim of the spring cup on the other end.

[1] The same fastener system was also used along the longitudinal direction where the doors met and around the aft end of the cowl doors.

The receptacles (see figures 1d, 3, and 4) were installed on the backside of the forward attachment flange (part of the engine inlet) with rivets. The receptacles consisted of a floating cup in a cage with a slotted hole at the bottom of the cup. In the as-installed configuration, the stud's cross-pin was inserted through the slot and the stud was turned clockwise. As the stud was turned, each arm of the cross-pin would slide along a helical ramp that passed over a raised bump and into a detent on the backside of the receptacle, as indicated in figure 4c. The appropriate stud length is determined by the total thickness of the panel assembly. If the stud grip length is too short, the cross-pin cannot pass over the bump. If the grip length is too long, the raised bump cannot stop the stud from rotating out of the locked position. Stud lengths come in 0.03-inch increments as indicated in table 1 below. For convenience, dash numbers will be used to refer to their respective stud lengths. The total material thickness is also given in the table below. Total material thickness is the recommended net thickness of the stack of panels sandwiched between the receptacle and the grommet. In this application, it is assumed that the top of the grommet is flush with the outer surface of the cowl door.

Table 1: Stud dash numbers and associated dimensional data.

Stud Dash Number	Total Stud Length, inch	Total Material Thickness (with Floating Receptacles), inch
-2	0.72	0.051 – 0.080
-3	0.75	0.081 – 0.110
-4	0.78	0.111 – 0.140
-5	0.81	0.141 – 0.170
-6	0.84	0.171 – 0.200
-7	0.87	0.201 – 0.230
-8	0.90	0.231 – 0.260

According to the Cessna 560 Illustrated Parts Catalog, the forward ends of the cowl doors were fastened using two lengths of studs. Twenty-eight of the studs were designated as S3412-103, which has the same stud length and total material thickness as the "-3" stud in the table above. According to a Textron Air Safety Investigator, the cowl doors and attachment flange were both nominally 0.040-inch thick panels (with additional unspecified thickness for primer and paint layers). In two locations around the flange, there were splice plates that were also nominally 0.040-inch thick. At each of those locations, the catalog specified the use of two S3412-104 studs, which have the same stud length and total material thickness as the "-4" stud in the table above.

The grommets are also available in different heights for different outer panel thicknesses. According to the Cessna 560 Illustrated Parts Catalog, the grommet part number for the cowl doors was S2319-63, which had a specified total height between 0.183 inch and 0.191 inch.

2. Examination of accident aircraft hardware

A piece of the upper cowl door, the lower cowl door, and quarter-turn fastener assemblies (also known as camlocks), were received by the NTSB Materials Laboratory for examination as shown below in figures 1a – d. The piece of the upper cowl door (see figure 1a) was the only piece of either cowl door that remained attached to the aircraft. The piece of the lower cowl door (see figure 1b) had impacted and wrapped around the inboard section of the right-side horizontal stabilizer. The fracture surfaces of both cowl pieces were examined and exhibited 45° slant fractures and occasionally 90° fractures with transverse shear lines that were consistent with a mixture of tensile and shear overstress.

The forward attachment flange fastener assemblies that were received by the Materials Lab are shown in figures 1a, c, and d. In the field, each receptacle and its associated hardware were given a number from 1 to 32. When viewed from the aft end of the engine looking forward, the numbering was started at the 9:00 position (the inboard side of the engine) and proceeded clockwise. Using this numbering system, the studs, grommets, and snap rings for receptacles 2 – 9 were still attached to the upper cowl door and are shown in figure 1a. The studs, grommets, and snap rings for receptacles 1 and 10 – 25 were sent without their corresponding receptacles and are shown in figure 1c. On scene examination of the aircraft indicated that the stud at receptacle 26 was missing its grommet and snap ring as seen in figure 3a and 1c. Receptacles 27 – 32 and their associated hardware were sent to the lab and are shown in figure 1d. On scene examination of the aircraft indicated that the stud at receptacle 28 was missing its grommet and snap ring and that the stud, grommet, and snap ring were all missing from receptacle 29, as shown in figures 3b and c, respectively. Those pieces were not recovered and were not examined by the lab.

The hardware was examined for part numbers or other identifying marks. The receptacles were stamped with the letter “M” on the backside. The stud heads were labelled with dash numbers and the dash numbers varied from position to position as shown in table 2 below. According to a Textron Air Safety Investigator, the numbers 10/11 and 22/23 receptacles are located at the splice plates referred to above. Outside of the splice plates, there were twenty “-3” studs, six “-4” studs, and one “-6” stud (plus the one unknown at receptacle 29). Across the two splice plates there were three “-7” studs and one “-6” stud. The length of a “-3”, “-4”, “-6” and “-7” stud was measured with a micrometer and each corresponded to the length given in table 1 above.

As shown in table 2, the grommets were all labelled as “MILSPEC GS” except for the grommets at receptacles 6 and 10, which were labelled “G” and “MILSPEC HS” instead. According to Milspec product information, GS-type grommets are nominally 0.187 inch in height and HS-type grommets are nominally 0.204 inch in height. The height of a GS grommet was measured with a micrometer and measured 0.189 inch in height while the height of the HS grommet measured 0.205 inch in height.

The number 29 receptacle was examined for any notable features, but none were found. Top-down, underside, and sideview images of the receptacle are shown in figures 4a – c, respectively. The interior of the number 29 receptacle cup is shown in figure 5a and closer view of the cup backside is shown in figure 5b. Deformation and wear of material was observed at the edge of the slot where the cross-pin passed through the

Table 2: Stud dash numbers, nominal studs lengths, and grommet ID marks for the receptacles on the forward attachment flange.

Receptacle Number	Stud - DASH-number	Nominal Stud Length, inch	Grommet ID
1	-3	0.72	MILSPEC GS
2	-4	0.75	MILSPEC GS
3	-4	0.75	MILSPEC GS
4	-3	0.72	MILSPEC GS
5	-3	0.72	MILSPEC GS
6	-3	0.72	G
7	-3	0.72	MILSPEC GS
8	-3	0.72	MILSPEC GS
9	-3	0.72	MILSPEC GS
10 (splice plate)	-7	0.84	MILSPEC HS
11 (splice plate)	-6	0.81	MILSPEC GS
12	-3	0.72	MILSPEC GS
13	-3	0.72	MILSPEC GS
14	-3	0.72	MILSPEC GS
15	-3	0.72	MILSPEC GS
16	-3	0.72	MILSPEC GS
17	-3	0.72	MILSPEC GS
18	-3	0.72	MILSPEC GS
19	-3	0.72	MILSPEC GS
20	-3	0.72	MILSPEC GS
21	-3	0.72	MILSPEC GS
22 (splice plate)	-7	0.84	MILSPEC GS
23 (splice plate)	-7	0.84	MILSPEC GS
24	-4	0.75	MILSPEC GS
25	-3	0.72	MILSPEC GS
26	-4	0.75	—
27	-4	0.75	MILSPEC GS
28	-3	0.72	—
29	?	—	—
30	-3	0.72	MILSPEC GS
31	-4	0.75	MILSPEC GS
32	-6	0.81	MILSPEC GS

base of the cup. The ramps and detents on the backside of the cup exhibited a rubbed appearance consistent with sliding contact.

The vertical walls of the slotted hole adjacent to the detent were examined for any deformation or contact damage as shown in figures 6a and 6b. The majority of the two vertical wall regions was still coated with white paint. On the side shown in figure 6a, the paint had chipped adjacent to the detent as indicated, but the metal surface exhibited a matte as-manufactured appearance. Another area, adjacent to the cup interior, exhibited removed paint and a rubbed appearance as indicated in the figure.

3. Additional measurements and testing

The receptacle 29 cup backside was measured for indications of wear of either the detent or raised bump using a laser scanner. Receptacle 29 and an exemplar receptacle were scanned with a tabletop coordinate measurement machine (CMM) with a laser scanner attachment and single point precision of 0.001 inch. The receptacles were scanned in two steps and the two scans were later merged. For the first scan, each receptacle was placed bottom-side up and clamped against a flat plate which served as a reference plane. For the second scan, the clamps were removed and the areas obscured by the clamps were scanned. The two scans were then aligned, merged, and converted into a mesh, the results of which are shown in figures 7a and 7b for the exemplar and receptacle 29, respectively. The scans were then used to measure the vertical distance from the reference plane to the tip of each stop, detent, and raised bump, as indicated in figure 7a. The tip/detent and bump/detent vertical distances were then calculated. The results are shown in table 3 below and are for information purposes only. The two sides of each receptacle were arbitrarily labelled 1 and 2.

Table 3: Measured attributes on the backsides of the exemplar receptacle and receptacle 29.

Receptacle / Side	Distance from reference plane to tip of stop, inch	Tip of stop to base of detent, inch	Tip of bump to base of detent, inch
Exemplar - side 1	0.552	0.111	0.025
Exemplar - side 2	0.553	0.112	0.027
Receptacle 29 - side 1	0.546	0.111	0.022
Receptacle 29 - side 2	0.551	0.112	0.028

The maximum and minimum distances from the tip of the stop to base of the detent were 0.112 inch and 0.111 inch, respectively; a difference of 0.001 inch. The vertical distances from the tip of the raised bump to the base of the detent measured 0.025 inch and 0.027 inch for the exemplar receptacle and 0.022 inch and 0.028 inch for receptacle 29.

Finally, the locking and unlocking torques of several studs from the forward attachment flange were measured and compared against a set of exemplar hardware. An aluminum plate was machined with through-holes for attaching an exemplar receptacle to the backside of the plate and for inserting a grommet through the topside of the plate above the receptacle cup. The plate was first milled until the total material thickness, measured from the top of the grommet to the underside of the plate, was 0.130 inch and later milled until the total material thickness was 0.085 inch, with measurements made at each plate thickness as described below. For each plate thickness, the receptacle was attached to the plate with machine screws. A stud was inserted through a grommet and then inserted into the hole above the receptacle cup. A torque gauge with a range of 0 lb-in to 20 lb-in and 0.1 lb-in resolution, attached to a data recorder, was then coupled to a Phillips head bit and the stud was repeatedly rotated back and forth between the locked and unlocked positions. The torque gauge/bit assembly was supported so as not to apply axial load to the stud during the measurement. The measurements are for information purposes only and the following limitations of the measurements should be noted:

1. There is no requirement for locking or unlocking torques;
2. The measurements were made on a single-piece solid plate and not a multi-panel stack;
3. Studs were selected from the accident aircraft with minimal damage but there still may have been some deformation of the cross-pins and spring cups;
4. The actual stack height on the accident aircraft likely differed from the test panel.

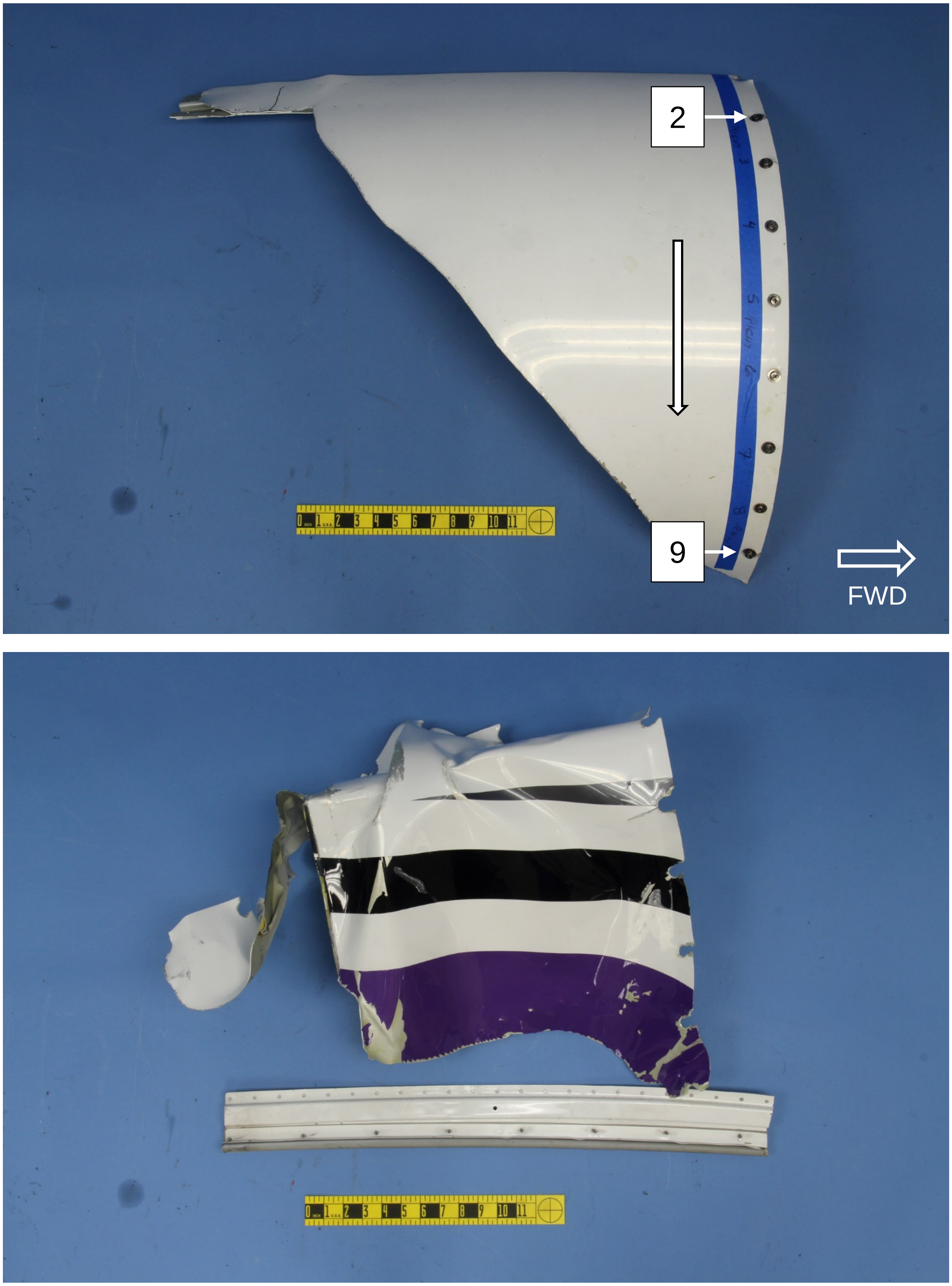
The results for the 0.085-inch thick plate are presented first followed by the results for the 0.130-inch thick plate. Figure 8a shows the locking and unlocking torque data for an exemplar S3412-103 stud, exemplar S2319-63 grommet and 0.085-inch thick plate. Over five cycles, the applied torque increased from 0 lb-in to a peak that ranged between 3.5 lb-in – 4.1 lb-in at which point the cross-pin crossed over the bumps into the detents and the applied torque was removed. During the unlocking phase, counterclockwise torque was applied and the torque decreased to a minimum that ranged between -4.7 lb-in to -5.2 lb-in, at which point the cross-pins popped out of the detents and the applied torque was removed. Figure 8b shows data from a similar test but with a “-3” stud from receptacle 5 on the accident aircraft right engine. Over the course of the test, the peak locking torques ranged from 3.8 lb-in to 4.4 lb-in and the peak unlocking torques ranged from -5.3 lb-in to -5.8 lb-in.

In addition to the exemplar stud and the stud at receptacle 5, locking and unlocking torque measurements were taken for a “-3” stud from receptacle 4, a “-4” stud from receptacle 24, and the “-6” stud at receptacle 32. For comparison, the data from one unlocking sequence from each measurement set have been extracted and time-aligned, as shown in figure 9. Over five cycles, the peak unlocking torques for the stud from receptacle 4 ranged from -4.9 lb-in to -5.7 lb-in. The peak unlocking torques for the “-4” stud from receptacle 24 ranged from -1.5 lb-in -1.6 lb-in and peak unlocking torques for the “-6” stud from receptacle 32 ranged from -0.6 lb-in to -0.7 lb-in.

The 0.130-inch plate thickness was greater than the maximum total material thickness for a “-3” stud so neither the exemplar nor any “-3” stud from the accident aircraft was tested at this plate thickness. Instead, locking and unlocking torque measurements were taken for the “-4” stud from receptacle 24, the “-6” stud from receptacle 32, and a “-7” stud from receptacle 10. For comparison, the data from one unlocking sequence from each measurement set have been extracted and time-aligned, as shown in figure 10. Over five cycles, the peak unlocking torques for the “-4” stud from receptacle 24 ranged from -3.9 lb-in to -4.1 lb-in. The peak unlocking torques for the “-6” stud from receptacle

32 ranged from -2.2 lb-in -2.3 lb-in and the peak unlocking torques for the “-7” stud from receptacle 10 ranged from -0.6 lb-in to -0.7 lb-in. In the locked position, the “-6” and “-7” stud heads stood proud of the grommet as shown in figures 11a and b, respectively.

Donald Kramer, Ph.D.
Sr. Materials Engineer



a)
b)

Figure 1: Images of components from the accident aircraft: a) piece of the upper cowl door with studs, grommets, and snap rings from receptacles 2 – 9 still attached; b) piece of the lower cowl door that struck the right-side horizontal stabilizer along with a piece of the seal assembly;

c)

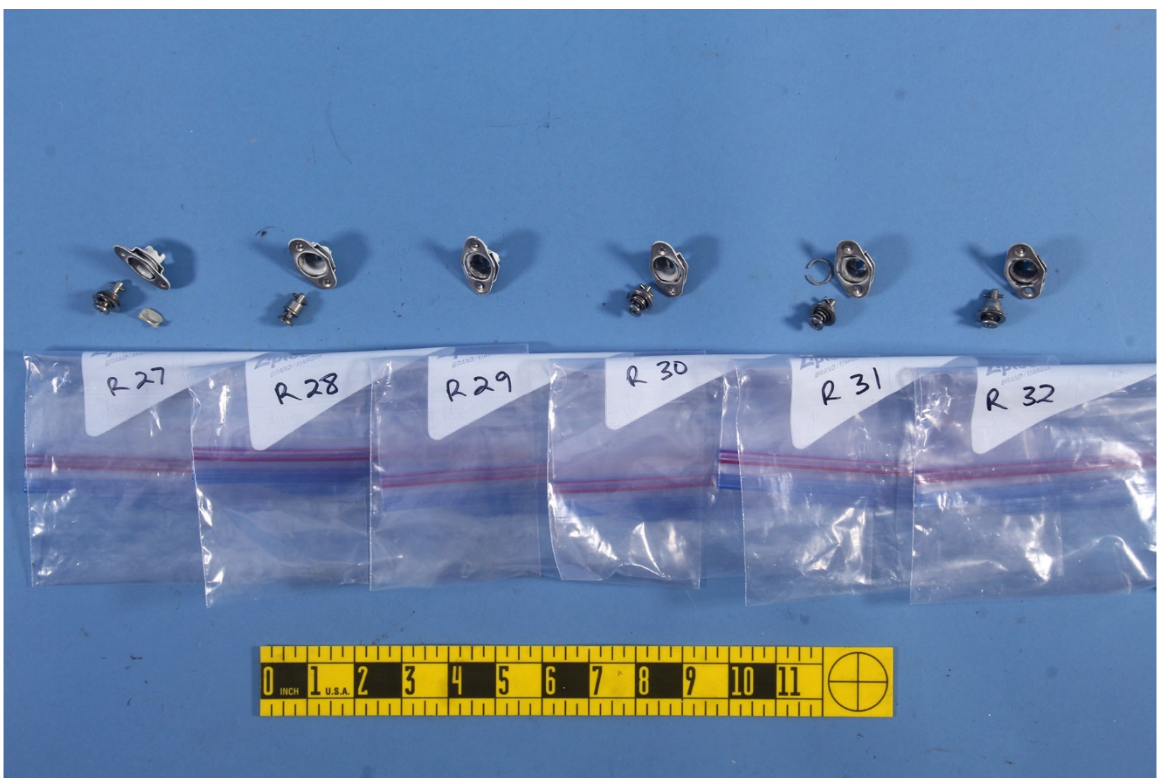

d)


Figure 1 (cont.): c) stud assemblies, grommets, and snap rings from receptacles 1 and 10 – 25 and the stud assembly from receptacle 26; and d) receptacles 27 – 32 with stud assemblies for 27, 28, and 30 – 32, and grommets and snap rings for 27 and 30 – 32.

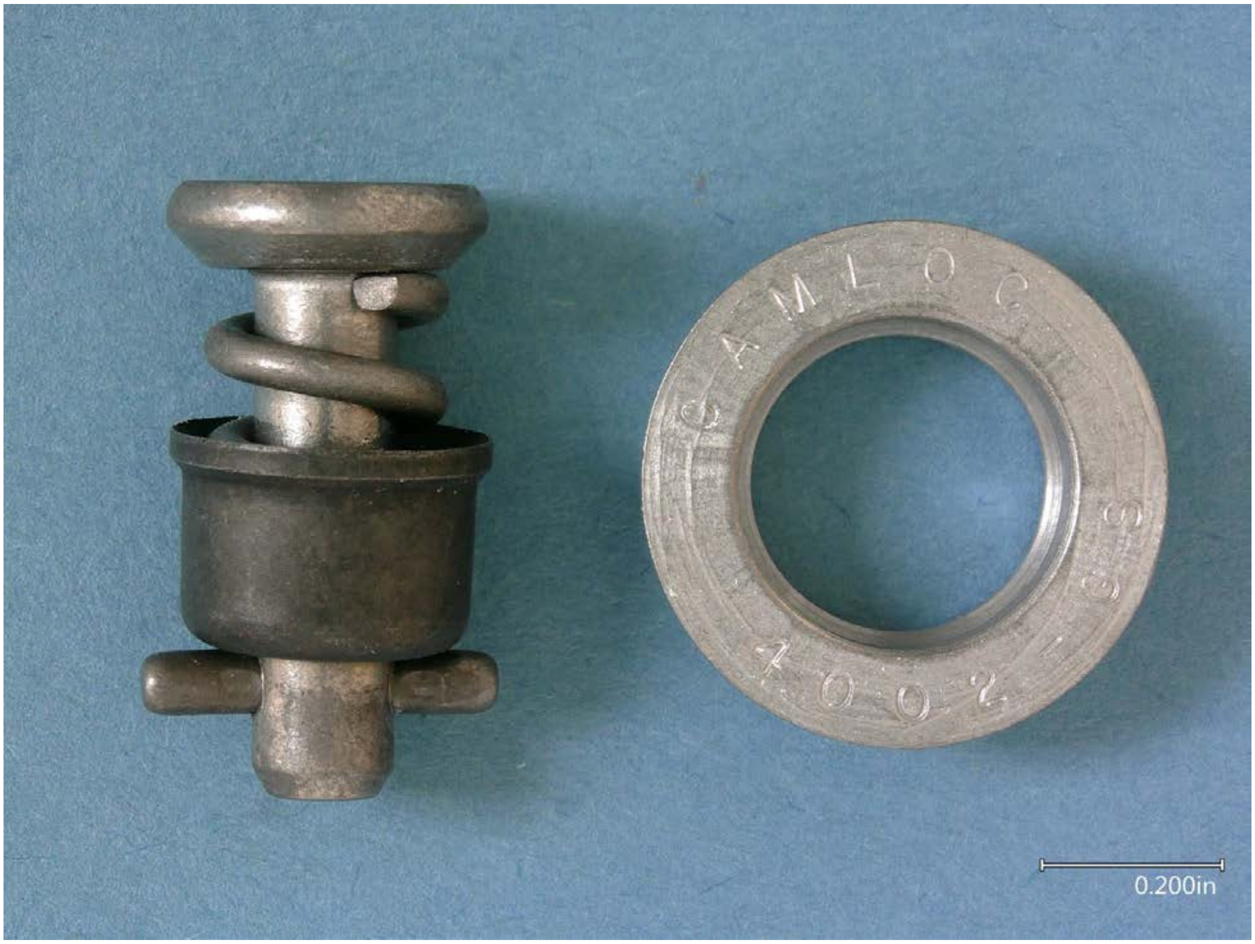


Figure 2: Image of an exemplar stud assembly and grommet.

a) b)

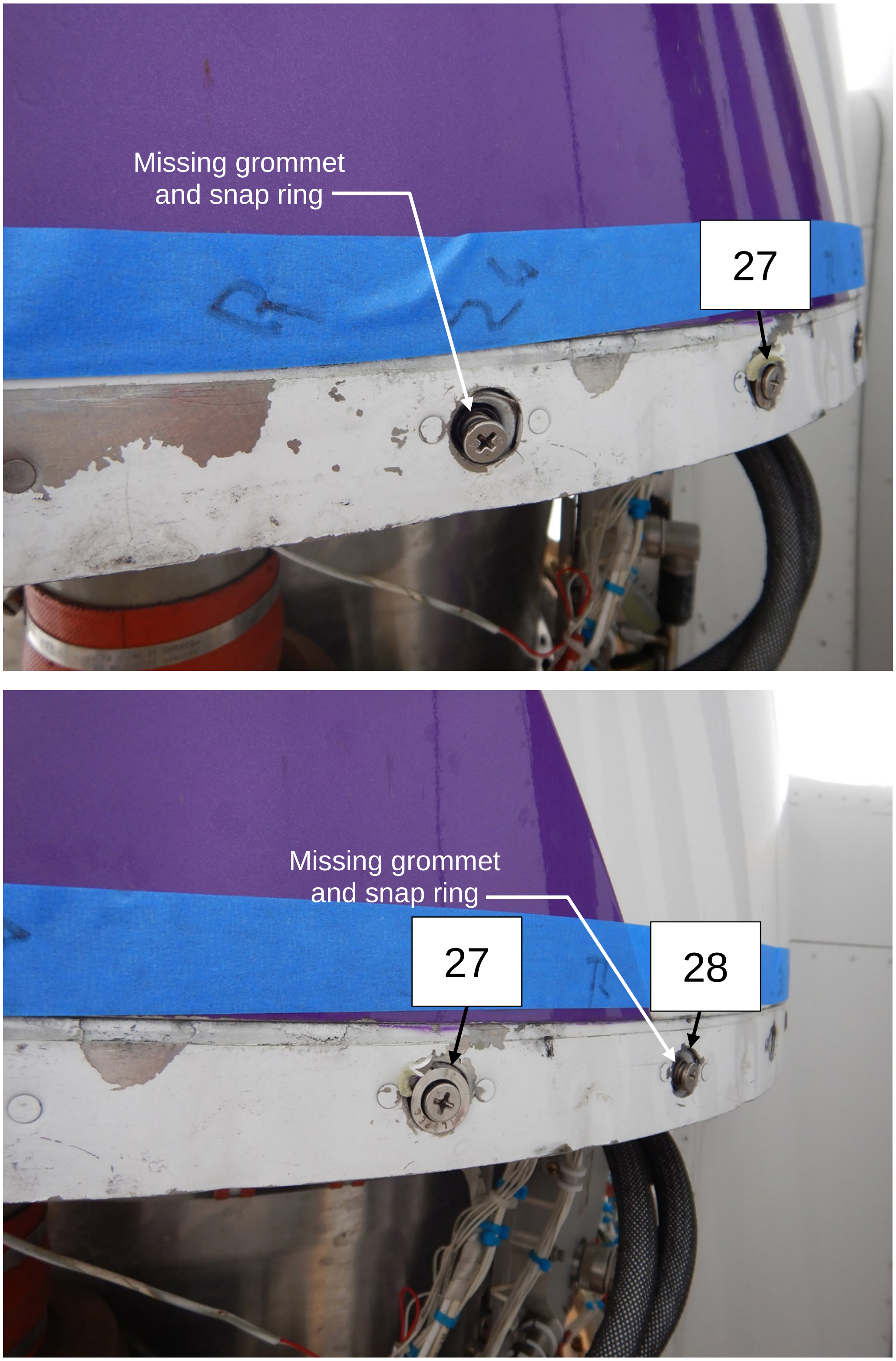


Figure 3: On-site images of the right-engine forward attachment flange showing the location of missing hardware: a) the missing grommet and snap ring at receptacle 26; b) the missing grommet and snap ring at receptacle 28;

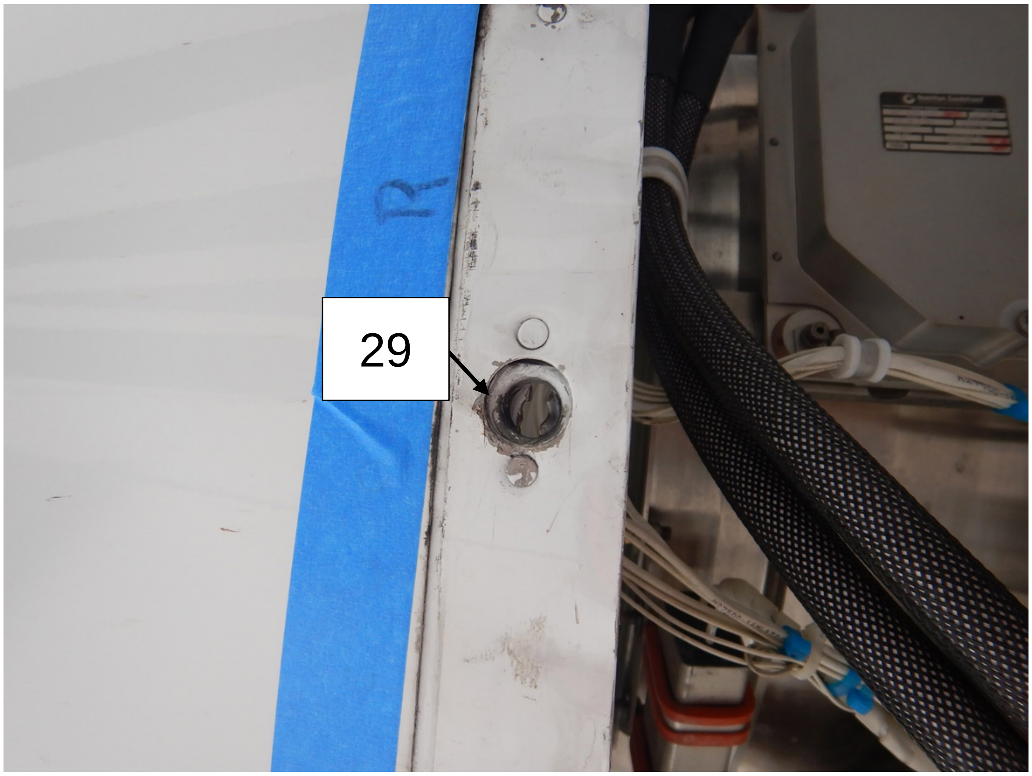
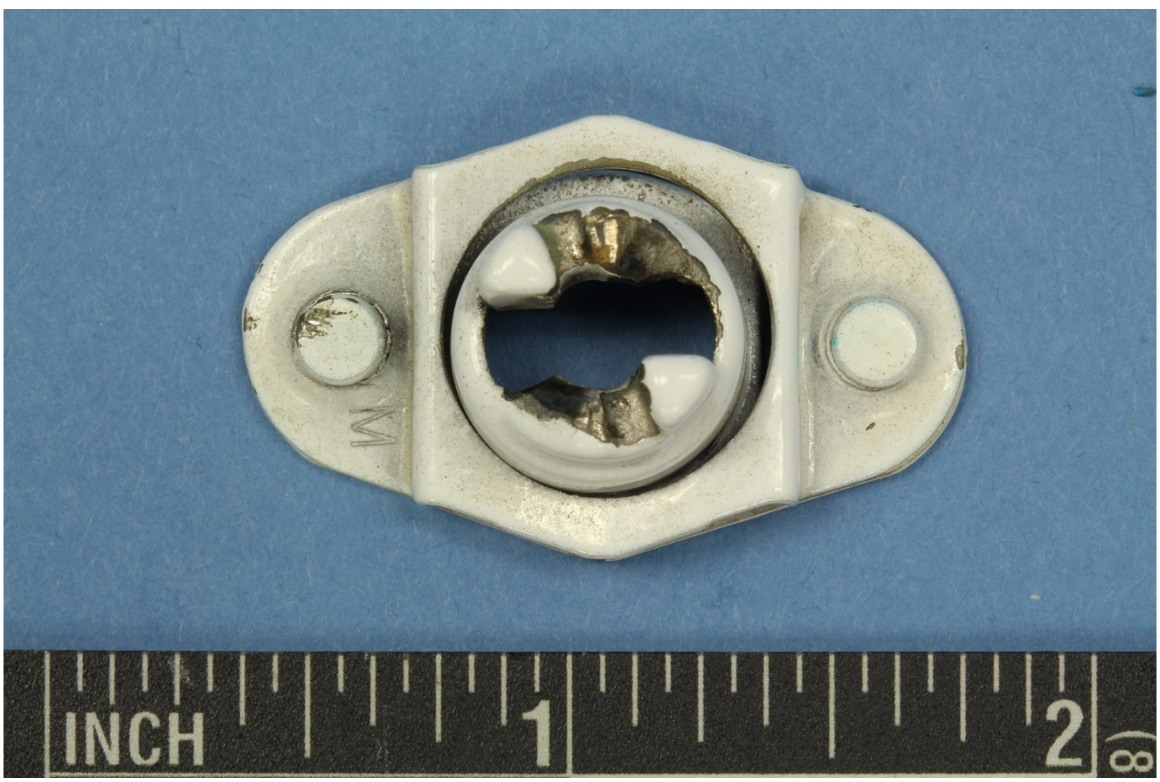
c) 

Figure 3 (cont.): and c) the missing stud, grommet, and snap ring at receptacle 29.

a)



b)

Figure 4: Images of receptacle 29: a) top down image; b) backside image;

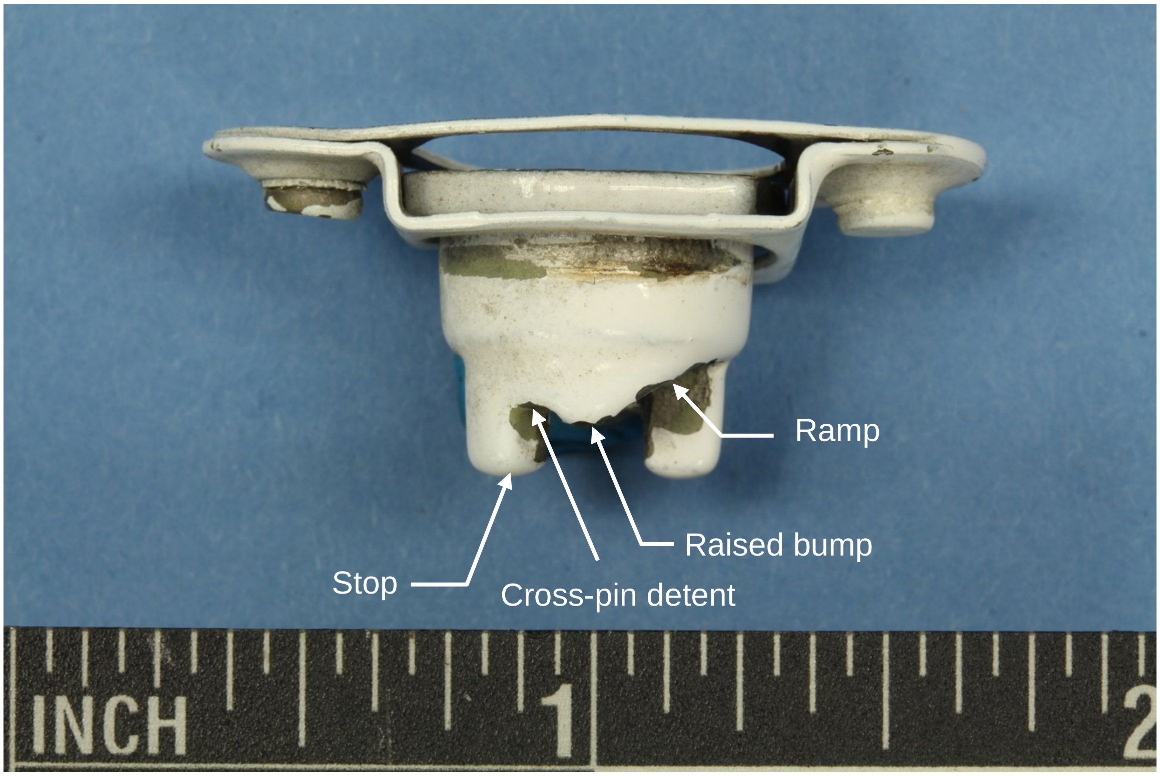
c) 

Figure 4 (cont.): and c) side view image with annotations of the cross-pin locking features.

a)

b)

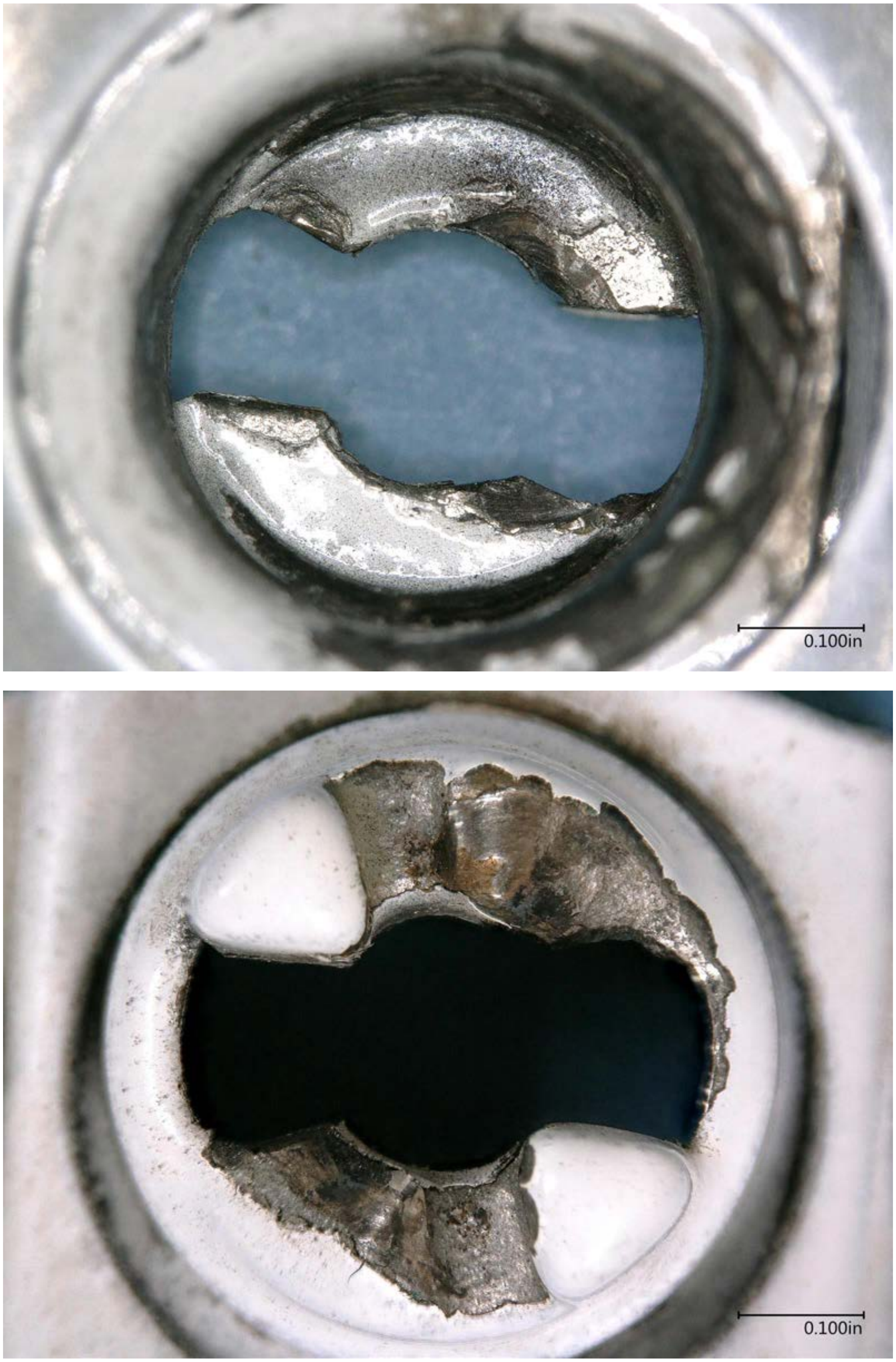
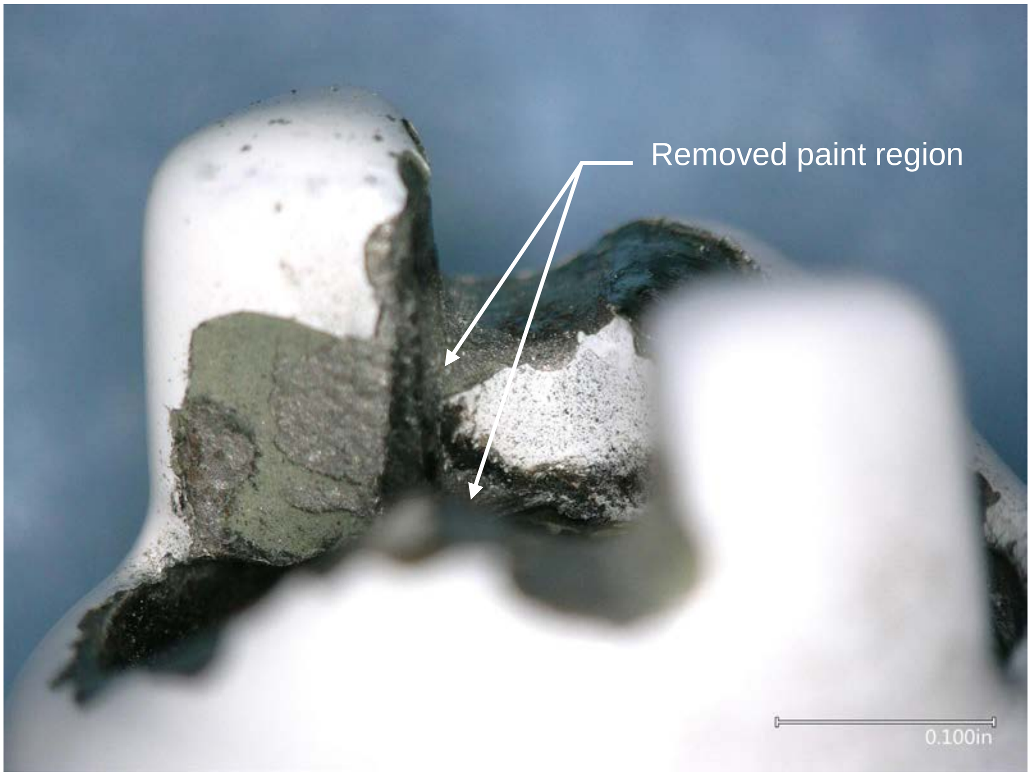


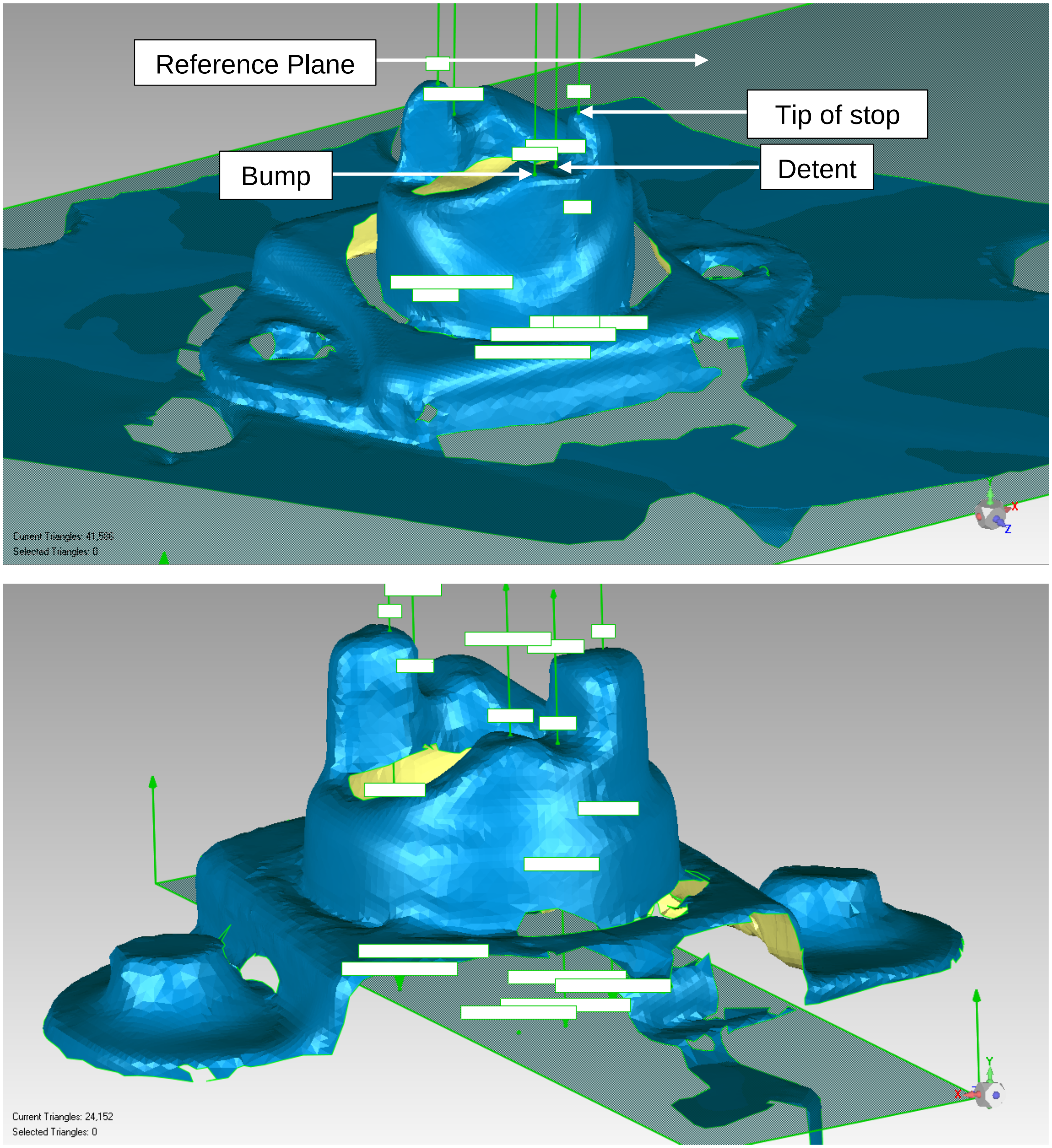
Figure 5: Higher magnification views of the receptacle cup for receptacle 29: a) cup side into which the stud and spring cup are inserted and b) backside with the ramp, raised bump, and detent that engage the cross-pin on the stud.



a)

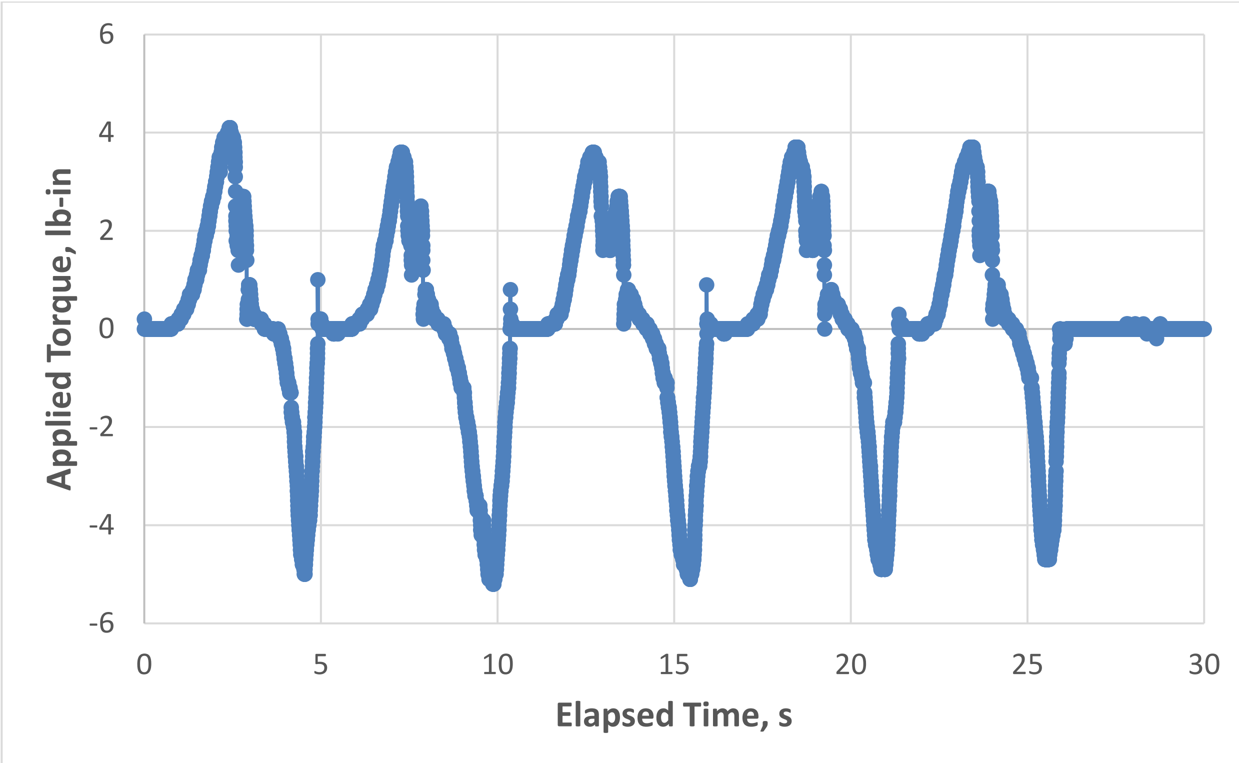
b)

Figure 6: Images of the slotted hole on receptacle 29 showing paint still present on the vertical wall below the detent: a) one detent region with paint chipped adjacent to the detent and removed from a spot adjacent to the cup and b) the second detent region with no paint removed.

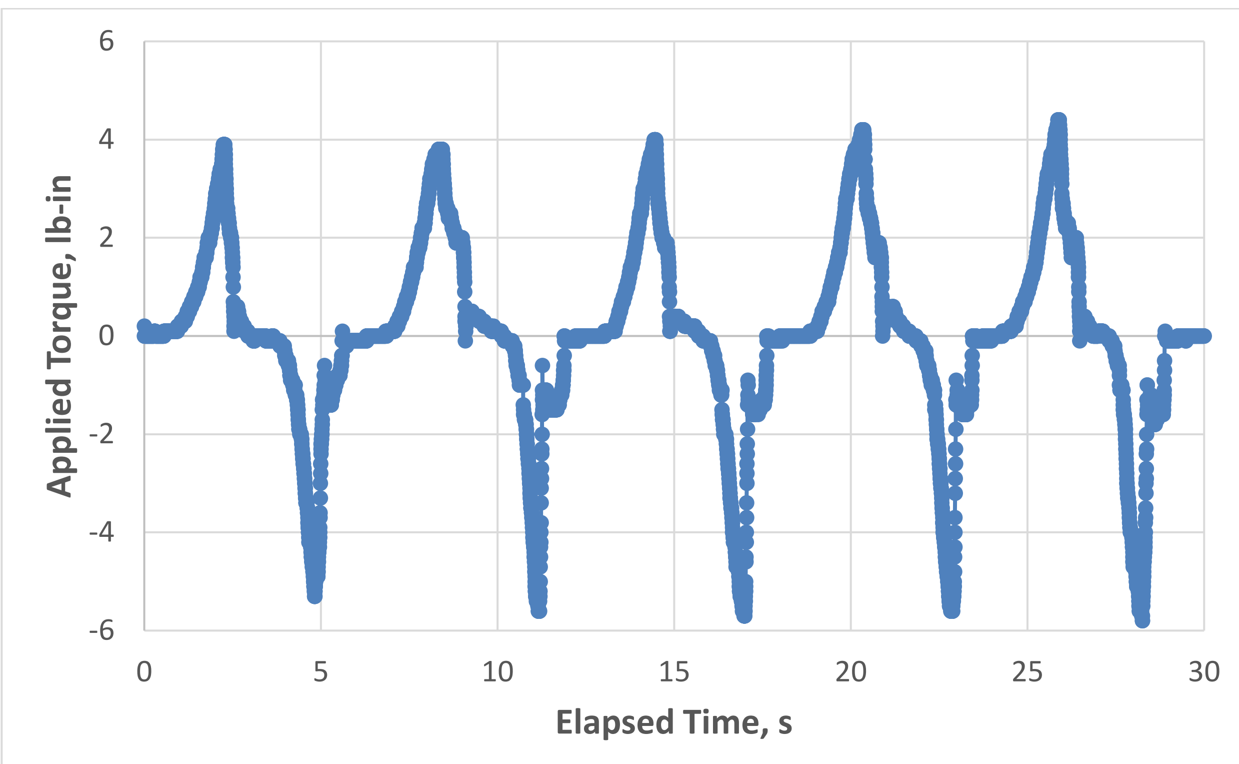


a) b)

Figure 7: 3D laser scan surface meshes used to measure the vertical distance from the flat face of the receptacle (coincident with the reference plane) to the tip end of the stop, the detent, and the tip of the raised bump: a) scan of an exemplar receptacle and b) scan of receptacle 29.



a)



b)

Figure 8: Locking and unlocking torque curves using an exemplar receptacle mounted to a plate with an effective thickness of 0.085 inch, an exemplar grommet, and different studs as follows: a) an exemplar “-3” stud (0.72 inch in length) and b) a “-3” stud from receptacle 5 from the accident aircraft.

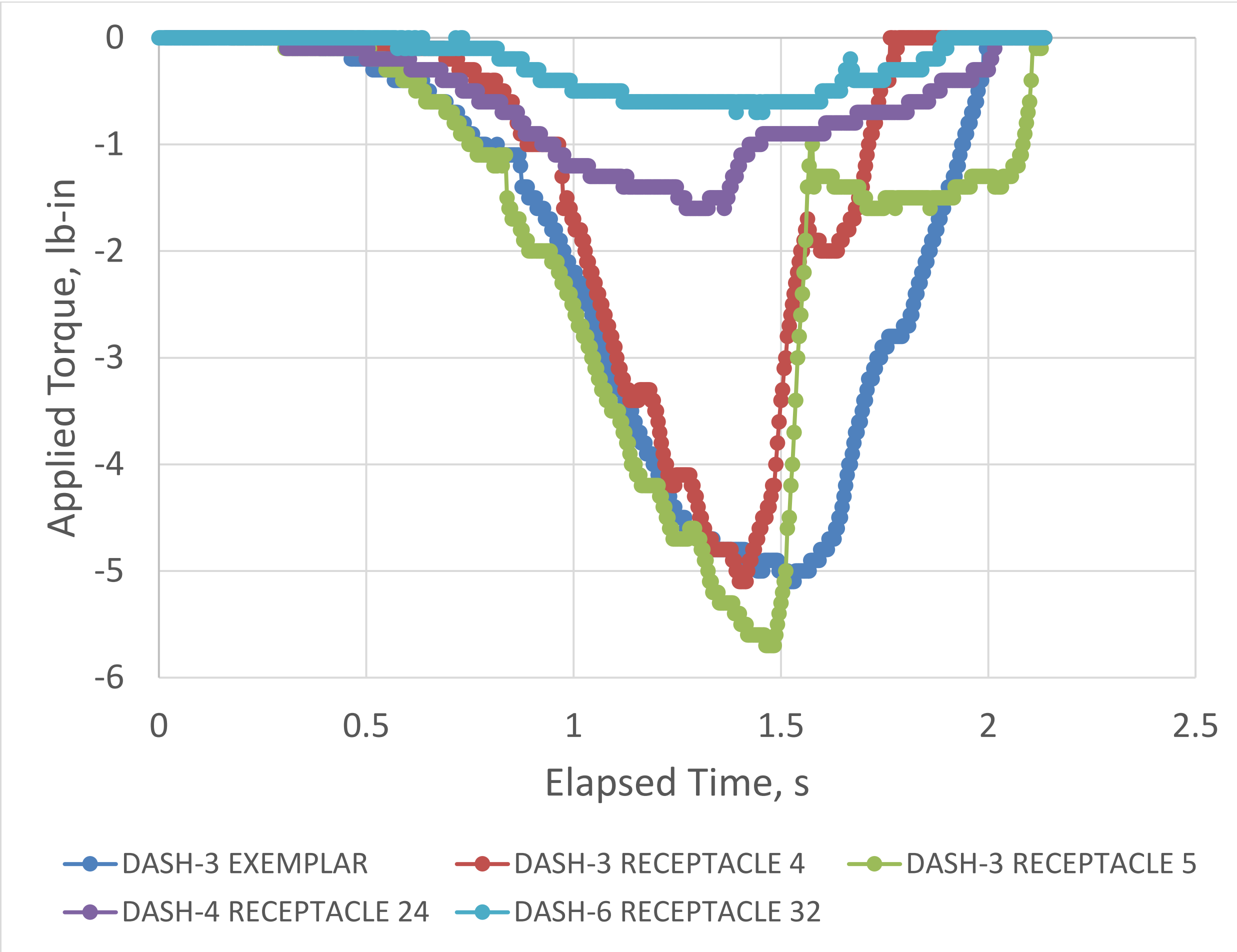


Figure 9: Time-aligned single unlocking curves extracted from the locking/unlocking data on the 0.085-inch thick plate. The data are from a “-3” exemplar stud, “-3” studs from receptacles 4 and 5, a “-4” stud from receptacle 24, and a “-6” stud from receptacle 32.

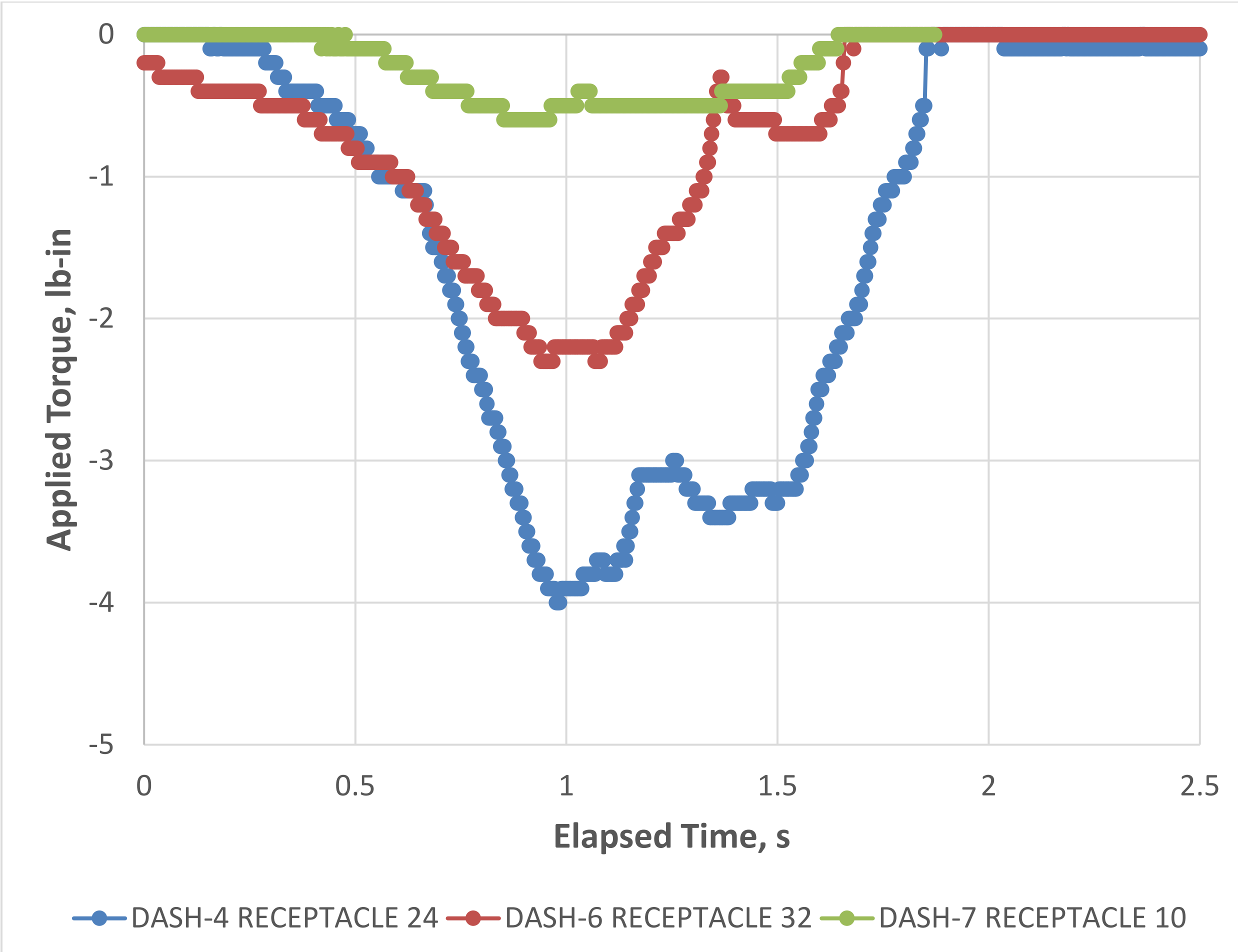


Figure 10: Time-aligned single unlocking curves extracted from the locking/unlocking data on the 0.130-inch thick plate. The data are from a “-4” stud from receptacle 24, a “-6” stud from receptacle 32, and a “-7” stud from receptacle 10.

a) 

b) 

Figure 11: Images of studs in the locked position on the 0.130-inch thick test plate. The stud heads protrude above the top of the grommet: a) "-6" stud from receptacle 32 and b) "-7" stud from receptacle 10.