National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

DCA22MA193

MATERIALS LABORATORY

Factual Report 23-021 Actuator - Experiments

June 6, 2023

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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 actuator assembly from the accident airplane and the exemplar actuator assembly.

C. EXAMINATION PARTICIPANTS

Specialist	Frank Zakar NTSB Washington, DC
Specialist	Adam Huray NTSB Washington, DC

D. DETAILS OF THE EXAMINATION

The following tests were performed for general characterization purposes only. The results of the tests performed in this report can vary based on many variables, such as the amount of torque applied by hand to the lock nut, position of the moisture seal within the clamp nut, length of the lock ring tang engaged in the clamp nut, condition of the end of the lock ring tang. The grease was removed from the clamp nut and actuator barrel threads for all tests.

Torque Testing

The accident actuator and the exemplar actuator (removed from an aircraft that was previously in-service) examined by the NTSB each had a moisture seal positioned between the clamp nut and upper eye bolt. The designs of the seals differed as outlined in the respective Materials Laboratory Factual Reports for the examination of the actuators. A moisture seal in this location is not shown or listed in the de Havilland illustrated parts catalog, aircraft maintenance manual, or actuator assembly drawing. The actuator design permits the clamp nut to rotate freely with the barrel when no external axial loads are acting on the actuator. For the two examined actuators, when an eye bolt was rotated by hand relative to the clamp nut, slight friction was felt between the eye bolt and clamp nut. Several torque tests were

conducted on the exemplar and accident actuators to try to characterize the rotational resistance between the eye end bolt and clamp nut portions. For the purpose of this report, this rotational friction was measured as a torque value. The torque measurements were made with an electronic torque sensor, RS Technologies, Division of PCB Load and Torque Inc, model 962 recorder, between 0 and 20 inch-pounds (in-lbs) range load cell. The torque tests were performed under various build-up conditions. Each successive torque test was conducted by adding or removing a part in the assembly (such as a moisture seal or bearings). The torque tests were arbitrarily labelled 1A through 1H. The tests were performed in sets of two (1A and 1B, 1C and 1D, 1E and 1F, 1G and 1H). One torque test in a set of two was conducted on an exemplar part and a second torque test was conducted on the accident part. Tests 1G and 1H were performed after the moisture seal was removed from the eye bolt. For tests 1E, the moisture seal was removed and re-installed prior to testing. For test 1F, the first two torque tests were conducted prior to the removal of the moisture seal and the final three tests were performed after the moisture seal was reseated within the clamp nut. . The remaining tests were performed prior to the removal of the moisture seal. The eye bolt for each actuator could be rotated by hand prior to, during, and after completion of the tests.

Torque Tests 1A (Exemplar Parts) and 1B (Accident Parts)

Torque test 1A (exemplar parts) and torque test 1B (accident parts) were performed with only the eye bolt, clamp nut, and respective moisture seal. To accomplish the torque measurements, the clamp nut portion was secured between the jaws of a bench vice. A 24 millimeter (mm) socket was attached to the top end of the eye bolt. The torque sensor was attached between the 24mm socket and a wrench. The wrench was continuously rotated by hand relative to the clamp nut and torque measurements were recorded.

In torque test 1A (exemplar parts) the torque values between the eye bolt and clamp nut measured between approximately 0.7 and 1.6 in-lbs with an average value of approximately 0.9 in-lbs. In torque test 1B (accident parts) the torque values measured between approximately 0.2 and 0.9 in-lbs with an average value of approximately 0.45 in-lbs. Table 1A-B shows the results of tests 1A and 1B (highlighted in yellow) and the testing configuration.

Torque Tests 1C (Exemplar Parts) and 1D (Accident Parts)

Torque tests 1A and 1B were repeated, with the exception that the parts (eye bolt, clamp nut, and respective moisture seal) were inserted into the barrel portion of

the actuator. The modified tests were referred to as torque tests 1C and 1D, respectively. The measured torque values for torque tests 1C (exemplar) and 1D (accident) were similar to those in 1A and 1B, respectively. Table 1C-D shows the results of tests 1C and 1D (highlighted in yellow) and the testing stack-up configuration.

Torque Tests 1E (Exemplar Parts) and 1F (Accident Parts)

Torque tests1C and 1D were repeated, with the exception that the bearings were installed on the shank portion of their respective eye bolts (included attachment nut, washer, and cotter pin). In summary, the modified torque tests were performed with the eye bolt, clamp nut, respective moisture seal, and bearings, and all of which were tested inside the barrel. The modified tests were referred to as torque tests 1E and 1F, respectively.

The attachment castellated nut was tightened by hand and then unscrewed (backed off) until the castellated portion of the nut encountered the first available hole in the threaded portion of the bolt. The cotter pin was installed securing the nut. In test 1E (exemplar parts), the torque between the eye bolt and clamp nut measured between approximately 0.6 and 0.9 in-lbs with an average value of approximately 0.7 in-lbs, even when pressure was applied by wrench to tighten the clamp nut.

During test 1F (accident parts), it was observed that the clamp nut required increased torque as it neared the position of seating against the top of the barrel. The amount of torque applied to the clamp nut near this position had a considerable effect on the eye bolt torque measurements observed during the test, with generally the higher the torque on the clamp nut equating to a higher torque needed to turn the eye bolt. Prior to any disassembly of the moisture seal, at higher torque values applied to the clamp nut, torque values of as high as 31 in-lbs (measured with a torque wrench) were observed between the eye bolt and clamp nut. The clamp nut was disassembled and detailed examination revealed the bottom side of the metal enclosure for the moisture seal extended approximately 0.07 inch beyond the bottom of the clamp nut. The seal fit snugly inside the clamp nut and a mallet was used to lightly tap the bottom side of the metal enclosure causing the metal enclosure of the moisture seal to fully seat itself into clamp nut. The clamp nut was re-installed into the barrel and hand tighten until the lock ring approached the 110° hole then back-off to 230° hole. At this point, the measured torque was in the range between 0.3 and 0.7 in-lbs. At lower torque values applied to the clamp nut (such as at 230° hole), the eye bolt torque behaved similar to lower torque values applied to the exemplar parts (0.6

and 0.9 in-lbs). Continued tightening of the accident clamp nut resulted in higher torque needed to turn the eye bolt.

It was unknown if the damage associated with the dent identified on the metal enclosure of the moisture seal (detailed in the Materials Laboratory Factual Report 23-019 for the Accident Actuator) had any effect on these results. Table 1E-F shows the results of tests 1E and 1F (highlighted in yellow) and the testing stack-up configuration.

As further observation, hand tight torque in the CW direction on the clamp nut when the seal was installed but the bearings were not installed resulted in the clamp nut turning approximately ¼ turn further than when the seal and the bearings were installed.

Torque Tests 1G (Exemplar Parts) and 1H (Accident Parts)

Torque tests1E and 1F were repeated, with the exception that the moisture seals were removed. In summary, the modified torque tests were performed with the eye bolt, clamp nut, bearings, all of which were tested in the barrel but without their respective moisture seal. The modified tests were referred to as torque tests 1G and 1H, respectively. Table 1G-H shows the results of tests 1G and 1H (highlighted in yellow) and the testing stack-up configuration.

As a general observation, when the eye bolts were spun by hand, without the moisture seals, the eye bolts had free spun around the clamp nut.[1] The eye bolts did not free spin when the moisture seals were attached to the actuator assembly. The results of the tests were similar regardless of which direction the eye bolt was spun.

Barrel Spin Test

A barrel spin test was conducted to determine whether a clamp nut can unscrew and separate from the barrel when the lock ring tang is not engaged with a hole in the clamp nut. This test was conducted without a lock ring (to simulate a missing lock ring). This test does not simulate actual conditions on the airplane and does not project or determine the time that a clamp nut can unscrew and separate from the barrel. Prior to starting the test, the clamp nut was tightened against the barrel and then slightly unscrewed so that no torque was applied against the barrel (a

[1] Free spin means that the eyebolt rotated easily and made multiple complete revolutions around the clamp nut when it was spun by hand.

tightening torque was not specified in the aircraft maintenance manual). In this condition, the clamp nut was free to rotate relative to the barrel. A test fixture was set up to hold the eye bolt in place relative to the barrel. A horizontal oriented steel rod was inserted into the bolt hole on the eye bolt and the ends of the rod were secured to stationary test stands. The barrel portion was vigorously spun (rotated by hand) in both directions, clockwise (CW) and counterclockwise (CCW) directions, repeatedly. Four barrel spin tests (arbitrarily labelled 2A, 2B, 2C, and 2D) were conducted.

Barrel spin test 2A was conducted with exemplar parts and test 2B was conducted with the accident parts. Tests 2A and 2B were performed with an eye bolt, clamp nut, moisture seal and barrel, without the bearings. In test 2A (exemplar part), the barrel separated from the clamp nut after approximately 1 minute, whereas those from the test 2B (accident parts) separated from the clamp nut after approximately 0.5 minute.[2] Table 2A-B shows the results of tests 2A and 2B (highlighted in yellow) and the testing stack-up configuration.

The two barrel spin tests 2A and 2B were repeated but this time with installed bearings, washer, attachment nut, and cotter pin. The modified tests were referred to as test 2C and 2D. For test 2C (exemplar parts), the barrel separated from the nut clamp after approximately 2 minutes, whereas the barrel for test 2D (accident parts) separated from the clamp nut after approximately 0.7 minutes. Table 2C-D shows the results of tests 2C and 2D (highlighted in yellow) and the testing stack-up configuration.

Barrel spin tests were conducted on the accident actuator with the moisture seal removed. As a general observation, with no torque on the clamp nut, the clamp nut had more of a tendency to spin equal with the barrel than in the previous tests with the moisture seal present, however; disproportionate movement between the clamp nut and barrel could still be achieved. The test was terminated after two minutes (the barrel did not unscrew and separate from the barrel within two minutes).

Lock Ring Seating Tests

Lock ring seating tests (tests 3A through 3D) were performed on the parts from the exemplar and accident actuators to determine whether it was possible to manually rotate the clamp nut by hand and cause the tang portion of the lock ring to disengage from a clamp nut hole. These tests were performed for general observational purposes only, with expected variation in results due to the manual

[2] The times listed are for reference only. The tests varied in both speed of barrel rotation and number of rotations in the clockwise and counterclockwise directions.

nature of the test procedures and potential differences in the natural seating position of the lock ring.[3] In addition, when the lock ring tang appeared to seat, it was unknown if the tang was in the vertical center of the drilled hole in the locknut. The lock ring from the exemplar actuator was used for all tests. 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).

For the test, the clamp nut was screwed on to the barrel and hand tightened (this was considered the starting point of each experiment). As indicated earlier, a torque requirement is not specified for the clamp nut. The exemplar lock ring was placed into the circumferential groove in the barrel and the tang portion of the lock ring was inserted into the hole in the barrel. The clamp nut was unscrewed until the tang engaged in the first available drilled hole in the clamp nut.

Test 3A (Exemplar Actuator)

Parts from the exemplar actuator were tested in the barrel with the moisture seal assembly and without the bearings (test 3A). Prior to screwing the clamp nut into the barrel, the outer surface of the clamp nut was marked with a black marker at the positions of the drilled holes that corresponded to the 180, 210, and 350 degrees positions, respectively. 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 square key slot, where the slot is the arbitrary zero position. The clamp nut was tightened against the barrel and unscrewed by hand. The first available engagement hole in the exemplar clamp nut was the 350 degree hole. Table 3A-B shows the results of test 3A (highlighted in yellow) and the testing stack-up configuration.

Test 3B (Accident Actuator)

Test 3A was repeated for the parts from the accident actuator (referred to as test 3B). Test was conducted in the barrel with the moisture seal assembly and without the bearings. Prior to screwing the clamp nut into the barrel, the outer surface of the clamp nut was marked with a black marker at the positions of the drilled holes that corresponded to the 90, 100, 110, 230, and 310 degrees positions,

[3] As detailed in the Materials Laboratory Factual Actuator Report 23-020 (for the exemplar actuator), there was a difference in the protrusion of the tang through the barrel between the natural lock ring resting position and when the lock ring was pressed inward. The variability of this difference is unknown.

respectively. The clamp nut and eye bolt were screwed onto the mating barrel threads until the clamp nut could no longer be turned by hand. The exemplar lock ring was installed in the barrel so that the tang penetrated the hole in the barrel. The clamp nut was slowly unscrewed by hand until the tang portion of the lock ring self-seated into the first available hole in the clamp nut. The experiment was repeated with the lock ring flipped 180 degrees. Table 3A-B shows the results of test 3B (highlighted in yellow) and the testing stack-up configuration.

Test 3C (Exemplar Actuator)

Lock ring seating test 3A was repeated for the exemplar parts but with installed bearings (referred to test 3C). The experiment was repeated with the lock ring flipped 180 degrees. Table 3C-D shows the results of test 3C (highlighted in yellow) and the testing stack-up configuration.

Test 3D (Accident Actuator)

Lock ring seating test 3C was repeated for the accident parts with installed bearings (referred to as test 3D). The experiment was repeated with the lock ring flipped 180 degrees. Table 3C-D shows the results of test 3D (highlighted in yellow) and the testing stack-up configuration.

Submitted by:

Frank Zakar
Senior Metallurgist

Table 1A-B Torque between eye bolt and clamp nut (in-lbs)				
Part	Eye bolt and clamp nut with moisture seal			
	Without bearing		With bearing; attachment nut; cotter pin	
	Not in Barrel	In Barrel	In Barrel	In Barrel
				Removed Moisture Seal
Exemplar	**Test 1A** (Range; Average) 0.7-1.6; 0.9	Test 1C (Range; Average) 0.7-1.6; 0.9	Test 1E Re-installed moisture seal. Test performed with dry bearings. WD-40 was not applied to bearings. Hand tighten clamp nut and back off to 180° hole. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin. Wrench tighten clamp nut. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin.	Test 1G Wrench tighten clamp nut to 130° position. Test performed with dry bearings. (WD-40 was not applied to bearings). Free spin.
Accident	**Test 1B** (Range; Average) 0.2-0.9; 0.45	Test 1D (Range; Average) 0.2-0.9; 0.45	Test 1F With moisture seal in the as-received installed condition, bottom side of the metal enclosure for the moisture seal extended approx. 0.07 inch beyond the bottom of the clamp nut. Clamp nut was screwed by hand into the barrel; the lock ring tang approached but did not engage into the 110° hole. Back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5 The clamp nut was turned by wrench until it was tight. At this point, the torque required to the turn the eye bolt was a high as 31 in-lbs.	Test 1H WD-40 was applied to bearings. Test with lock ring at 110° hole (no torque on clamp nut), hand tight, and wrench tight - all were free spin.

			Re-installed moisture seal. The clamp nut was disassembled and the bottom side of the metal enclosure was struck all around with a mallet causing the metal enclosure of the moisture seal to seat itself fully into clamp nut.WD-40 was applied to bearings. Hand tighten clamp nut to 110° hole then back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5	
			Hand tighten clamp nut to (about 120° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-2.0; 1.5	
			Wrench tighten clamp nut (about 90° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-3.8; 2.0	

Table 1C-D Torque between eye bolt and clamp nut (in-lbs)				
Part	Eye bolt and clamp nut with moisture seal			
	Without bearing		With bearing; attachment nut; cotter pin	
	Not in Barrel	In Barrel	In Barrel	In Barrel
				Removed Moisture Seal
Exemplar	Test 1A (Range; Average) 0.7-1.6; 0.9	**Test 1C** (Range; Average) 0.7-1.6; 0.9	Test 1E Re-installed moisture seal. Test performed with dry bearings. WD-40 was not applied to bearings. Hand tighten clamp nut and back off to 180° hole. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin. Wrench tighten clamp nut. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin.	Test 1G Wrench tighten clamp nut to 130° position. Test performed with dry bearings. (WD-40 was not applied to bearings). Free spin.
Accident	Test 1B (Range; Average) 0.2-0.9; 0.45	**Test 1D** (Range; Average) 0.2-0.9; 0.45	Test 1F With moisture seal in the as-received installed condition, bottom side of the metal enclosure for the moisture seal extended approx. 0.07 inch beyond the bottom of the clamp nut. Clamp nut was screwed by hand into the barrel; the lock ring tang approached but did not engage into the 110° hole. Back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5	Test 1H WD-40 was applied to bearings. Test with lock ring at 110° hole (no torque on clamp nut), hand tight, and wrench tight - all were free spin.

			The clamp nut was turned by wrench until it was tight. At this point, the torque required to the turn the eye bolt was a high as 31 in-lbs.	
			Re-installed moisture seal. The clamp nut was disassembled and the bottom side of the metal enclosure was struck all around with a mallet causing the metal enclosure of the moisture seal to seat itself fully into clamp nut.WD-40 was applied to bearings. Hand tighten clamp nut to 110° hole then back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5	
			Hand tighten clamp nut to (about 120° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-2.0; 1.5	
			Wrench tighten clamp nut (about 90° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-3.8; 2.0	

Table 1E-F Torque between eye bolt and clamp nut (in-lbs)				
Part	Eye bolt and clamp nut with moisture seal			
	Without bearing		With bearing; attachment nut; cotter pin	
	Not in Barrel	In Barrel	In Barrel	In Barrel
				Removed Moisture Seal
Exemplar	Test 1A (Range; Average) 0.7-1.6; 0.9	Test 1C (Range; Average) 0.7-1.6; 0.9	**Test 1E** Re-installed moisture seal. Test performed with dry bearings. WD-40 was not applied to bearings. Hand tighten clamp nut and back off to 180° hole. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin. Wrench tighten clamp nut. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin.	Test 1G Wrench tighten clamp nut to 130° position. Test performed with dry bearings. (WD-40 was not applied to bearings). Free spin.
Accident	Test 1B (Range; Average) 0.2-0.9; 0.45	Test 1D (Range; Average) 0.2-0.9; 0.45	**Test 1F** With moisture seal in the as-received installed condition, bottom side of the metal enclosure for the moisture seal extended approx. 0.07 inch beyond the bottom of the clamp nut. Clamp nut was screwed by hand into the barrel; the lock ring tang approached but did not engage into the 110° hole. Back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5 The clamp nut was turned by wrench until it was tight. At this point, the torque required to the turn the eye bolt was a high as 31 in-lbs.	Test 1H WD-40 was applied to bearings. Test with lock ring at 110° hole (no torque on clamp nut), hand tight, and wrench tight - all were free spin.

			Re-installed moisture seal. The clamp nut was disassembled and the bottom side of the metal enclosure was struck all around with a mallet causing the metal enclosure of the moisture seal to seat itself fully into clamp nut.WD-40 was applied to bearings. Hand tighten clamp nut to 110° hole then back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5	
			Hand tighten clamp nut to (about 120° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-2.0; 1.5	
			Wrench tighten clamp nut (about 90° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-3.8; 2.0	

Table 1G-H Torque between eye bolt and clamp nut (in-lbs)				
Part	Eye bolt and clamp nut with moisture seal			
	Without bearing		With bearing; attachment nut; cotter pin	
	Not in Barrel	In Barrel	In Barrel	In Barrel
				Removed Moisture Seal
Exemplar	Test 1A (Range; Average) 0.7-1.6; 0.9	Test 1C (Range; Average) 0.7-1.6; 0.9	Test 1E Re-installed moisture seal. Test performed with dry bearings. WD-40 was not applied to bearings. Hand tighten clamp nut and back off to 180° hole. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin. Wrench tighten clamp nut. (Range; Average) 0.6-0.9; 0.7 Eye bolt rotates but does not free spin.	**Test 1G** Wrench tighten clamp nut to 130° position. Test performed with dry bearings. (WD-40 was not applied to bearings). Free spin.
Accident	Test 1B (Range; Average) 0.2-0.9; 0.45	Test 1D (Range; Average) 0.2-0.9; 0.45	Test 1F With moisture seal in the as-received installed condition, bottom side of the metal enclosure for the moisture seal extended approx. 0.07 inch beyond the bottom of the clamp nut. Clamp nut was screwed by hand into the barrel; the lock ring tang approached but did not engage into the 110° hole. Back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5 The clamp nut was turned by wrench until it was tight. At this point, the torque required to the turn the eye bolt was a high as 31 in-lbs.	**Test 1H** WD-40 was applied to bearings. Test with lock ring at 110° hole (no torque on clamp nut), hand tight, and wrench tight - all were free spin.

			Re-installed moisture seal. The clamp nut was disassembled and the bottom side of the metal enclosure was struck all around with a mallet causing the metal enclosure of the moisture seal to seat itself fully into clamp nut.WD-40 was applied to bearings. Hand tighten clamp nut to 110° hole then back-off to 230° hole. Eye bolt rotates but does not free spin. (Range; Average) 0.3-0.7; 0.5	
			Hand tighten clamp nut to (about 120° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-2.0; 1.5	
			Wrench tighten clamp nut (about 90° position). Eye bolt rotates but does not free spin. (Range; Average) 1.0-3.8; 2.0	

Table 2A-B **Barrel Spin Test** Time Required for Barrel to Unscrew and Separate from Clamp Nut; Performed Without a Lock Ring (Minutes)		
Part	Eye bolt and clamp nut with moisture seal	
	Without bearing	With bearing; attachment nut; cotter pin
Exemplar	**Test 2A** 1 Minutes	Test 2C 2 minutes
Accident	**Test 2B** 0.5 Minutes	Test 2D 0.7 Minutes

Table 2C-D **Barrel Spin Test** Time Required for Barrel to Unscrew and Separate from Clamp Nut; Performed Without a Lock Ring (Minutes)		
Part	Eye bolt and clamp nut with moisture seal	
	Without bearing	With bearing; attachment nut; cotter pin
Exemplar	Test 2A 1 Minutes	**Test 2C** 2 minutes
Accident	Test 2B 0.5 Minutes	**Test 2D** 0.7 Minutes

Table 3A-B Lock Ring Seating		
Part	Eye bolt and clamp nut with moisture seal	
	Without bearing	With bearing; attachment nut; cotter pin
	In Barrel	In Barrel
Exemplar	**Test 3A** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten (screw) clamp nut [turn nut clamp CW]. This is original start position. Unscrew clamp nut [CCW] to first hole (350° hole). Once lock ring tang was seated in the 350° hole, the clamp nut could not be unscrewed (CCW). The clamp nut could be screwed CW, popping out and disengaging the lock ring tang. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut (turn clamp nut CW). Unscrew clamp nut (CCW) to first hole (350° hole). Once lock ring tang was seated in the 350° hole, the clamp nut could not be screwed CW. The clamp nut could be turned CCW, popping out and disengaging the lock ring tang, and with the lock ring tang riding on the clamp nut threads the clamp nut could be completely unscrewed from the barrel using hand force.	**Test 3C** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut (turn clamp nut CW) Unscrewed to first hole (350° hole). Once lock ring tang seated in 350° hole, cannot move clamp nut in either direction. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut and then unscrew until lock ring tang seated in 350° hole. Cannot screw clamp nut CW back to original start position. The clamp nut could be unscrewed CCW, popping out and disengaging the lock ring tang, and with the lock ring tang riding on the clamp nut threads the clamp nut could be completely unscrewed from the barrel using hand force.
Accident	**Test 3B** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut by hand; no gap between bottom of clamp nut and top of barrel. Unscrew to 90° hole,	**Test 3D** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut to a hand tight position where the gap between bottom of clamp nut and top of barrel varied between 0.010 and 0.016 inch depending on location of measurement.

	From 90° hole clamp nut cannot reverse back to start position but can turn CCW to 100° hole. From 100° hole clamp nut can go back to 90° hole (CW) but cannot go to 110° hole (CCW). From 110° hole clamp nut cannot turn either way. Lift tang from 110° hole with tool and seat lock ring tang in 230° hole. From 230° hole, clamp nut cannot turn CCW, but can be turned CW to go back to 110° hole. Lift tang out of 230° hole using tool, the clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten nut clamp. Unscrew to 90° hole. The clamp nut cannot be screwed (CW), but the clamp nut can be unscrewed (CCW) to the 100° hole and the lock ring tang will pop out and disengage from the 90° hole. At the 100° hole, the clamp nut can be turned in both directions. At the 110° hole, the clamp nut cannot turn either direction. Lift tang from 110° hole and engage with 230° hole. At 230° hole, the clamp nut cannot be screwed CW, but can be unscrewed (CCW). From here the clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole.	Unscrew clamp nut until it engaged the 110° hole. From 110° hole, cannot move clamp nut in either direction. Lift tang from 110° hole with tool and let tang seat in 230° hole. At 230° hole, clamp nut could turn CCW (toward 310° hole), but not CW. The clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut until it engages with the 110° hole. From 110° hole, clamp nut cannot be screwed (CW) to the 100° hole but can be unscrewed (CCW) to the 230° degree hole. At 230° hole, clamp nut cannot be screwed (CW) but can be unscrewed (CCW) until it is unscrewed completely from the barrel without engaging in the 310° hole.

Table 3C-D Lock Ring Seating		
Part	Eye bolt and clamp nut with moisture seal	
	Without bearing	With bearing; attachment nut; cotter pin
	In Barrel	In Barrel
Exemplar	**Test 3A** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten (screw) clamp nut [turn nut clamp CW]. This is original start position. Unscrew clamp nut [CCW] to first hole (350° hole). Once lock ring tang was seated in the 350° hole, the clamp nut could not be unscrewed (CCW). The clamp nut could be screwed CW, popping out and disengaging the lock ring tang. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut (turn clamp nut CW). Unscrew clamp nut (CCW) to first hole (350° hole). Once lock ring tang was seated in the 350° hole, the clamp nut could not be screwed CW. The clamp nut could be turned CCW, popping out and disengaging the lock ring tang, and with the lock ring tang riding on the clamp nut threads the clamp nut could be completely unscrewed from the barrel using hand force.	**Test 3C** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut (turn clamp nut CW) Unscrewed to first hole (350° hole). Once lock ring tang seated in 350° hole, cannot move clamp nut in either direction. **Flip lock ring 180°** Lock ring is bent to the left relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut and then unscrew until lock ring tang seated in 350° hole. Cannot screw clamp nut CW back to original start position. The clamp nut could be unscrewed CCW, popping out and disengaging the lock ring tang, and with the lock ring tang riding on the clamp nut threads the clamp nut could be completely unscrewed from the barrel using hand force.
Accident	**Test 3B** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut by hand; no gap between bottom of clamp nut and top of barrel. Unscrew to 90° hole,	**Test 3D** Lock ring is bent to the right relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut to a hand tight position where the gap between bottom of clamp nut and top of barrel varied between 0.010 and 0.016 inch depending on location of measurement.

	From 90° hole clamp nut cannot reverse back to start position but can turn CCW to 100° hole. From 100° hole clamp nut can go back to 90° hole (CW) but cannot go to 110° hole (CCW). From 110° hole clamp nut cannot turn either way. Lift tang from 110° hole with tool and seat lock ring tang in 230° hole. From 230° hole, clamp nut cannot turn CCW, but can be turned CW to go back to 110° hole. Lift tang out of 230° hole using tool, the clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole. **Flip lock ring 180°** Lock ring is bent to the <u>left</u> relative to the tang portion when looking into exterior hole in the barrel. Tighten nut clamp. Unscrew to 90° hole. The clamp nut cannot be screwed (CW), but the clamp nut can be unscrewed (CCW) to the 100° hole and the lock ring tang will pop out and disengage from the 90° hole. At the 100° hole, the clamp nut can be turned in both directions. At the 110° hole, the clamp nut cannot turn either direction. Lift tang from 110° hole and engage with 230° hole. At 230° hole, the clamp nut cannot be screwed CW, but can be unscrewed (CCW). From here the clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole.	Unscrew clamp nut until it engaged the 110° hole. From 110° hole, cannot move clamp nut in either direction. Lift tang from 110° hole with tool and let tang seat in 230° hole. At 230° hole, clamp nut could turn CCW (toward 310° hole), but not CW. The clamp nut can be completely unscrewed out of the barrel without engaging in the 310° hole. **Flip lock ring 180°** Lock ring is bent to the <u>left</u> relative to the tang portion when looking into exterior hole in the barrel. Tighten clamp nut until it engages with the 110° hole. From 110° hole, clamp nut cannot be screwed (CW) to the 100° hole but can be unscrewed (CCW) to the 230° degree hole. At 230° hole, clamp nut cannot be screwed (CW) but can be unscrewed (CCW) until it is unscrewed completely from the barrel without engaging in the 310° hole.