September 29, 2023 Aviation Investigation Report AIR-23-01

Abrupt Loss of Pitch Control and Water Impact
West Isle Air dba Friday Harbor Seaplanes de Havilland DHC-3, N725TH

Mutiny Bay, Washington
September 4, 2022

Abstract: This report discusses the September 4, 2022, accident involving a float-equipped airplane operated by West Isle Air as a commercial passenger air service flight to various seaplane bases in the San Juan Islands. While the airplane was in cruise flight en route to its destination, the airplane abruptly pitched down and impacted the water in Mutiny Bay, Washington. The pilot and nine passengers were fatally injured, and the airplane was destroyed. Safety issues identified in this report include the need to ensure the presence of the lock ring in the horizontal stabilizer trim actuator assembly to prevent a loss of pitch control, the need to install a secondary retention feature on the horizontal stabilizer trim actuator, the potential hazard of installing a moisture seal (a component not approved by the airplane manufacturer) on the horizontal stabilizer trim actuator, and the need for clear and concise guidance from the manufacturer regarding the horizontal stabilizer actuator inspection and maintenance procedures. As a result of this investigation, the National Transportation Safety Board makes two safety recommendations to the Federal Aviation Administration, three safety recommendations to Transport Canada and three safety recommendations to Viking Air.

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Acronyms and Abbreviations

agl	above ground level
ACS	airworthiness concern sheet
ADS-B	automatic dependent surveillance-broadcast
AD	airworthiness directive
AIRMET	airmen’s meteorological information
AMM	aircraft maintenance manual
AMT	aviation maintenance technician
CAR	US Civil Air Regulations
CASA	civil aviation safety alert
CFR	*Code of Federal Regulations*
DOM	director of maintenance
EDS	energy dispersive spectroscopy
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
IPC	illustrated parts catalog
msl	mean sea level
NTSB	National Transportation Safety Board
SAIB	special airworthiness information bulletin
SDR	service difficulty report
SL	service letter
STC	supplemental type certificate
TC	Transport Canada
TIS	time in service
TSB	Transportation Safety Board of Canada

Executive Summary

What Happened

On September 4, 2022, about 1509 Pacific daylight time, a float-equipped airplane operated by West Isle Air as a commercial passenger air service flight abruptly pitched down and impacted the water in Mutiny Bay near Freeland, Washington, while en route to its destination. The pilot and nine passengers were fatally injured, and the airplane was destroyed.

Examination of the airplane revealed that the clamp nut that attached the top eye end and bearing assembly of the horizontal stabilizer trim actuator to the actuator barrel had unscrewed from the barrel. The examination also found that the circular wire lock ring, which was designed to prevent the clamp nut from unscrewing, was not present.

What We Found

The National Transportation Safety Board (NTSB) found that if a lock ring is not present to secure the actuator barrel and the clamp nut together, they can become separated, and the actuator would not be able to control the position of the horizontal stabilizer, resulting in a loss of airplane pitch control. Additionally, a secondary locking feature is not required. Requiring such a feature could provide redundancy if a lock ring is not installed, fails, or separates from the clamp nut in flight.

We also found that, to prevent environmental elements from entering the actuator, maintenance personnel installed a moisture seal between the clamp nut and the eye bolt.[1] The moisture seal, which was not approved by the airplane manufacturer in any documentation, has the potential to create interference in the clamp up of the top eye end and bearing assembly.[2] In addition, the moisture seal increased the rotational friction between the clamp nut and eye bolt, which has the potential to increase the rate of separation between the clamp nut and barrel in the absence of the lock ring.

The investigation identified maintenance documents and guidance pertaining to the horizontal stabilizer trim actuator assembly that, although found not to be

[1] An eye bolt is located within the eye end and bearing assembly. One end of the eye bolt is threaded, and the opposite end (the head) is formed into a ring or eye for lifting, pulling, or securing. Refer to figure 10 and section 1.8.1 for a description of the eye bolt.

[2] The term "clamp up" refers to how the adjacent parts of the assembly match up to each other when a compressive load (in this case caused by the tightening of the clamp nut) forces them together.

causal in this accident, could lead to errors concerning the lock ring installation. For example, maintenance documents do not currently define how many holes are allowed to be drilled into a clamp nut, specify a torque requirement for the installation of the clamp nut, instruct personnel to inspect the clamp nut lock ring hole(s) for damage before installation, or ensure that the lock ring is installed properly.

We determined that the probable cause of this accident was the in-flight unthreading of the clamp nut from the horizontal stabilizer trim actuator barrel due to a missing lock ring, which resulted in the horizontal stabilizer moving to an extreme trailing-edge-down position rendering the airplane's pitch uncontrollable.

What We Recommended

On October 26, 2022, about 7 weeks into the investigation, the NTSB issued urgent safety recommendations to the Federal Aviation Administration (FAA) and Transport Canada (TC).[3] These recommendations asked that all operators of de Havilland Canada DHC-3 airplanes be required to conduct an immediate one-time inspection of the horizontal stabilizer trim actuator lock ring in accordance with the instructions in Viking Air Service Letter (SL) DHC-3-SL-27-001 and report their findings to the respective regulatory agencies.[4]

The FAA acted promptly in response to our recommendations, and on November 2, 2022, issued Airworthiness Directive (AD) 2022-23-08 based on the preliminary findings of this investigation. The AD was applicable to all DHC-3 airplanes and required a one-time visual inspection of the stabilizer trim actuator lock ring to ensure it was present, correctly seated in the groove in the upper housing, and engaged in the clamp nut. The AD further required application of a torque seal after the inspection.[5] The inspection was required to be completed within 10 hours time in service (TIS) after the effective date of the AD and the results were to be reported to the FAA.

TC also acted promptly by issuing Civil Aviation Safety Alert (CASA) 2022-04 on November 2, 2022. This alert notified owners, operators, and maintainers of DHC-3 airplanes in Canada of this accident and recommended that the inspection

[3] Safety Recommendation A-22-23 was issued to the FAA and was classified Closed—Acceptable Action on February 22, 2023. Safety Recommendation A-22-24 was issued to TC and is classified Open—Acceptable Alternate Response.

[4] Viking Air Limited is the current type certificate holder for the DHC-3 airplane.

[5] Maintenance personnel use a torque seal to indicate a component has been properly torqued. The torque seal hardens after application and will crack or become misaligned if the component has loosened.

and corrective actions described in Viking's SL be completed and findings reported to Viking Air. CASA 2022-04 also noted that a red-colored seal was installed between the actuator clamp nut and upper bearings on the accident airplane. As a result, TC recommended that when the actuator is disassembled to carry out periodic lubrication and inspection requirements, maintainers should ensure that the configuration of the actuator components is according to the type design.

As of January 2023, TC had contacted the owners of approximately 82 percent of Canada's DHC-3 fleet and learned that they had either completed Viking Air's SL or planned to do so before returning their aircraft to service. Additionally, as of the date of this report, TC is working with Viking Air to contact the remaining 18 percent of the fleet.

Although the inspection requirements issued by the FAA and recommendations issued by TC shortly after the accident ensured, for operators that complied, that the horizontal stabilizer actuator lock rings were installed on DHC-3 airplanes, we remain concerned that the hazard of a missing or failed lock ring may still exist. Therefore, we recommend that the FAA require the installation of an FAA-approved secondary retention feature on the horizontal stabilizer actuator clamp nut. Because this installation could take time for operators to implement, we also recommend (as an interim measure) that the FAA require operators of DHC-3 airplanes to visually inspect both the lock ring and the associated torque seal required by AD 2022-23-08 at an interval that ensures safe flight.

Because the type certificate for the DHC-3 is held in Canada, we also make two companion recommendations to TC.[6] We recommend operators of DHC-3 airplanes (1) install an approved secondary retention feature on the horizontal stabilizer actuator clamp nut, and (2) visually inspect the lock ring. Because CASA 2022-04 did not include a requirement for a torque seal (as AD 2022-23-08 did), we make a third recommendation to TC to require operators of DHC-3 airplanes to install a torque seal to be inspected at an interval that ensures safe flight.

We also recommend that Viking Air (1) develop inspection criteria for maintenance personnel to determine whether the horizontal stabilizer trim actuator lock ring is airworthy or needs to be replaced, (2) instruct DHC-3 operators to remove moisture seals that are installed within horizontal stabilizer actuators and are not approved by Viking Air or a regulatory agency, and (3) develop specific overhaul

[6] A type certification is issued by the State of the Operator, signifying the approval of the design of the aircraft and all component parts (including propellers, engines, control stations, etc.). It states the design is in compliance with applicable airworthiness, noise, fuel venting, and exhaust emissions standards.

inspection procedures for the horizontal stabilizer actuator, and revise the aircraft maintenance manual accordingly.

1. Factual Information

1.1 History of Flight

On September 4, 2022, about 1509 Pacific daylight time, a float-equipped de Havilland DHC-3 (Otter), N725TH, was destroyed when it impacted the water in Mutiny Bay, near Freeland, Washington, and sank. The pilot and nine passengers were fatally injured. The airplane was owned by Northwest Seaplanes, Inc., and operated as a Title 14 *Code of Federal Regulations* (*CFR*) Part 135 scheduled passenger flight by West Isle Air dba Friday Harbor Seaplanes. The flight originated at Friday Harbor Seaplane Base (W33), Friday Harbor, Washington, with an intended destination of Will Rogers Wiley Post Memorial Seaplane Base (W36), Renton, Washington. Visual meteorological conditions prevailed at the time of the accident.[1]

The accident pilot was scheduled to fly the accident airplane on three multiple-leg roundtrips on the day of the accident. The first roundtrip flight was uneventful; it departed from W36 about 0930, made four stops, and returned about 1215.

The accident occurred during the pilot's second trip of the day. A review of recorded automatic dependent surveillance–broadcast (ADS-B) data revealed that the second roundtrip departed W36 about 1253 and arrived at Lopez Seaplane Base, (W81), Lopez Island, Washington, about 1328.[2] The data showed that the flight then departed W81 and landed at Roche Harbor Seaplane Base (W39) about 1356. The airplane departed W39 about 1432, arrived at W33 about 1438, and departed about 1450.

According to ADS-B data, after the airplane departed W33, it flew a southerly heading before turning south-southeast. The en route altitude was between 600 and 1,000 ft above mean sea level (msl), and the groundspeed was between 115 and 135 knots. At 1508:40, the altitude was 1,000 ft msl, and the groundspeed had decreased to 111 knots. Based on performance calculations, at 1508:43, the airplane pitched up about 8° and then abruptly pitched down about 58°. The data ended at 1508:51, when the airplane's altitude was 600 ft msl and the estimated descent rate

[1] Visit ntsb.gov to find additional information in the public docket for this NTSB accident investigation (case number DCA22MA193). Use the CAROL Query to search safety recommendations and investigations.

[2] ADS-B is an advanced surveillance technology that combines an aircraft's positioning source, aircraft avionics, and a ground infrastructure to create an accurate surveillance interface between aircraft and air traffic control.

was more than 9,500 ft per minute (the flightpath of the airplane is depicted in figure 1).[3]

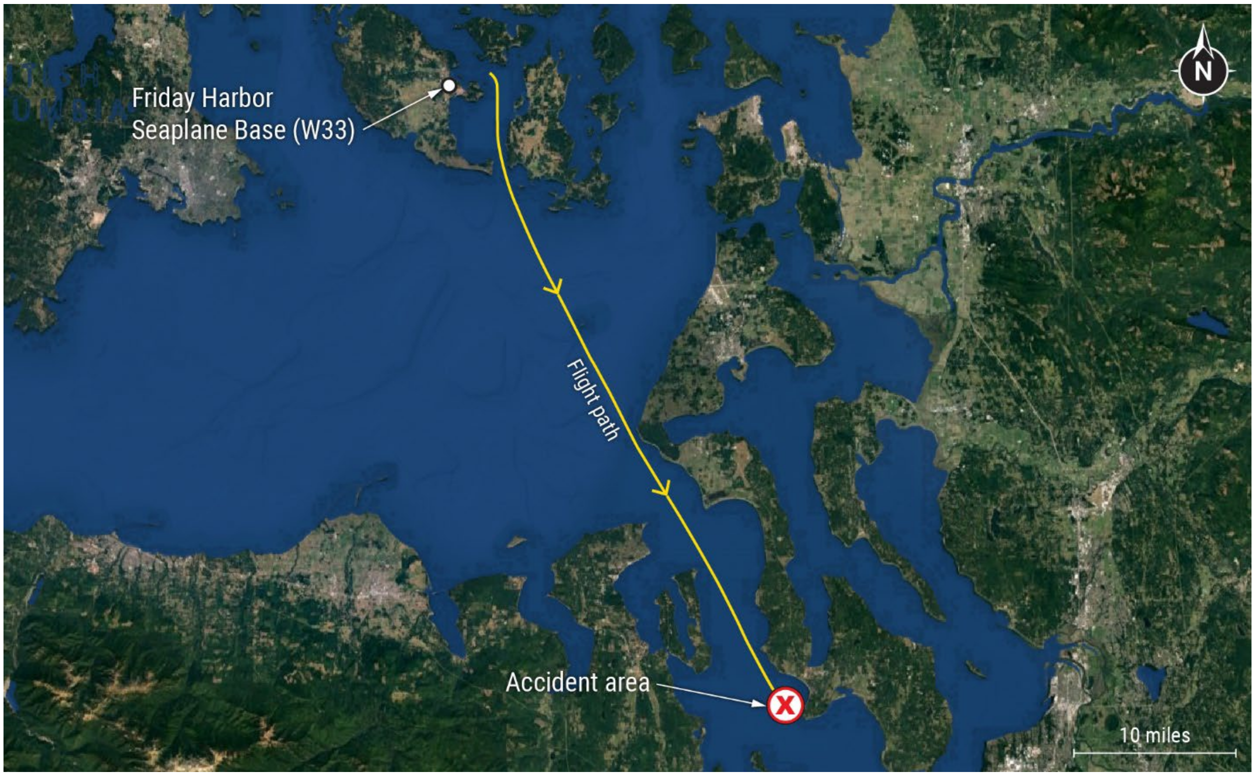

Figure 1. Flightpath of the accident airplane based on ADS-B data.

Witnesses near the accident site reported, and security camera video confirmed, the airplane was in level flight before it entered a slight climb and then pitched down. One witness described the descent as "near vertical" and estimated the airplane was in an 85° nose-down attitude before impact with the water. Several witnesses described the airplane as "spinning," "rotating," or "spiraling" during portions of the steep descent. One witness reported hearing the engine/propeller and noted that he did not hear any "pitch change" in the sounds. The airplane continued in a nose-low, near-vertical descent until it impacted water in Mutiny Bay.

1.2 Personnel Information

The pilot, age 43, held a commercial pilot certificate with ratings for airplane single-engine land, single-engine sea, multiengine land, and instrument airplane. The

[3] The NTSB conducted a performance study using ADS-B data to estimate the airplane's position, speed, pitch, and load factor during the flight. The NTSB relied on these data, in part, because the airplane was not required to be equipped with a flight data recorder or cockpit voice recorder and was not equipped with any other avionics that recorded flight data.

pilot's most recent Federal Aviation Administration (FAA) second-class medical certificate was dated May 31, 2022, with no limitations.

The pilot flew for Northwest Seaplanes and West Isle Air on a seasonal basis, typically May through October, starting in 2015.[4] The two companies transitioned to a single FAA Part 135 certificate, West Isle Air, in 2022.

The pilot completed his initial proficiency check in the DHC-2 (Beaver) on July 7, 2013, and his initial proficiency check in the DHC-3 (Otter) on June 19, 2017, both with Northwest Seaplanes. His most recent competency check was completed in the DHC-3 on July 29, 2021, also with Northwest Seaplanes. He was scheduled for another competency check during the week of the accident.[5]

The pilot operated the accident airplane during the 2 days before the accident, on similar routing to the accident flight, logging a total flight time of 7.2 hours. As of the day of the accident, he had accumulated 3,686 hours of total flight experience, more than 1,300 hours of which were accumulated in the DHC-3.

1.3 Airplane Information

The accident airplane (shown in a preaccident photo in figure 2) was manufactured by de Havilland Canada in 1967.[6] The original airplane was powered by a single reciprocating radial engine and later converted to a turboshaft engine (a General Electric Aviation Czech model H80-200).[7] As of September 1, 2022, the

[4] According to the chief pilot for West Isle Air, all company pilots were seasonally employed.

[5] FAA regulations allow for a pilot to complete their competency check during the month before or after their base month. According to the chief pilot for West Isle Air, the accident pilot's base month was August 2021; therefore, on the date of the accident, the accident pilot was in his grace month.

[6] In 2006, Viking Air Limited acquired type certificates for seven de Havilland legacy aircraft, including the DHC-3 Otter. The transfer of the type certificates established Viking as the original equipment manufacturer and provided the exclusive right to restart production for any of these aircraft.

[7] (1) This conversion was completed in accordance with Stolaris Aviation, Inc. Supplemental Type Certificate (STC) SA09857SC; (2) Viking Air submitted a report to the NTSB, published by the Transportation Safety Board of Canada, titled "Aviation Investigation Report A11W0048 – Effect of Turbine Conversions," which stated, in part, "The conversion of piston-engine aircraft to turbine-engine aircraft allows an aircraft such as the DHC-3 Otter to routinely cruise at much higher speeds. Since gust loads are proportional to speed, higher speeds result in higher gust loads. In addition, the different engine and propeller will result in different propeller wash patterns and airframe vibration harmonics. Vibrations and loadings will differ from one turbine conversion to another due to different engine rotation speeds, the number of propeller blades, and the direction of propeller rotation. All of these factors can combine to result in dissimilar and accelerated wear patterns on a converted aircraft.

engine had accumulated 2,162.2 total hours. The propeller installed on the accident engine was an Avia V508E three-bladed aluminum, feathering, and reversable constant-speed propeller with a maximum allowed rotational speed of 2,200 rpm. The airplane was purchased by Northwest Seaplanes and registered with the FAA on December 18, 2018.

Figure 2. View of accident airplane (Source: Calvin Bard).

1.3.1 Pitch Control System

The airplane's pitch is controlled by the trimmable horizontal stabilizer and the positions of the elevators. The horizontal stabilizer provides pitch stability for the airplane, and the elevators are the moveable sections mounted to hinges on the rear spar of the horizontal stabilizer that control the pitching motion of the airplane (see figure 3).[8]

Accelerated wear could manifest itself as flight control rod-end and hinge looseness and fatigue cracking."

[8] An elevator trim tab is installed along the inboard trailing edge of the left elevator. The trim tab is connected through cables, pulleys, bell cranks, and linkages to the flap system to automatically alleviate control forces with flap extension. An elevator servo tab is installed along the inboard trailing edge of the right elevator. The servo tab is connected through a linkage to the right elevator to automatically alleviate control forces with elevator movement. The trim tab and servo tab are not controllable by the pilot.

The elevators are controlled by the pilot using the control column in the cockpit. The horizontal stabilizer's incidence (angle relative to the longitudinal axis of the fuselage) is controlled through use of the trim handwheel located on the right side of the pilot's seat in the cockpit. The horizontal stabilizer trim handwheel is connected by cables to the horizontal stabilizer trim actuator (see enlarged image in figure 3), which serves as the horizontal stabilizer's rear-mounting point (the horizontal stabilizer trim actuator is discussed further in section 1.3.2). The forward-mounting point of the horizontal stabilizer consists of two hinge assemblies, one riveted to the fuselage bulkhead and one to the stabilizer front spar. The horizontal stabilizer trim actuator will lower or raise the rear-mounting point and thereby change the stabilizer incidence.

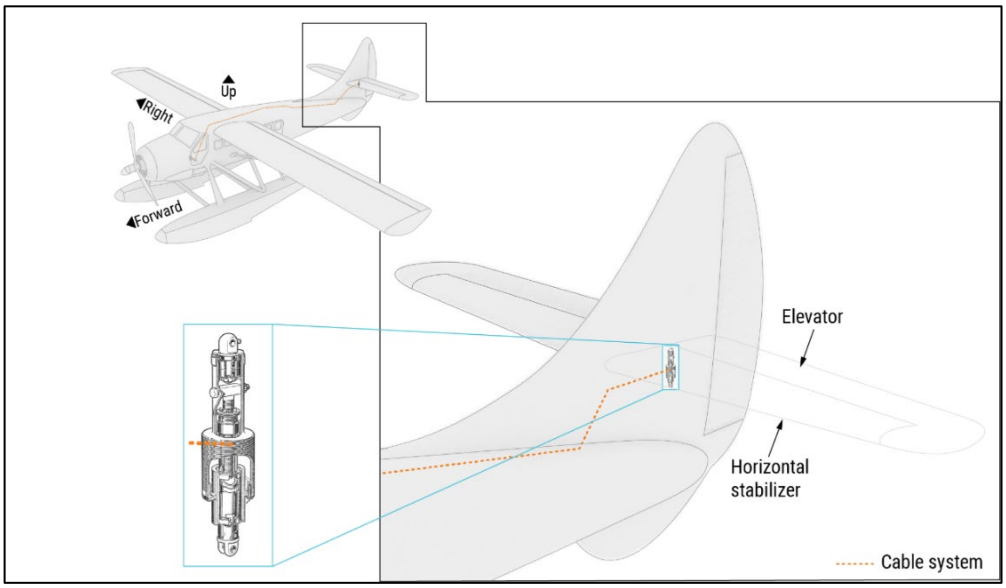

Figure 3. Schematic of the horizontal stabilizer control system, with horizontal stabilizer trim actuator enlarged (Source: Viking Air, annotated by the NTSB).

1.3.2 Horizontal Stabilizer Trim Actuator

The horizontal stabilizer trim actuator is part of the airplane's pitch trim control system. The pitch trim wheel in the cockpit uses control cables, without electrical or hydraulic assistance, to rotate the body of the actuator around a threaded assembly inside the actuator, extending (lengthening) or retracting (shortening) the overall length of the actuator. This extension or retraction changes the incidence of the horizontal stabilizer, thereby providing a mechanism for the pilot to relieve elevator control force pressure.

The horizontal stabilizer trim actuator is attached to the horizontal stabilizer with a bolt that connects the top eye end of the actuator to the rear mounting structure on the stabilizer. According to the DHC-3 aircraft maintenance manual (AMM), a clamp nut attaches the top eye end and bearing assembly to the barrel of the actuator (see figure 4). Both the clamp nut and the barrel end of the horizontal stabilizer trim actuator are threaded so that the clamp nut can be securely screwed into the actuator barrel. The bearing assembly is designed to allow the barrel of the actuator to freely turn around the top eye end.

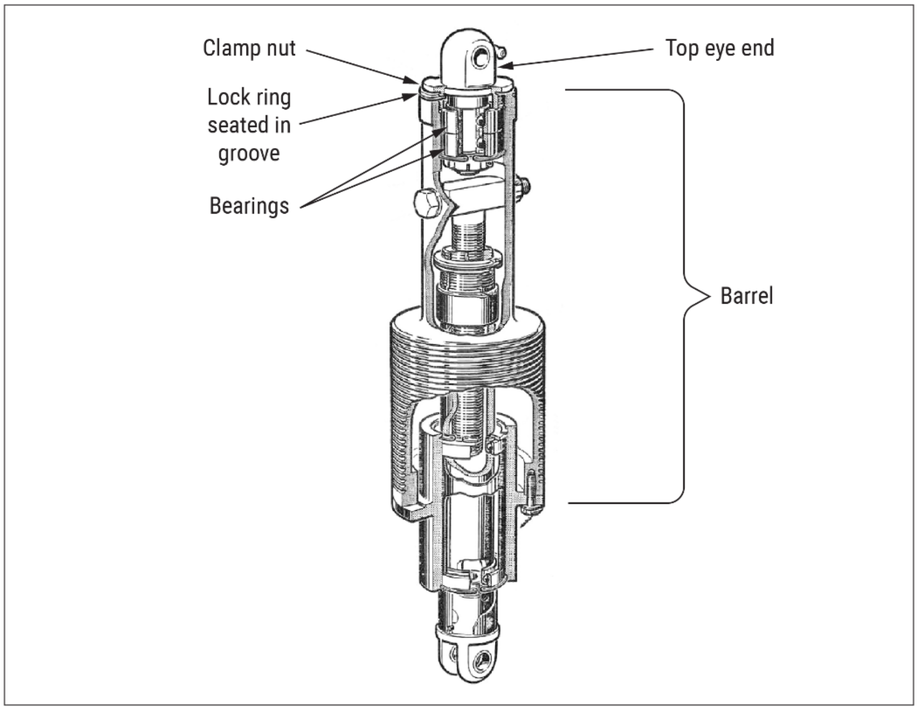

Figure 4. Horizontal stabilizer trim actuator (Source: Viking Air).

During normal assembly (at the time of manufacture), once the clamp nut is properly screwed into the horizontal stabilizer trim actuator barrel, a hole is drilled through the clamp nut (utilizing the existing hole in the lock ring groove of the barrel as a guide) that aligns with another hole in the lock ring groove on the actuator barrel.[9] When the lock ring is installed on the barrel, the tang portion of the lock ring (the portion that is bent inward, as shown in figure 5) must pass through the hole in the actuator barrel and into the hole in the clamp nut, engaging both components and preventing the clamp nut from unscrewing from the actuator barrel.

[9] For subsequent maintenance activities in which the clamp nut is removed, maintenance personnel would typically align the hole in the clamp nut with the existing hole in the lock ring groove on the actuator barrel upon reinstallation of the clamp nut. However, there is no guidance restricting the drilling of subsequent holes in the clamp nut.

Figure 5. Exemplar lock ring.

1.3.3 Maintenance Information

The airplane was maintained in accordance with the manufacturer's requirements and 14 *CFRs* 91.409 and 135.411, which included both 100-hour and annual inspections. Northwest Seaplanes provided maintenance for West Isle Air and used a 100-hour/annual inspection checklist for each inspection. The checklist items related to the horizontal stabilizer included "inspection of the horizontal stabilizer for security, loose rivets, cracks, dents, and corrosion." Maintenance personnel also used the manufacturer's airframe maintenance manual, illustrated parts catalogs (IPC), and wiring diagrams to maintain and ensure the airworthiness of the airplane.

The airplane's most recent 100-hour inspection was performed on September 1, 2022 (the airplane had accumulated 24,430.2 hours as of that date). Included at that time were recurring inspections required by Airworthiness Directives (AD) 83-04-05 (for the control column lower assembly) and 2011-18-11 (for the elevator control tabs). Additionally, a left-hand rudder retract cable was replaced during the 100-hour inspection.

The previous 100-hour inspection was performed on August 16, 2022, which included replacement of the horizontal stabilizer hinge bolts, a right-hand engine ignitor, and a left-hand float locker latch. The 100-hour inspection also included the recurring inspections required by ADs 83-04-05 and 2011-18-11. The airplane's maintenance records indicated that the most recent annual inspection was completed on April 12, 2022 (at a total time in service of 24,077.7 hours).

The director of maintenance (DOM) stated that the last time the horizontal stabilizer trim actuator clamp nut was removed was on April 21, 2022, to replace the actuator bearings.[10] The lock ring must be removed to replace the bearings. The DOM reported that after the clamp nut is seated and the holes are aligned, the lock ring pin is inserted, and the lock ring is wrapped around and secured like a "circlip."[11]

There were no maintenance logs reflecting this bearing change; however, the DOM pointed to a labor time sheet that recorded the aviation maintenance technician (AMT) performing "elevator trim" work on that day.[12] The work was done shortly after other work to prepare the airplane for the upcoming season (including the annual inspection noted previously), and, according to the DOM, it was common practice to replace the bearings at the beginning of each flying season. There were no records of pilots reporting stiff trim wheel operation after the maintenance activity that occurred on April 21, 2022 (which would precipitate a bearing replacement during the flying season).[13]

The DOM also reported that, during the April 2022 maintenance, he installed a moisture seal (red in color) in the clamp nut that was intended to keep water out and prevent the bearings from seizing. He further stated that this was the first time he installed the seal, which is not listed in the parts diagram, AMM, or actuator assembly drawing. When asked if he remembered seeing a seal in the clamp nut, the AMT did not recall seeing one the last time he worked on the actuator, which was about 1 year before the accident.

1.4 Meteorological Information

At 1515, the automated weather observing station at Jefferson County International Airport (0S9), located 10 nautical miles west-northwest of the accident site, reported wind from 310° at 10 knots, visibility 10 statute miles, few clouds at 4,000 ft and 7,500 ft above ground level (agl), broken ceiling at 9,000 ft agl, temperature 20°C, dew point 14°C, and an altimeter setting of 30.02 inches of mercury.

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[10] According to the DOM and the aviation maintenance technician AMT, maintenance on the horizontal stabilizer trim actuator is completed by removing it from the airplane for disassembly then reinstalling it on the airplane (instead of performing the work while it is installed on the airplane).

[11] A circlip is a type of fastener or retaining ring consisting of a semi-flexible metal ring with open ends that can be snapped into a machined groove on a dowel pin or other part to permit rotation but to prevent axial movement.

[12] The most recent recorded maintenance of a bearing replacement was on October 5, 2021.

[13] A December 2017 supplement to the AMM (Viking Air DHC-3 Supplemental Inspection and Corrosion Control Manual) prescribed an inspection, disassembly, and cleaning procedure for the actuator to occur at 4-year intervals. The operator reported that it performed preventative maintenance on the actuator annually during pre-season maintenance.

Airmen's meteorological information (AIRMET) Tango was issued at 1345 for moderate turbulence below 12,000 ft.[14] Additionally, a pilot who flew near the accident location reported that he was in an airplane (a Cessna 120) much smaller and lighter than the accident airplane while headed southbound and that he passed Whidbey Island about 1430. He stated he experienced “fairly extreme” windshear as his altitude varied between 1,500 and 2,000 ft agl.

West Isle Air company procedures specified that if pilots encountered turbulence, they should allow the airplane to climb with the turbulence, which was expected to result in less stress on the airplane than if pilots attempted to hold altitude.

A search of archived information indicated that although the accident pilot used ForeFlight to update a route string on the day of the accident, no airport information or weather imagery was viewed inside the ForeFlight application.[15] The accident pilot also did not request weather information from Leidos Flight Service.[16]

1.5 Wreckage and Impact Information

The airplane impacted Mutiny Bay and sank to a depth of about 200 ft. Wreckage was recovered between September 6 and September 30, 2022. After recovery from Mutiny Bay, the wreckage was transported to a secure facility for examination. The main items recovered included the nose fuel tank, engine mount and engine, propeller hub and blades, forward fuselage, center fuselage, tail section (empennage), right wing, most of the floats, some sections of flaps, and the left and right elevators (see figure 6).

[14] An AIRMET advises of potentially hazardous weather phenomena that are occurring or forecast to occur along an air route that may affect flight safety.

[15] (1) ForeFlight is a mobile application designed to assist pilots with flight planning. It includes information about facilities such as airports, navigation aids, and air traffic control. It also aids pilots in tasks including flight planning, weather monitoring, and document management; (2) A route string is a course programmed into ForeFlight (either by the pilot or automatically generated by ForeFlight) that a pilot reviews and could use to fly from their departure point to their destination, including navigation checkpoints or airport stops along the way.

[16] Leidos Flight Service provides general aviation pilots with preflight and in-flight meteorological and aeronautical information.

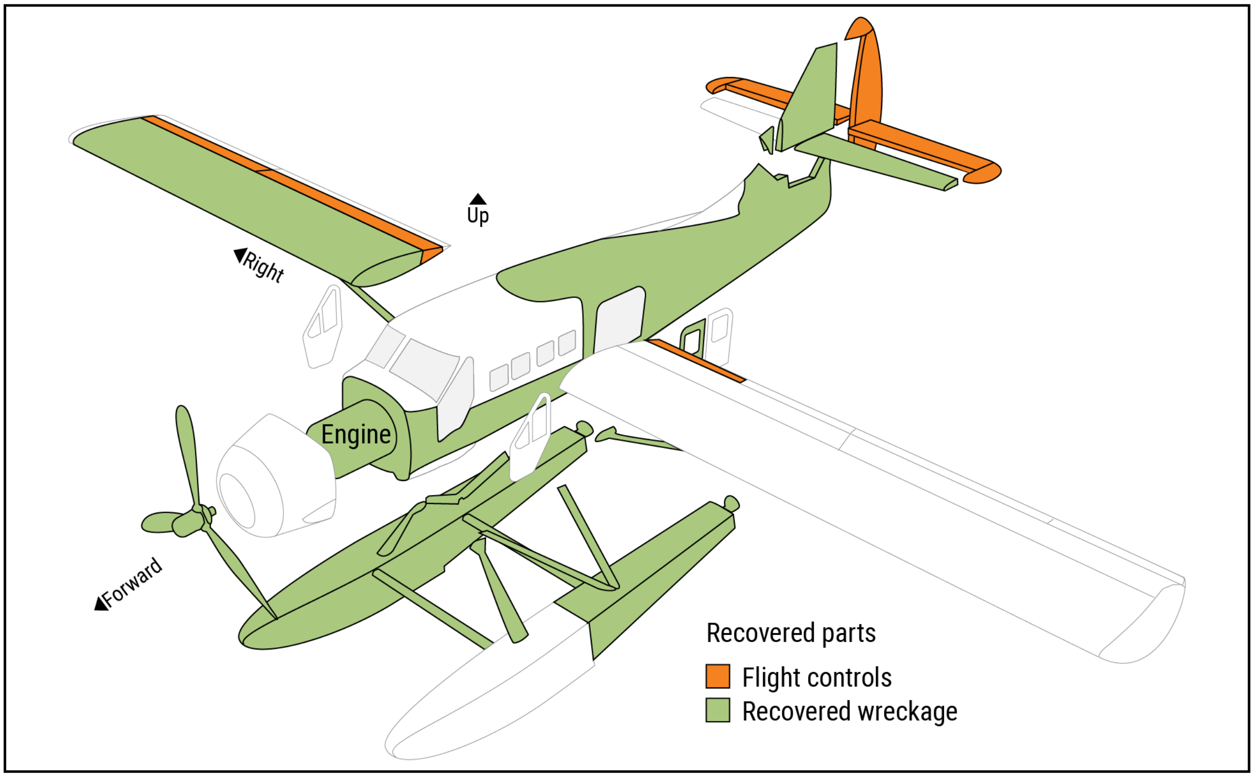

Figure 6. A diagram of the recovered wreckage and flight controls (Source: Viking Air, recreated by NTSB).

The aft fuselage and empennage were separated from the rest of the airplane during recovery. The left side of the horizontal stabilizer, vertical stabilizer, and the lower portion of the rudder remained attached to the empennage. The left and right elevators were separated from the horizontal stabilizer.

An indentation in the shape of the horizontal stabilizer leading edge was observed on the left side fuselage skin just forward of the stabilizer cutout. The horizontal rib assembly installed in the aft fuselage below the horizontal stabilizer (shelf) and the fuselage side skins were crushed downward near the location of the stabilizer rear spar. Linear (fore-aft) scrapes were observed on the horizontal stabilizer lower skin rivet lines coincident with the edges of the shelf.

Most of the right side of the horizontal stabilizer was fractured off and not recovered. About 2 feet of the forward spar and leading edge of the right horizonal stabilizer remained attached. The forward end of this section was pulled outboard away from the fuselage and had a downward bend located about 6 inches from the root. The remaining part of the stabilizer fractured from this section on a 45° angle downward and aft. A downward indentation on the leading edge started at the stabilizer root and extended outboard about 2 feet.

The center and left side of the horizontal stabilizer remained attached to the forward hinge points in the aft fuselage and was twisted clockwise (as viewed looking down) about 15° around the center of the stabilizer. The entire left side of the stabilizer was mostly intact but was damaged and bent.

The left elevator was mostly intact but damaged and separated from the stabilizer at the hinge points. It was buckled, with the outboard section bent slightly upwards, and the forward and aft spars were broken at the location of the upward bend. The inboard 5 inches of the left elevator trim tab hinge was partially separated from the auxiliary spar.[17] The hinge was fractured in this location and cracks were visible in the inboard elevator auxiliary spar. The remaining portion of the trim tab hinge remained attached to the auxiliary spar with a dark residue consistent with fretting observed on the inboard 12 inches.[18]

The trim tab control surface was mostly intact and was deformed downward on the inboard end. The trim tab balance weights were intact, and the arm was bent about 90° outboard. The left elevator upper skin had two small areas of multiple shallow indentations about 6.25 and 7.5 inches forward of the auxiliary spar.

The right elevator was mostly intact but damaged and was separated from the stabilizer at the hinge points. The elevator was buckled with the outboard section bent upward and the forward and aft spars were broken at the upward bend. The right elevator counterweights and the servo tab were intact and in place.

The horizontal stabilizer trim actuator's top eye end and bearing assembly clamp nut were found unscrewed from the actuator's upper housing with no obvious damage to the threads. The top eye end and bearing assembly remained connected to the horizontal stabilizer mounting bracket by the upper actuator attachment bolt (see figure 7) and could pivot freely about this bolt. The clamp nut could spin about

[17] The auxiliary spar is a lateral structural member installed aft of the elevator rear spar where the trim tab is attached on the left and the servo tab is attached on the right.

[18] Fretting refers to wear that occurs when two metallic surfaces are in contact with each other and encounter small oscillatory movement.

the top eye end. The lower actuator housing could rotate freely fore-aft about the lower attachment bolt.

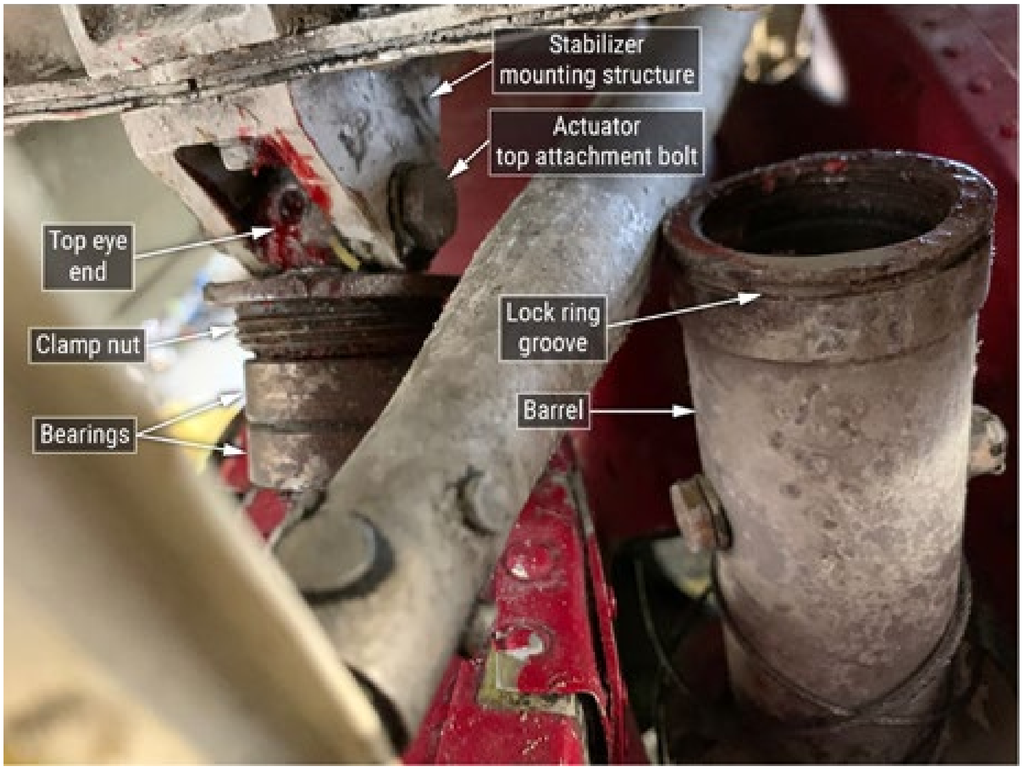

Figure 7. Photograph of the clamp nut and barrel separation on the accident airplane.

When the barrel assembly was rotated full forward about the lower attachment bolt, the barrel contacted structure (which was bent inward and downward in this location). The lower center skin of the horizontal stabilizer was punched through at a 90° angle directly above the actuator when it was in the full-forward position. The punch-through was round and left a circular grease imprint on the contact surface that was consistent with the top of the actuator barrel assembly without the top eye end and bearing assembly present. The lock ring was not present in the lock ring groove of the upper barrel assembly. The through-hole in the lock ring groove was mostly clean, and light could be seen through it. The area below the actuator, as well as inside the horizontal stabilizer in the area of the punch-through, was searched for the lock ring both visually and with a magnet, but the lock ring was not found.[19]

[19] Details about the examinations of additional wreckage components can be found in the Airworthiness Group Chair's Factual Report in the public docket.

1.6 Medical and Pathological Information

The Island County Coroner's Office, Coupeville, Washington, performed an autopsy of the pilot. His cause of death was multiple blunt force trauma injuries. Postmortem toxicology testing performed by the FAA Forensic Sciences Laboratory detected ethanol in the pilot's urine (0.058 g/dL), liver tissue (0.048 g/hg), and brain tissue (0.048 g/hg).[20]

Ethanol is the intoxicating alcohol in beer, wine, and liquor, and, if consumed, can impair judgment, psychomotor performance, cognition, and vigilance. However, consumption is not the only possible source of ethanol in postmortem specimens. Ethanol can sometimes be produced by microbes in a person's body after death. Postmortem ethanol production is made more likely by severe trauma and delayed recovery of remains. The pilot's autopsy report noted his body was recovered from the submerged wreckage 25 days after the crash. FAA testing detected n-propanol, another alcohol that can be produced by microbes in a person's body after death, in the pilot's urine specimen.

The pilot's postmortem toxicological testing did not identify any other substances likely to have impairing effects.

1.7 Survival Aspects

Initial responders to the accident site included the United States Coast Guard, Island County Sheriff's Office, Washington Department of Fish and Wildlife, Customs and Border Patrol, private citizens, and members of the Tulalip Tribes. Private citizens recovered one floating victim and several pieces of floating debris that were turned over to the Island County Sheriff's Office. The Coast Guard continued search and rescue operations for about 24 hours after the accident.

West Isle Air used FlightRadar24 to follow fights en route, while any irregularities were normally reported by the pilot via cell phone text messages.[21] The West Isle Air chief pilot had been monitoring the accident flight periodically and had not received any text messages. He later reported that all seemed normal until he noticed that the airplane appeared to have landed at Port Townsend, which he observed "was strange and cued me to what's going on." He then attempted to contact the pilot by cell phone.

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[20] In tissue, concentrations in g/hg are approximately equivalent to concentrations in g/dL.

[21] Flightradar24 is an internet-based service that shows real-time aircraft flight tracking information on a map. It includes origins and destinations, flight numbers, aircraft types, positions, altitudes, headings, and groundspeeds.

1.8 Tests and Research

1.8.1 Horizontal Stabilizer Trim Actuator Assembly Examination

The horizontal stabilizer trim actuator assembly (with separated top eye end and bearing assembly) was sent to the NTSB Materials Laboratory for further examination. The top end of the actuator barrel at the outer surface contained a circumferential groove for a circular wire lock ring. The lock ring was not attached to the groove portion of the barrel and no fragment of the lock ring was found in the hole within the groove.

The manufacturer specification for the diameter of the tang hole in the barrel (intended for engaging the lock ring) was 0.098 inches; the specified diameter was confirmed by easily inserting the shank portion of a 0.098-inch nominal diameter drill bit into the tang 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 portion of the barrel contained circumferential gouge marks that extended about 0.9 inches to either side of the tang hole (see figure 8). The groove in areas outside of the gouge marks exhibited light contact (polished) marks consistent with the size of a lock ring.

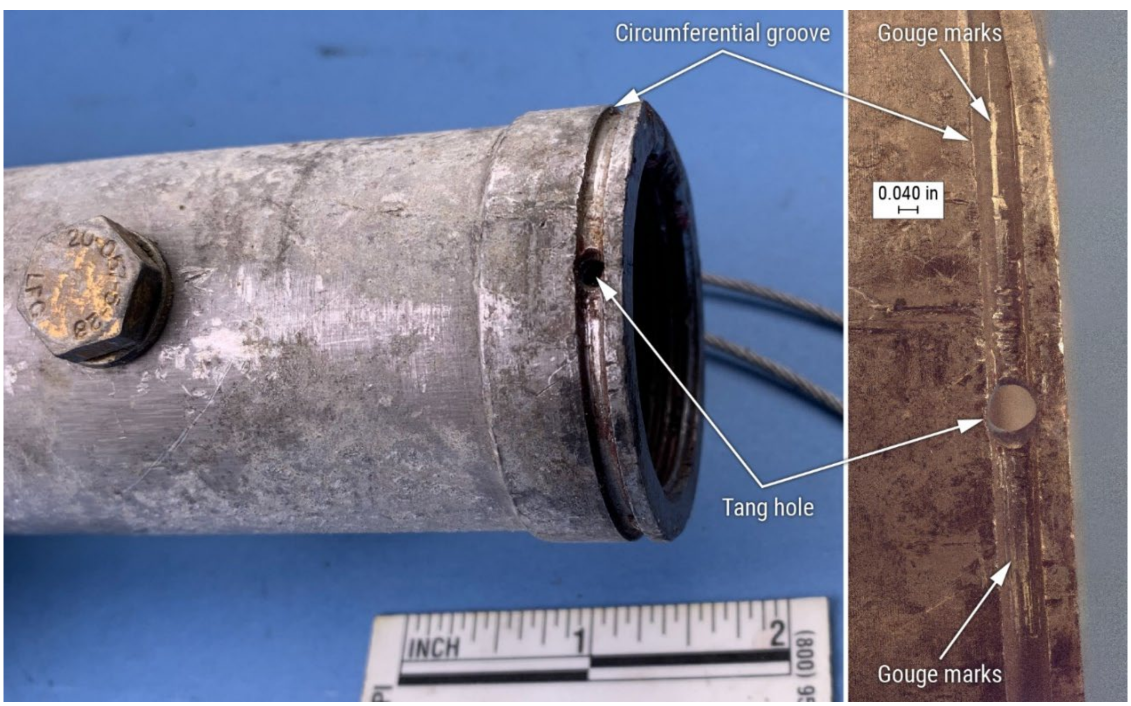

Figure 8. Photographs of the top end of the horizontal stabilizer actuator barrel.

Note: The left image shows the circumferential groove and tang hole for the lock ring; the right image is a close-up view of gouge marks in the groove.

Several longitudinal gouge marks were noted in the general area of the tang hole (see figure 9).

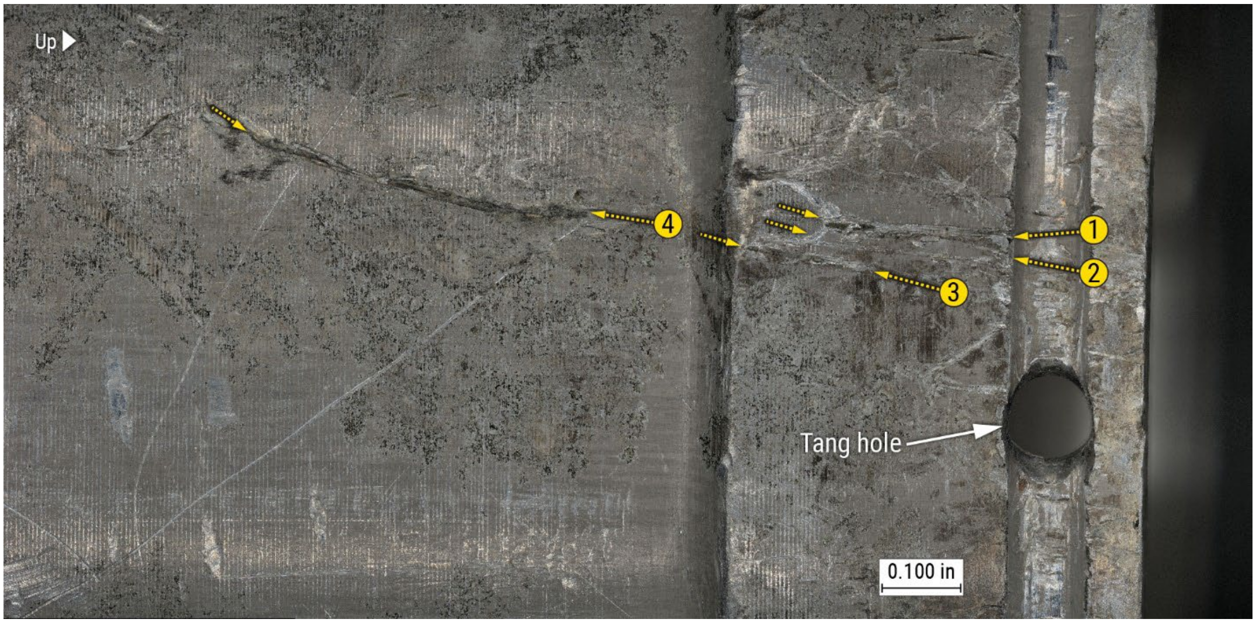

Figure 9. Side view of the horizontal stabilizer actuator barrel.

Note: The image shows the longitudinal-like gouge marks that extended from the circumferential groove, in the areas between arrows "1" through "4".

The areas corresponding to the locations of the bearings on the top end of the barrel exhibited light scouring marks that were circumferentially oriented. The inner threads of the barrel were intact and contained no evidence of stripping.

The top eye end and bearing assembly contained an eye bolt, a clamp nut, a moisture seal that was not part of the type design, bearings, a castellated nut, a washer, and a cotter pin (see figure 10). The grease fitting at the top of the eye end was fractured from the eye end, leaving a threaded fragment inside the hole for the grease fitting. In the as-received condition, the outer race of the two bearing assemblies could not be rotated by hand relative to the eye bolt.

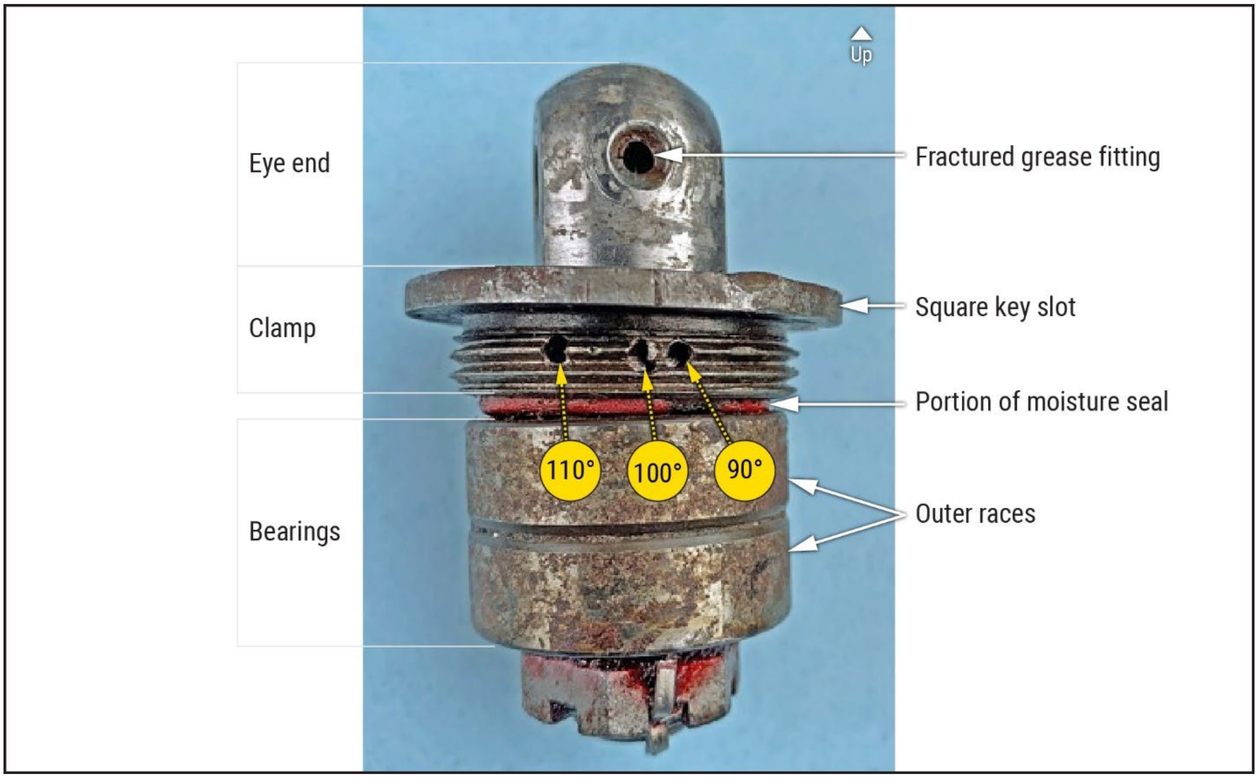

Figure 10. Photograph of the top eye end and bearing assembly showing three of five holes drilled into the clamp nut.

Note: The photograph was taken after the assembly was cleaned.

Five drilled through-holes were observed in the area of the clamp nut's external threads. None of the holes contained a fragment of the lock ring or foreign material. The positions of the drilled holes around the clamp nut were measured relative to the square key slot (which was arbitrarily assigned the 0° position). Two of the five drilled through-holes (located at 90° and 110°) were unobstructed, and the remaining through-holes (located at 100°, 230°, and 310°) were obstructed by wall deformation that reduced the diameter of the through-holes.[22]

The shank end of a 0.0755-inch diameter drill bit, which simulated the diameter of the lock ring, was inserted into the drilled through-holes in the clamp nut to determine whether the drill bit could be fully inserted. The through-holes at the 90° and 110° positions allowed full insertion of the drill bit. The end of the drill bit could be partially inserted in the through-holes at the 100°, 230°, and 310° positions, stopping at the flat bottom of these holes.

[22] When questioned by email about instructions for drilling additional holes, the airplane manufacturer responded, "The type design only allows for one hole in the clamp nut. If the holes in the barrel and clamp nut do not align, then the maintainer should contact Viking Air."

During interviews, the DOM and AMT both reported that they never drilled holes into the clamp nut. The DOM further stated the AMM contained no instructions for when the lock ring and hole do not line up.[23] A review of the AMM confirmed there was no information pertaining to multiple holes in the clamp nut (no authorization was given to drill additional holes or what to do if multiple holes were observed). Interviews with personnel from Viking Air indicated there should only be one hole drilled in the clamp nut.

1.8.2 Exemplar and Accident Horizontal Stabilizer Trim Actuators Examination and Testing

An exemplar horizontal stabilizer trim actuator assembly (with installed top eye end and bearing assembly and lock ring) was sent to the NTSB Materials Laboratory for examination and comparison to the accident actuator.[24] On the exemplar actuator assembly, the top end of the actuator barrel at the outer surface contained a circumferential groove that accommodated a circular wire lock ring. A lock ring was seated in the groove and the tang portion of the lock ring was inserted into one of two drilled holes that were located 180° apart within the groove.

The clamp nut contained three drilled holes. The circumferential positions of the drilled holes were measured when looking down at the center of the eye bolt and rotating clockwise relative to a square key slot (which was assigned the 0° position). As measured from this point, the drilled holes in the clamp nut were approximately located at the 180°, 210°, and 350° positions.

The dimensions of the exemplar lock ring were measured with a caliper. The diameter of the lock ring measured about 0.08 inches (the specified range is 0.07 inches to 0.09 inches). The inner diameter of the ring, in the general area of the tang, measured about 1.79 inches (the specified range is 1.73 inches to 1.77 inches), and when rotated 90° away from the tang portion measured about 1.77 inches. The inner radius of the tang bend as measured with a digital microscope was approximately 0.04 inches (the specified range for the inner radius of the tang bend is 0.0782 inches to 0.109 inches). In addition, a bevel was observed at the end of the tang portion, either from wear or as a result of the manufacturing process.

The lock ring was attached to (inserted into) the circumferential outer groove portion of the exemplar actuator barrel, and the length of the tang portion that protruded beyond the inner threads of the barrel was about 0.027 inches, as

[23] The DOM reported that if the lock ring and hole do not line up, he would take the clamp nut off and try again until they lined up.

[24] The exemplar horizontal stabilizer trim actuator assembly was provided from an airplane used by another operator.

measured with a digital microscope. A gap was observed between the inner diameter of the lock ring and the outer face of the groove at the base of the tang (where the tang is bent into the circumferential portion of the lock ring). To close this gap, the opposite ends of the lock ring, in the area of the tang, were compressed with a C-clamp so that all portions of the lock ring made full contact with the groove portion of the barrel.

Having been compressed, the tang portion of the lock ring protruded farther beyond the inner thread of the barrel. The distance between the crown portion of the barrel inner thread and the tip of the tang portion measured about 0.064 inches (slightly more than double the length compared to that of a free-sitting, non-compressed lock ring).

The accident actuator and the exemplar actuator each had a moisture seal (of different designs) positioned between the clamp nut and top eye bolt.[25] The actuator design permits the clamp nut to rotate freely with the barrel around the eye bolt. When the top eye ends on the two examined actuators were manually rotated relative to the clamp nuts, rotational friction was felt between the eye end and clamp nut due to the presence of the moisture seals.[26]

In addition, on the accident actuator, it was observed that the seal fit very snuggly within the clamp nut and, in the as-received position, approximately 0.07 inches of the metal enclosure of the seal was protruding beyond the bottom of the clamp nut. When the seal was protruded and the top eye end and bearing assembly was assembled, the seal contacted the inner race of the upper bearing and prevented the clamp nut from seating properly on the outer race of the upper bearing.

1.8.3 Torque Testing

To characterize the rotational resistance, measured as a torque value, when rotating the eye bolt, several torque tests were conducted on the exemplar and accident actuators at the NTSB Materials Laboratory. 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

[25] A moisture seal in this location is not shown or listed in the Viking IPC, AMM, or actuator assembly drawing. According to the DOM, the seal was installed on the accident actuator to prevent environmental elements from entering the internal bearings (which required frequent replacement due to corrosion) and was the first time they had installed such a seal.

[26] In the as-received condition on the exemplar actuator, the lock ring was secure in the clamp nut hole and the moisture seal installed.

bearings). Torque value measurements were obtained for general characterization purposes only and may not fully represent the preaccident conditions.

The first test was performed with only the eye bolt, clamp nut, and respective moisture seal. For the exemplar actuator, the average torque value was about 0.9 in-lbs. between the eye bolt and clamp nut. The accident actuator had an average value of about 0.45 in-lbs.

The second test included the eye bolt, clamp nut, and respective moisture seal inserted into the barrel portion of the actuator. The torque values were similar to the first test.

The third test was performed inside the barrel with the eye bolt, clamp nut, respective moisture seal, and bearings. For the exemplar actuator, the torque required to rotate the eye bolt averaged about 0.7 in-lbs. (both with and without torque applied to the clamp nut). For the accident actuator, the clamp nut required increased torque as it neared the position of seating against the top of the barrel. With the moisture seal in the as-received position, torque values as high as 31 in-lbs. were required to rotate the eye bolt when the clamp nut was fully tightened with a wrench. After the moisture seal was reassembled and a mallet was used to seat the seal into the clamp nut, the eye bolt required 2.5 in-lbs. to rotate when the clamp nut was fully tightened with a wrench.

The fourth test was performed with the moisture seals removed. As a general observation, regardless of the torque applied to the clamp nuts, when the eye bolts were manually spun, they rotated easily and completed multiple revolutions within the clamp nut. For comparison, with the moisture seal installed, and no torque applied to the clamp nuts, the eye bolts spun with little force required but did not spin freely for multiple revolutions.

1.8.4 Barrel Spin Testing

A barrel spin test was conducted at the NTSB Materials Laboratory 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 on the exemplar and accident actuators, with the moisture seals installed, no torque applied to the clamp nut, and without a lock ring (to simulate a missing lock ring). In this condition, the lock ring was not preventing the clamp nut from rotating within the barrel. The barrel portion was vigorously and repeatedly spun by hand in both clockwise and counterclockwise directions, demonstrating that a clamp nut can separate from the barrel.[27]

Barrel spin tests were also conducted on the accident actuator without the moisture seal installed. As a general observation, with no torque on the clamp nut, the clamp nut had more of a tendency to spin with the barrel when the moisture seal was not installed than when it was installed. The test was terminated after 2 minutes (the clamp nut did not unscrew and separate from the barrel within 2 minutes); however, some rotational movement of the clamp nut within the barrel was observed during this time.[28]

1.8.5 Lock Ring Seating Tests

Tests were performed at the NTSB Materials Laboratory on the exemplar and accident actuators to observe the exemplar lock ring engagement when the clamp nut was turned by hand while the barrel remained stationary. The tests were performed with and without bearings. In summary, the results of this testing showed that for both actuators, the exemplar lock ring was able to disengage from some of the clamp nut holes when the clamp nuts were turned using hand force only.[29] Several variables contributed to the lock ring disengagement such as damage or deformation of the holes, lock ring radius, and condition of the lock ring tang. The NTSB could not determine which clamp nut hole (if any) was engaged by the lock ring before the accident.[30]

[27] The test was performed on the exemplar and accident actuators. In both tests, the clamp nut separated; however, the time to separation varied. The laboratory testing was not intended to represent or predict time for separation.

[28] The test was terminated after 2 minutes because the intention of the test was to demonstrate relative movement rather than to determine the time it would take for the clamp nut to unscrew from the barrel.

[29] Details of the testing can be found in the NTSB Materials Laboratory Factual Report No. 23-021, June 6, 2023, in the docket for this accident.

[30] The lock ring used in these tests was not the same lock ring that may have been installed in the accident actuator; therefore, this testing was for general investigative purposes only.

1.8.6 Horizontal Stabilizer Lower Skin Panel Examination

A lower skin panel from the horizontal stabilizer was examined at the NTSB Materials Laboratory. The panel contained a puncture with the ruptured flap portion that was deformed upward. The bottom face of the punctured skin exhibited a deformed curved pattern that was consistent with the shape and size of the horizontal actuator barrel outer diameter when the top eye end and bearing assembly was not present (see figure 11). The bottom surface of the flap was covered with translucent red grease (around and within the impression mark).

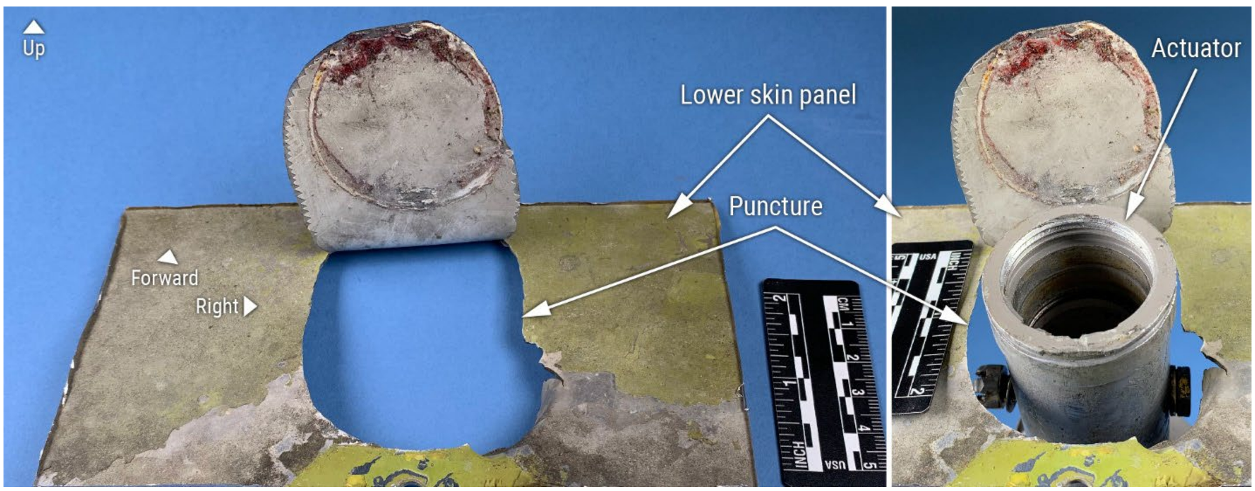

Figure 11. Photographs of the lower skin panel for the horizontal stabilizer.

Note: The left side of the image shows the puncture, and the right side of the image shows the barrel portion of the horizontal stabilizer trim actuator inserted into the open end of the puncture.

The flap and panel portions were examined further by X-ray energy dispersive spectroscopy (EDS) analysis of the fracture faces to determine whether traces of the lock ring could be detected. The flat panel portion was specified as an aluminum alloy, whereas the lock ring was specified as carbon steel spring wire that was to be coated with cadmium or zinc. EDS analysis revealed no evidence of cadmium or zinc transferred to the aluminum fracture faces.

1.8.7 Left Elevator Assembly Examination

Examination of the left elevator assembly revealed the inboard end of the auxiliary spar contained three cracks (arbitrarily referred to as cracks "1", "2", and "3") (see figure 12). Cracks "1" and "3" were located in the same area that contained a

2-inch-long repair doubler (installed at the inboard end on the forward face of the auxiliary spar).[31]

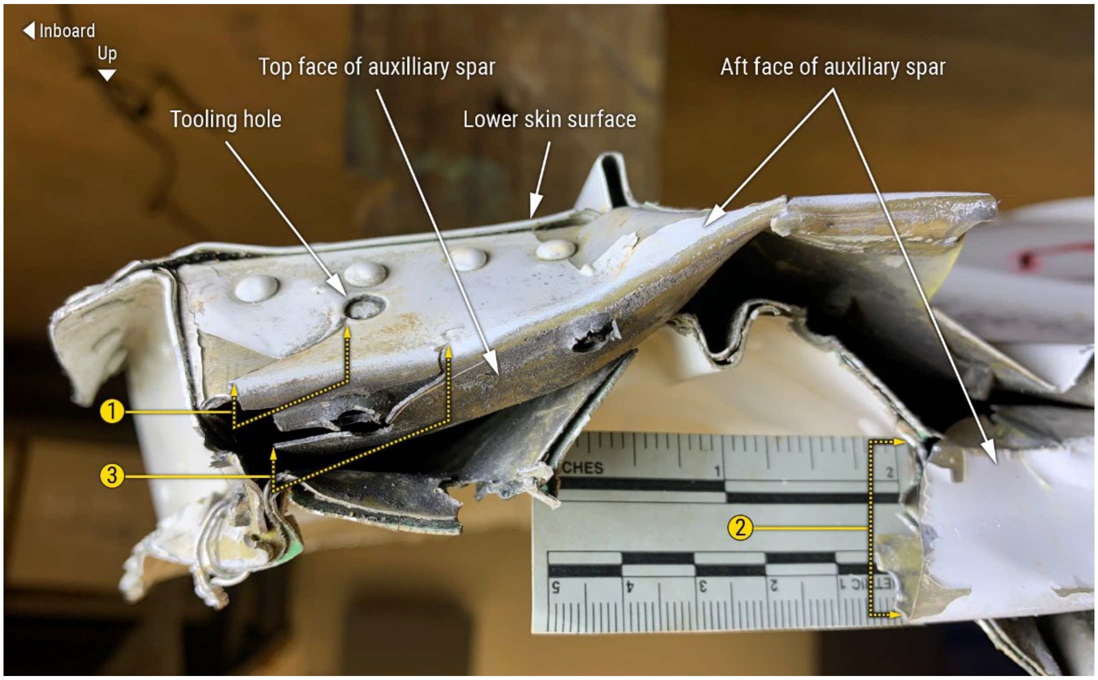

Figure 12. Photograph of the auxiliary spar for the left elevator, after the tab was removed, showing cracks "1", "2" and "3" (view looking forward).

The cracks were examined by bench binocular microscope and scanning electron microscope. Cracks "1" and "3" revealed fracture features consistent with fatigue cracking, and crack "2" revealed evidence of overstress separation with no evidence of fatigue cracking. The repair doubler was intact, and no cracking was noted on it. The outboard end of the auxiliary spar was disassembled (de-riveted) from the left elevator to expose all surfaces of the auxiliary spar. The remaining portion of the auxiliary spar contained no evidence of cracks.

1.9 Organizational and Management Information

West Isle Air was issued a Part 135 Air Operator Certificate on January 9, 1989. At the time of the accident, West Isle Air operated one DHC-3 (the accident airplane) and five DHC-2 airplanes.

West Isle Air operated scheduled passenger air service from Renton, Washington, to various seaplane bases in the San Juan Islands, as well as on-demand

[31] Typically, a repair doubler would be installed to prevent any cracking from further propagation.

charter flights to lodges and resorts in Canada. Pilots had the discretion to vary the order in which they landed at the various destinations in the San Juan Islands due to traffic congestion at the seaplane dock, the number of passengers departing/arriving at each, or weight and balance.

1.10 Additional Information

1.10.1 Postaccident Safety Actions

As a result of this accident, on October 26, 2022, the NTSB issued Urgent Safety Recommendation A-22-23 to the FAA and Urgent Safety Recommendation A-22-24 to TC. These recommendations asked the FAA and TC to require all operators of de Havilland Canada DHC-3 airplanes to conduct an immediate one-time inspection of the horizontal stabilizer trim actuator lock ring in accordance with the instructions in Viking Air SL DHC-3-SL-27-001, issued October 26, 2022, and report their findings to the respective regulatory agencies (NTSB 2022).[32]

The SL recommended that DHC-3 airplane operators "visually confirm that the stabilizer actuator lock ring is present, correctly seated in the groove in the upper housing…and the lock ring tang is engaged in the clamp nut." The SL stated that this action was to be performed "upon receiving this SL, regardless of when the most recent maintenance was completed."[33]

On November 2, 2022, the FAA issued AD 2022-23-08 based on the preliminary findings of this investigation and our recommendation. The AD was applicable to all DHC-3 airplanes and required a one-time visual inspection of the stabilizer trim actuator lock ring to ensure it was present, correctly seated in the groove in the upper housing, and engaged in the clamp nut. The AD further required application of a torque seal after the inspection. The inspection was required to be completed within 10 hours time in service (TIS) after the effective date of the AD and the results were to be reported to the FAA (FAA 2022b).

As of August 24, 2023, the FAA reported that 16 US-registered airplanes and 3 Canadian-registered airplanes had been inspected, and there were no reports of

[32] TC is the department within the Government of Canada responsible for developing regulations, policies, and services of air transportation in Canada. This recommendation was also made to TC because Viking Air, the type certificate holder for the airplane, is based in Canada.

[33] The SL was published on October 26, 2022, the same day the NTSB's urgent safety recommendations were issued.

missing or incorrectly installed lock rings.[34] However, a Canadian operator voluntarily reported to the FAA that, in 2019, it discovered an actuator with a lock ring that was completely broken in half. Half of the lock ring was found in the lower fuselage, and the other portion remained on the actuator with the tang barely engaged in the barrel hole. A crack was also visually observed in the tang bend of the lock ring. The clamp nut had a double-drilled hole in the threads and was backed out about one-half turn from its secured position.[35] The same operator further reported that in 2019 on another airplane it found a lock ring installation with the tang through the barrel hole but not fully engaged in the clamp nut hole. In this instance, the nut had not rotated from its secured position.

On November 2, 2022, TC issued Civil Aviation Safety Alert (CASA) 2022-04 that notified owners, operators, and maintainers of DHC-3 airplanes in Canada of this accident and recommended that they complete the inspection and corrective actions described in Viking's SL (TC 2022). CASA 2022-04 also noted that a red-colored seal was installed between the actuator clamp nut and upper bearings on the accident airplane. As a result, Transport Canada recommended that when the actuator is disassembled to carry out periodic lubrication and inspection requirements, maintainers should ensure that the configuration of the actuator components is according to the type design.

TC further confirmed that a copy of the CASA was sent to all contracting states and known states of registry on November 2, 2022. [36] As of January 2023, TC had contacted the owners of about 82 percent of Canada's DHC-3 fleet and learned that they have either completed Viking Air's SL or plan to do so before returning their aircraft to service. Additionally, as of the date of this report, TC is working with Viking Air to contact the remaining 18 percent of the fleet.

On March 28, 2023, the FAA issued Special Airworthiness Information Bulletin (SAIB) 2023-05 to all operators of DHC-3 airplanes that provided the following recommendations: (1) perform maintenance according to the manufacturer's instructions for continued airworthiness using approved parts, (2) check the lock ring and clamp nut for engagement, (3) perform repetitive visual inspection of the actuator at intervals not exceeding 110 hours, (4) seek industry input on prevention techniques for water intrusion in the horizontal stabilizer actuator, and (5) install an

[34] As of this date, the FAA reported there were 67 DHC-3 airplanes registered in the United States.

[35] The term "double-drilled hole" indicates that more than one drilling operation was performed at the same hole location, which, in extreme cases, results in two connecting holes that appear similar to a hollowed-out figure-eight.

[36] According to Viking Air, there are also five aircraft that operate outside the United States and Canada.

approved secondary retention feature to retain the actuator lock ring or clamp nut (FAA 2023).[37]

1.10.2 Left Elevator Auxiliary Spar

Because the FAA received a report from an operator (not the accident operator) that detected cracks on two of its airplanes through visual inspection during routine maintenance, the FAA published an airworthiness concern sheet (ACS) on September 15, 2022, to solicit information from all operators of DHC-3 airplanes.[38] The ACS asked operators to provide any information on cracking of the elevator auxiliary spar on DHC-3 airplanes (FAA 2022c).

On October 4, 2022, the FAA issued Emergency AD 2022-21-51 applicable to all DHC-3 airplanes requiring repetitive detailed visual inspections of the entire left elevator auxiliary spar for cracks, corrosion, and previous repairs. The inspection was required to be completed within 10 hours TIS or 3 days after receipt of the emergency AD, whichever came first, and repetitively at intervals not to exceed 110 hours TIS (FAA 2022a).[39] If any cracks, corrosion beyond Level 1, or previous repairs were found, the AD required the replacement of the left elevator auxiliary spar.[40] The AD also required operators to report the results after each inspection.

[37] SAIB 2023-05 was issued to alert DHC-3 operators about information gathered from this accident investigation. According to the SAIB, the intent was to share available information from the investigation that may benefit the safety of the 2023 Otter operational season.

[38] The cracks were located at the inboard end of the left elevator auxiliary spar adjacent to the elevator trim tab balance weight. The affected airplanes were in compliance with previously issued AD 2011-18-11, which required elevator control tabs be inspected for discrepancies. This AD was issued in response to concern that excessive free-play in the elevator control tabs could develop, which could lead to loss of tab control linkage and severe elevator flutter. Such elevator flutter could lead to possible loss of control.

[39] The emergency AD further stated airplanes that had an inspection of the left elevator auxiliary spar within the previous 90 days were not required to undergo the first inspection required by this AD.

[40] According to FAA Order 8300.12, "Corrosion Prevention and Control Programs," dated November 29, 1993, Level 1 corrosion is damage occurring between successive inspections that is local and can be reworked/blended out within allowable limits as defined by the manufacturer in a structural repair manual, service bulletin, etc.

1.10.3 Secondary Locking Mechanism

The DHC-3 was certificated in Canada in 1952. At that time, US Civil Air Regulations (CAR) required a single locking mechanism for fasteners such as the clamp nut.[41] Specifically, CAR 3.294—Standard Fastenings stated, in part:

> All bolts, pins, screws, and rivets used in the structure shall be of an approved type. The use of an approved locking device or method is required for all such bolts, pins, and screws. Self-locking nuts shall not be used on bolts subject to rotation during the operation of the airplane.[42]

In 1996, the then-equivalent US Federal Aviation Regulations (FAR) were amended to require two locking devices. Specifically, 14 *CFR* 23.607 states in part, "Each removable fastener must incorporate two retaining devices if the loss of such fastener would preclude continued safe flight and landing." These regulations applied only to newly designed airplanes in the normal category (14 *CFR* Part 23 airplanes). As of the date of this report, there is no requirement to retrofit existing aircraft with a secondary locking device.

After this accident and based on the preliminary information published, another DHC-3 operator began development of a secondary lock feature for the horizontal stabilizer trim actuator clamp nut. As a result, the FAA issued Supplemental Type Certificate (STC) No. SA02761SE on January 31, 2023.

The STC provides a secondary retention method for the stabilizer actuator clamp nut, helping to prevent the clamp nut from unscrewing if the lock ring disengages, fails, or is inadvertently not installed. The STC provides a new clamp nut with a raised flange on the upper edge where safety wire can be attached. A new drilled head screw block bolt, washers, and castellated nut are provided to allow for the installation of safety wire between the clamp nut and bolt, and a new lock ring is provided for the clamp nut. The STC instructions state that only one hole is allowed in the clamp nut.

1.10.4 Loss of Pitch Control Events

This investigation identified two previous accidents in which failures related to the horizontal stabilizer trim actuator resulted in a horizontal stabilizer that was not

[41] The type certificate data sheet for the DHC-3, A-815, lists the certification basis of CAR 10 (Certification and Approval of Import Aircraft and Related Products) and CAR 3 (Airplane Airworthiness – Normal, Utility, Acrobatic, and Restricted Purpose Categories).

[42] The effective date of CAR 3.294 was November 1, 1949.

controlled by the actuator and was able to freely float to some degree. In both cases it was reported that the accident aircraft pitched down.

The first accident occurred on June 20, 1989, involving a DHC-3 airplane, in Palmer, Alaska.[43] The NTSB's accident report cited the following failure mode for the horizontal stabilizer trim actuator: "the aluminum sleeve which the steel shaft threads into was totally without threads. The steel shaft could be moved in and out of the sleeve without resistance." This failure mode would have resulted in an uncontrollable horizontal stabilizer, with the likely allowable movement of the stabilizer in the trailing edge down direction limited by at least the length of the actuator in its most retracted position. The accident report further stated that when the failure occurred, the nose of the aircraft quickly pitched down.

The second event occurred on November 1, 2001, involving a Canadian registered DHC-3 airplane. The NTSB was notified of the event by the FAA because a service difficulty report (SDR) was filed by the Canadian operator.[44] According to the SDR, shortly after takeoff, "the [airplane's] control column pitched violently forward and back before returning to a neutral position. The aircraft then pitched down and contacted the water in a nose down, wings level attitude." The report further stated, "Investigation revealed the cable-operated jackscrew jammed due to internal corrosion of the jackscrew. Once jammed, the rivet securing the fork end to the actuator sheared resulting in a free-floating horizontal stabilizer."

1.10.5 Manufacturer Maintenance Guidance

A review of the AMM (the document that maintenance personnel used to maintain and ensure the airworthiness of the accident airplane) revealed no information regarding whether the orientation of the horizontal stabilizer actuator lock ring was important for proper engagement. It also did not provide inspection criteria to determine if the lock ring was suitable for reuse or if it was installed correctly.

Regarding the clamp nut for the horizontal stabilizer actuator assembly, the AMM did not specify a torque value that should be used when securing the clamp nut to the horizontal stabilizer trim actuator assembly barrel. The AMM also did not authorize the drilling of additional holes in the clamp nut or provide guidance pertaining to what the acceptable condition of the holes should be if maintenance personnel became aware of them.

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[43] The NTSB case number for this report is ANC89IA099.

[44] The report can be found on the FAA SDR website by searching the date of the event.

Regarding a lubrication schedule for the horizontal stabilizer trim actuator, a review of the DHC-3 AMM revealed a lubrication diagram that included symbols to specify the frequency and type of application; no written instructions were included regarding the lubrication requirements (see figure 13).[45] Based on the diagram, maintenance personnel should apply one type of grease to the upper end of the horizontal actuator using a grease gun at each 100-hour inspection and internally apply another type of grease, by hand, every 400 hours.[46]

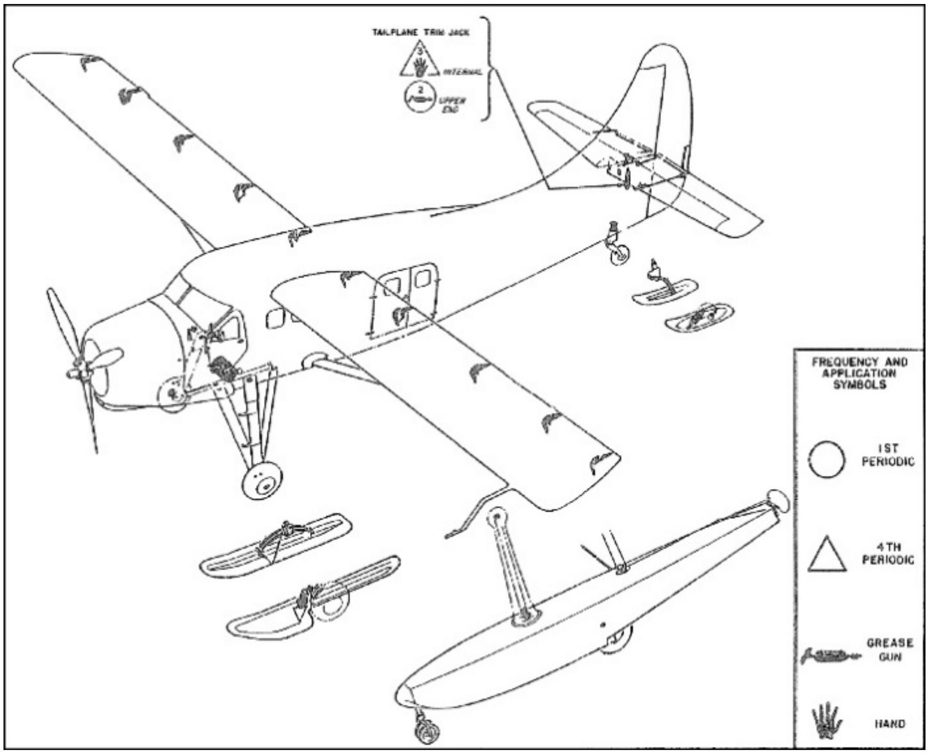

Figure 13. Lubrication diagram for the airplane (Source: Viking Air, edited by NTSB).

[45] A grease gun is a tool used for applying lubricants and greases to various mechanical or moving parts.

[46] The diagram uses the term "tailplane trim jack" for the horizontal stabilizer trim actuator.

2. Analysis

2.1 Introduction

The accident occurred when the float-equipped airplane impacted the water in Mutiny Bay during a scheduled passenger flight from Friday Harbor Seaplane Base (W33), Friday Harbor, Washington, to Will Rogers Wiley Post Memorial Seaplane Base (W36), Renton, Washington. The accident occurred during the pilot's second trip of the day; each trip involved multiple flight legs, and the accident flight was the fifth leg of the second trip.

About 18 minutes into the flight, the airplane began a climb, reaching a maximum altitude of about 1,000 ft msl before entering a rapid descent. Flight track data ended shortly thereafter. Witnesses near the accident site reported, and security camera video confirmed, that the airplane was in level flight before it entered a slight climb and then pitched down in a nose-low, near-vertical descent until water impact.

Examination of the airplane revealed that the clamp nut that attaches the top eye end and bearing assembly of the horizontal stabilizer trim actuator to the actuator barrel had unscrewed from the barrel. The examination also found that the circular wire lock ring, which was designed to prevent the clamp nut from unscrewing, was not present.

This analysis discusses the accident sequence (section 2.2), provides details about how the clamp nut was able to become unscrewed from the actuator (section 2.2.1), how the loss of pitch control occurred (section 2.2.2), and evaluates the following:

- the function and critical importance of the lock ring to secure the clamp nut to the horizontal stabilizer trim actuator barrel (section 2.2.3);
- potential failure modes of the lock ring identified through experimental testing of an exemplar lock ring (section 2.2.4);
- safety actions taken during the investigation that prompted inspections of all DHC-3 airplanes to ensure that the lock ring was secure in the horizontal stabilizer trim actuator (section 2.2.5);
- the benefit of a secondary locking feature to ensure that the clamp nut would remain attached to the barrel if the lock ring becomes disconnected or is not installed (section 2.2.5);
- the unintended consequences of the installation of an unapproved moisture seal, which likely interfered with the clamp up of the top eye end

and bearing assembly and increased the rotational friction between the clamp nut and eye bolt (section 2.2.6);

- the importance of clear and concise guidance from the manufacturer regarding the horizontal stabilizer actuator inspection and maintenance procedures (section 2.3)

The investigation did not identify safety issues in any of the following areas:

- *Pilot qualification or medical condition*. The pilot held a commercial pilot certificate and met the qualifications specified by regulations and company requirements. No evidence was found of any significant medical conditions. Ethanol was detected in the pilot's postmortem toxicological specimens, but some or all of this ethanol might have been produced after his death, a possibility made more likely by his severe traumatic injuries and the delayed recovery of his remains. Although the toxicological results could not be used to determine whether the pilot had consumed ethanol, the circumstances of the accident indicated no likely means by which known effects of ethanol might have contributed to the outcome.
- *Weather conditions*. Visual meteorological conditions prevailed at the time of the accident and moderate turbulence was reported in the area.[47] Company procedures instructed pilots to allow the airplane to climb with the turbulence, expecting that climbing would result in less stress on the airplane than attempting to hold altitude. Therefore, although it is possible that the airplane encountered turbulence and that the pilot might have initiated a climb because of the turbulence, it is not likely that the turbulence initiated the accident sequence.
- *Observed cracking on the horizontal stabilizer auxiliary spars*. Examination of the auxiliary spars identified cracking and the presence of a doubler that was installed as a repair for the cracking.[48] However, because the repair was still intact, and the cracking did not result in structural failure, the identified cracking did not contribute to the accident.

Thus, the NTSB concludes that none of the following were safety issues for the accident flight: (1) pilot qualification deficiencies or impairment due to a medical condition, (2) weather conditions at the time of the accident, or (3) observed cracking on the horizontal stabilizer auxiliary spars.

[47] Visibility of 10 statute miles was reported, and the lowest cloud layer reported was few clouds at 4,000 ft.

[48] The FAA issued Emergency AD 2022-21-51 after the accident (on October 4, 2022) because of reports of maintenance personnel noticing cracking on the auxiliary spars of another airplane. The auxiliary spars were examined as a precautionary measure.

2.2 Accident Sequence

According to ADS-B data, the airplane departed W33 and flew a southerly heading before turning south-southeast. The en route altitude was between 600 and 1,000 ft msl, and the groundspeed was between 115 and 135 knots. About 18 minutes after departure, the airplane's altitude was 1,000 ft msl, and the groundspeed reduced to 111 knots. Performance calculations indicated that, at this time, the airplane had pitched up about 8° and then abruptly pitched down 58°. The data ended 8 seconds later, when the airplane was at an altitude of 600 ft msl and had a descent rate that was more than 9,500 fpm.

Witnesses near the accident site reported, and security camera video confirmed, that the airplane was in level flight before it entered a slight climb and then pitched down in a near-vertical descent. Several witnesses described the airplane as "spinning," "rotating," or "spiraling" during portions of the steep descent. One witness reported hearing engine/propeller noise and noted that he did not hear any "pitch change" in the noise. The airplane continued in a nose-low, near-vertical descent until it impacted the water in Mutiny Bay.

2.2.1 Horizontal Stabilizer Actuator Assembly Failure Sequence

Examination of the airplane revealed that the clamp nut that attaches the top eye end and bearing assembly of the horizontal stabilizer trim actuator to the actuator barrel had unscrewed from the barrel. The examination also found that the circular wire lock ring, which was designed to prevent the clamp nut from unscrewing, was not present.

The lower center skin of the horizontal stabilizer displayed a round hole that matched the size and shape of the horizontal actuator barrel. A circular grease imprint and deformation pattern was observed on the contact surface. The aluminum fracture faces surrounding the hole did not exhibit any indications of a transfer of the cadmium or zinc coating that is typically present on the outer surface of a lock ring; this observation suggested the lock ring was not present at the time the hole was made.

The grease imprint and deformation pattern were consistent with the top of the actuator upper barrel assembly punching through the lower skin of the horizontal stabilizer without the top eye end and bearing assembly present. This damage indicated that the clamp nut unscrewed first and, with the actuator rotated full forward about the lower attachment bolt, the top of the actuator barrel contacted the lower center skin of the horizontal stabilizer and punched through, deforming the skin at a 90° angle.

Additionally, the horizontal stabilizer shelf was crushed downward near the location of the stabilizer rear spar. Linear scrapes on the horizontal stabilizer lower skin rivet lines coincident with the edges of the shelf indicated that aerodynamic force likely moved the horizontal stabilizer beyond normal travel limits to the trailing-edge-down position as a result of the top eye end and bearing assembly of the horizontal stabilizer actuator separating from the barrel. The left elevator upper skin had two small areas of multiple shallow indentations forward of the auxiliary spar that were consistent with impacts from the trim tab balance weight, which occurred when the horizontal stabilizer traveled beyond its design limits.

2.2.2 Exemplar Aircraft Stabilizer Movement Comparison and Previous Accidents

The NTSB examined a similar (exemplar) aircraft to compare the movement limits of the stabilizer. On the exemplar aircraft, as the stabilizer moved to the trailing-edge-down position, the left elevator trim tab balance weight approached the elevator upper skin but did not contact the elevator upper skin as observed on the accident airplane. The trim tab balance weight did not contact the surface because the stabilizer movement was bound by its design limits.

For the accident airplane, it was possible for the horizontal stabilizer to reach a point in the trailing-edge-down position beyond its normal limits of travel where the balance weight could contact the elevator surface after the clamp nut of the horizontal stabilizer trim actuator unscrewed from the barrel. In addition, because the balance weight arm was found bent at a 90° angle, the indentations observed on the left elevator upper skin had to occur before the balance weight arm was bent.

Additionally, the investigation identified two previous accidents in which failures related to the horizontal stabilizer trim actuator resulted in a horizontal stabilizer that was not controlled by the actuator and the horizontal stabilizer was able to freely float to some degree. In both cases the accident airplane reportedly pitched down, similar to the airplane involved in the Mutiny Bay accident. Therefore, based on the physical evidence discovered on the accident airplane, examination of an exemplar aircraft, video evidence of the accident, and the reported aircraft behavior in two known historical events, the NTSB concludes that a failure in the horizontal stabilizer trim actuator caused the accident airplane to abruptly pitch down during the accident sequence, from which recovery was not possible.

2.2.3 Lock Ring

Despite a visual search of the airplane wreckage as well as a search with a magnet, the lock ring was not found. Therefore, the investigation could not determine whether the lock ring was installed and failed or whether it was never installed. Maintenance personnel reported they reinstalled the lock ring when the internal bearings in the horizontal stabilizer trim actuator were last replaced (5 months before the accident).

Testing performed on the accident and exemplar actuators showed that when simulating normal trim wheel movement without a lock ring present, the clamp nut could rotate (screw and unscrew) within the actuator barrel depending on which way the barrel was turning. Because the accident airplane's clamp nut was able to rotate in both directions with normal trim wheel operation, over time it could unscrew then be screwed back in within the barrel. Also, any starting torque or friction between the clamp nut and barrel could prevent or delay the clamp nut from unscrewing from the barrel. For these reasons, it was not possible to determine how long the lock ring was missing from the accident airplane.

Because of the NTSB's finding early in the investigation that a missing or an improperly installed horizontal stabilizer actuator lock ring could result in a reduction or loss of pitch control during flight in DHC-3 airplanes and a concern that other DHC-3 airplanes could be missing lock rings, the NTSB issued urgent safety recommendations to the FAA (A-22-23) and TC (A-22-24) about 7 weeks after the accident. These recommendations asked that all operators of US- and Canadian-registered DHC-3 airplanes be required to conduct an immediate one-time inspection of the horizontal stabilizer trim actuator lock ring in accordance with the instructions in Viking Air SL DHC-3-SL-27-001 and report their findings to the respective regulatory agencies.

The FAA acted promptly in response and, on November 2, 2022, issued AD 2022-23-08, which was applicable to all US-registered DHC-3 airplanes, requiring a one-time visual inspection of the stabilizer trim actuator lock ring to ensure that it was present and correctly installed and that a torque seal was applied. The AD required the inspection to be completed within 10 hours TIS after the effective date of the AD, with the results reported to the FAA. Consequently, Safety Recommendation A-22-23 was classified Closed—Acceptable Action on February 22, 2023.

TC also acted promptly in response and on November 2, 2022, issued CASA 2022-04. This safety alert notified owners, operators, and maintainers of DHC-3 airplanes in Canada of this accident and recommended that they complete the inspection and corrective actions described in Viking Air's SL and report the findings to Viking Air (TC 2022). CASA 2022-04 also noted that a red-colored seal was installed between the actuator clamp nut and upper bearings on the accident airplane. As a result, TC recommended that when the actuator is disassembled to carry out periodic lubrication and inspection requirements, maintainers should ensure that the configuration of the actuator components is according to the type design.

TC also reported that the findings from the inspections described in Viking Air's SL did not indicate a systemic issue related to the actuator lock ring but that it was still investigating this safety issue to determine if any mandatory corrective actions are needed for DHC-3 airplanes. On December 19, 2022, Safety Recommendation A-22-24 was classified Open—Acceptable Alternate Response, pending confirmation from TC that all DHC-3 airplanes registered in Canada have been inspected in accordance with Viking Air's SL.

On February 7, 2023, TC reported that the owners of about 82% of Canada's DHC-3 fleet had either completed Viking Air's SL or planned to do so before returning their aircraft to service and that TC was working with the type certificate holder to contact the owners of the remaining 18% of the fleet. TC further confirmed that a copy of the CASA was sent to all contracting states and known states of registry on November 2, 2022.

As of August 24, 2023, the FAA reported that 16 US-registered airplanes (out of 67 airplanes in the US fleet) and 3 Canadian-registered airplanes had been inspected, with no reports of missing or incorrectly installed lock rings. Although the NTSB is unaware of any reports of a clamp nut completely unthreading in flight, a Canadian operator voluntarily reported that, in 2019, it discovered an actuator with a lock ring that was completely broken in half. One half of the lock ring was found in the lower fuselage, and the other one-half remained on the actuator with the tang barely engaged in the barrel hole. A crack was also visually observed in the tang bend of the lock ring. The clamp nut had a double-drilled hole in the threads and was backed out about one-half turn from its secured position, demonstrating an in-service occurrence of the clamp nut unscrewing when the lock ring was not securing it in place.

The same operator further reported that, in 2019, it found a lock ring installation in which the tang was through the barrel hole but was not fully engaged in the clamp nut hole. In this instance the nut had not rotated from its secured position.

Therefore, as demonstrated in laboratory testing and from the evaluation of an in-service occurrence, the NTSB concludes that it is possible for a clamp nut to unscrew from its barrel during DHC-3 airplane operations if the lock ring is not present or if the lock ring is damaged such that it does not retain the clamp nut, which would then allow the top eye end and bearing assembly to separate from the actuator and result in a loss of pitch control.

2.2.4 Exemplar Lock Ring Examination and Experimental Testing

Examination of an exemplar lock ring found that its inner diameter in the general area of the tang measured 1.79 inches, which was greater than the specified range of 1.73 to 1.77 inches. The age of the exemplar lock ring was unknown;

therefore, it is unknown whether the out-of-specification inner diameter was caused by repeated installations over time, a one-time event, or a manufacturing defect.

In addition, the inner radius of the lock ring tang bend was 0.04 inches (less than the specified range which was 0.0782 inches to 0.109 inches), and a bevel was observed at the end of the tang portion. The bevel could have resulted either from wear or from the manufacturing process, which was also suspected of contributing to the lock ring disengaging from some of the holes in the lock nut during the experimental testing.

Experimental testing with the lock ring revealed that, when the lock ring tang was inserted into the barrel through-hole, the length of the tang portion protruded about 0.027 inches beyond the inner threads of the barrel. When the lock ring was compressed with a C-clamp so that all portions of the lock ring made full contact with the circumferential groove portion of the barrel, the tip of the tang portion extended about 0.064 inches beyond the inner threads of the barrel (slightly more than double the length compared with that of a free-sitting non-compressed lock ring).

In general, the experimental testing provided an in-service example of a lock ring that did not retain the clamp nut as designed. The NTSB therefore concludes that deformation of the inner diameter of the lock ring, the condition of the lock ring tang, or the radius of the tang bend can prevent the lock ring from retaining the clamp nut as intended by design.

To prevent the lock ring from potentially failing or disengaging from the clamp nut hole, the NTSB recommends that Viking Air develop inspection criteria for maintenance personnel to determine whether the horizontal stabilizer trim actuator lock ring is airworthy or needs to be replaced; the inspections should be performed at an interval that ensures safe flight.

2.2.5 Secondary Retention Feature

A missing or failed lock ring is a source of a single-point failure in the horizontal stabilizer actuator assembly, as demonstrated by the circumstances of this accident, laboratory testing, and a report of an in-service failure. At the time the accident airplane's design was certificated in 1952, certification regulations only required a single locking mechanism for fasteners such as the clamp nut. In 1996, the regulations were amended to require two locking devices "if the loss would preclude continued safe flight and landing." However, these regulations only applied to newly designed (normal category) aircraft. There is no requirement to retrofit existing aircraft with a secondary locking feature.

After the accident and based on the preliminary information published, another DHC-3 operator began developing a secondary locking feature for the horizontal stabilizer trim actuator clamp nut. As a result, the FAA issued STC No. SA02761SE 4 months after the accident. The STC approves for installation a secondary retention feature that includes a newly designed clamp nut with a raised flange on the upper edge where safety wire can be attached; this feature is intended to prevent the clamp nut from unscrewing if the lock ring is missing or fails. The NTSB believes this proactive approach is a positive step to preventing the horizontal stabilizer trim actuator clamp nut from becoming unscrewed from the barrel if the lock ring is missing or fails.

The NTSB notes that the FAA and TC issued AD 2022-23-08 and CASA 2022 04, respectively, during the accident investigation requiring (in the case of AD 2022-23-08) and recommending (in the case of CASA 2022-04) operators to visually inspect the stabilizer trim actuator lock ring to ensure it was present, but this was just a one-time inspection. AD 2022-23-08 also required a torque seal be applied to the clamp nut. Additionally, the FAA's issuance of SAIB 2023-05 provided further opportunities to mitigate the hazards identified in this investigation, specifically related to the lock ring.[49]

The NTSB notes that if operators act on the recommendations outlined in the SAIB, the safety issues identified in this investigation may be mitigated in other DHC-3 airplanes. However, because SAIBs are only advisory in nature, the NTSB is concerned that not all operators will take the recommended action, like installing a secondary retention feature. This concern is heightened considering the different reasons a lock ring may become disengaged from the clamp nut, such as incorrect installation, deformation of the lock ring, or damage to a lock ring hole in the clamp nut could prevent the lock ring from seating properly.

The NTSB remains concerned that this hazard can be catastrophic and represents a single point of failure. Therefore, the NTSB concludes that a secondary retention feature for the DHC-3 horizontal actuator assembly clamp nut is necessary to mitigate the potential single-point-of-failure hazard represented by a missing or defective lock ring. Therefore, the NTSB recommends that the FAA require operators of DHC-3 airplanes to install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut.

We recognize that this installation could take time for operators to implement; therefore, as an interim measure, the NTSB recommends that the FAA require operators of DHC-3 airplanes to visually inspect both the horizontal stabilizer actuator

[49] The SAIB recommended operators check the lock ring and clamp nut for engagement, perform repetitive visual inspection of the actuator at intervals not exceeding 110 hours, and install an approved secondary retention feature to retain the actuator lock ring or clamp nut.

lock ring and the associated torque seal at an interval that ensures safe flight or until a secondary retention feature is installed.

Because the type certificate for the DHC-3 is held by Viking Air, based in Canada, the NTSB makes companion recommendations to TC. The NTSB recommends that TC require operators of DHC-3 airplanes to install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut. The NTSB also recommends that TC require operators of DHC-3 airplanes to visually inspect the horizontal stabilizer actuator lock ring at an interval that ensures safe flight or until a secondary retention feature is installed.

The NTSB notes that while the intent of AD 2022-23-08 (issued by the FAA) and CASA 2022-04 (issued by TC) was similar, the language contained in these documents differed regarding a torque seal requirement. AD 2022-23-08 required a torque seal be applied to the clamp nut and lock ring (in addition to the lock ring inspection); however, CASA 2022-04 did not recommend installing a torque seal. Therefore, the NTSB recommends that TC require operators of DHC-3 airplanes to install a torque seal on the horizontal stabilizer actuator clamp nut and lock ring and inspect the torque seal at an interval that ensures safe flight until a secondary retention feature is installed.

2.2.6 Moisture Seal

Examination of the horizontal stabilizer trim actuator also revealed that, during its last bearing replacement, the actuator was reassembled with a moisture seal installed between the clamp nut and the eye bolt. According to the DOM, the seal was installed to prevent environmental elements from entering the internal bearings (which were prone to corrosion and required frequent replacement) and that this was the first time maintenance personnel had installed such a seal.

Laboratory examination and experimental testing revealed that the presence of the moisture seal caused rotational friction between the clamp nut and the eye bolt. Without the moisture seal installed and no torque on the clamp nut, the eye bolt freely spun, completing multiple rotations before coming to a stop. When the same test was repeated with the moisture seal present, the top eye bolt could spin without much force applied but stopped spinning once the applied force was removed. Testing of an exemplar actuator, which had a moisture seal of a design different than that installed on the accident actuator, resulted in similar observations.

Unique to the accident moisture seal, however, was that, as the clamp nut neared the seated position, additional torque was required to seat it, and additional force was required to rotate the top eye bolt. Testing showed that with the moisture seal in the as-received condition, the eye bolt required as much as 31 in-lbs. of torque to rotate it when the clamp nut was torqued tightly using a wrench. In a second test, after the seal was reassembled and a mallet was used to seat the seal into the clamp nut, the eye bolt required 2.5 in-lbs. to rotate it when the clamp nut was torqued tightly using a wrench.

The results varied likely because of the position of the seal as installed, which could cause interference in the clamp up of the top eye end and bearing assembly.[50] The seal, in the as-received position, fit snuggly within the clamp nut and protruded approximately 0.07 inches beyond the bottom of the clamp nut. When tightening the clamp nut, the protruded seal contacted the inner race of the upper bearing and prevented the clamp nut from seating properly on the outer race of the upper bearing. Any restriction on the movement of the clamp nut caused by seal interference can add unintended stress to the lock ring.

Another test was performed to determine if the additional friction between the clamp nut and eye bolt caused by the moisture seal could cause the clamp nut to move within the barrel when the barrel was spun and the lock ring was not present. The actuator design permits the clamp nut to rotate freely with the barrel. Any friction between the clamp nut and eye bolt restrict the free rotation of the clamp nut, which will make it easier for the barrel to rotate around the clamp nut instead of the clamp nut rotating with the barrel when the barrel is spun. The testing revealed that with no torque applied to the clamp nut, it had an increased tendency to spin equally with the barrel when the moisture seal was not installed, as designed, than when the moisture seal was installed.

This testing suggests that the moisture seal increased the rotational friction between the clamp nut and eye bolt, which has the potential to increase the rate of separation between the clamp nut and barrel in the absence of the lock ring. The NTSB notes, however, that the effects of this friction on the events that occurred during the accident sequence could not be determined due to variables, such as the original thread condition (threads were cleaned before testing for examination), starting torque on the clamp nut, exact position of the moisture seal within the clamp nut, actual effects of in-flight loads (if any), and trim wheel usage (amount of rotations in the pitch-up/pitch-down directions), which could cause the clamp nut to screw and unscrew in the barrel.

The NTSB recognizes that maintenance personnel's installation of the moisture seal in the accident actuator was intended to be proactive (to prevent corrosion and a mechanical failure of the bearings). However, the unintended consequence was

[50] The term "clamp up" refers to how the adjacent parts of the assembly match up to each other when a compressive load (in this case caused by tightening the clamp nut) forces them together.

increased rotational friction between the clamp nut and eye bolt and likely interference with the clamp up of the top eye end and bearing assembly.

Thus, the NTSB concludes that maintenance personnel's installation of a moisture seal in the horizontal stabilizer actuator deviated from the manufacturer's maintenance procedures and led to increased rotational friction between the clamp nut and eye bolt and likely interference with the clamp up of the top eye end and bearing assembly.

Because a moisture seal was found installed on both the accident airplane and an exemplar airplane, the NTSB is concerned that other DHC-3 operators may have installed a moisture seal with the same intent but are unaware of the potential negative consequences. Therefore, the NTSB recommends that Viking Air notify DHC-3 operators of the circumstances of this accident and instruct them to remove moisture seals that are installed within horizontal stabilizer actuators and are not approved by Viking Air or a regulatory agency.

2.3 Manufacturer Maintenance Guidance

A review of the documents that maintenance personnel used to maintain and ensure the airworthiness of the accident airplane identified areas that lacked specificity and could be improved by adding or clarifying information. For example, a review of the DHC-3 AMM revealed a lubrication diagram that included only symbols to specify the frequency and type of application; no written instructions were included regarding the lubrication requirements.

Additionally, the guidance did not provide instructions to inspect the existing clamp nut hole(s) to ensure they were in airworthy condition, nor did it specify that additional holes could not be drilled.[51] When questioned by email about instructions for drilling additional holes, the airplane manufacturer responded, “The type design only allows for one hole in the clamp nut. If the holes in the barrel and clamp nut do not align, then the maintainer should contact Viking Air.”

Because the lock ring could have seated on the lock ring groove if a damaged hole prevented it from retaining the clamp nut, it is unlikely that the damaged holes contributed to the accident. However, the lack of guidance from the airplane manufacturer regarding only one hole in the clamp nut (or whether the clamp nut

[51] The accident clamp nut had five holes drilled in it to engage the lock ring tang, and an exemplar clamp nut provided for testing had three holes drilled in it. Maintenance personnel stated they did not drill any holes in the accident clamp nut. Three of the five holes on the accident clamp nut were damaged such that a drill bit the size of the lock ring could not be fully inserted into the hole.

should be interchanged with other actuators) is concerning for such a critical component.[52]

Multiple holes drilled in a clamp nut can present potential hazards that maintenance personnel may not be aware of. For example, if there is more than one hole in the clamp nut, maintenance personnel might be unsure which hole would provide the correct position for the clamp nut, or a mechanic could unknowingly align the lock ring with a damaged hole.

Maintenance personnel would also benefit from the inclusion of a torque requirement in the AMM for the installation of the clamp nut to ensure the clamp nut is properly secured, as intended by design, on the horizontal stabilizer actuator barrel. Currently, there is no mention of how to properly install the clamp nut in the AMM.

Regarding the lock ring installation, as of the date of this report, the AMM makes no mention of whether the lock ring is a reusable item or whether its orientation is a factor during installation. Additionally, there are no procedures specified to ensure that the lock ring is airworthy or has been installed properly.

Testing performed on an exemplar actuator and the accident actuator revealed several circumstances that could contribute to a lock ring disengaging from the clamp nut (singularly or in combination). These included a deformed lock ring radius and condition of the lock ring tang, as well as damage or deformation of the clamp nut holes, all of which likely occur over time, or handling by maintenance personnel, and could be identified by maintainers if they had the correct information.

NTSB laboratory testing on a previously in-service stabilizer trim actuator and the accident actuator demonstrated that the conditions noted above concerning the lock ring and the clamp nut holes could result in the inability of the lock ring to retain the clamp nut as intended by design. The NTSB found that the AMM, which provides the instructions that maintainers use to assemble the actuator, does not provide guidance related to these conditions.

Because there is no specific guidance relating to these components in the AMM, maintenance personnel must rely on industry practices and their experience to ensure inspections are performed properly. Consequently, the NTSB is concerned that the lack of details in the AMM could contribute to installation or mechanical failures. As a result, the NTSB concludes that clear and concise inspection and

[52] a possible reason the holes may not align during assembly is the installation of a clamp nut that was previously installed on another actuator.

overhaul criteria regarding the assembly of the horizontal stabilizer actuator are critical to prevent its failure.

Therefore, the NTSB recommends that Viking Air revise the DHC-3 AMM to include inspection and overhaul procedures for the horizontal stabilizer actuator that specify how many holes can be drilled into the clamp nut and how to determine if the holes are airworthy, a proper torque value for installing the clamp nut, and how to install the lock ring and verify that it is properly seated and functions as intended.

3. Conclusions

3.1 Findings

1. None of the following were safety issues for the accident flight: (1) pilot qualification deficiencies or impairment due to a medical condition, (2) weather conditions at the time of the accident, or (3) observed cracking on the horizontal stabilizer auxiliary spars.

2. A failure in the horizontal stabilizer trim actuator caused the accident airplane to abruptly pitch down during the accident sequence, from which recovery was not possible.

3. It is possible for a clamp nut to unscrew from its barrel during DHC-3 airplane operations if the lock ring is not present or if the lock ring is damaged such that it does not retain the clamp nut, which would then allow the top eye end and bearing assembly to separate from the actuator and result in a loss of pitch control.

4. Deformation of the inner diameter of the lock ring, the condition of the lock ring tang, or the radius of the tang bend can prevent the lock ring from retaining the clamp nut as intended by design.

5. A secondary retention feature for the DHC-3 horizontal actuator assembly clamp nut is necessary to mitigate the potential single-point-of-failure hazard represented by a missing or defective lock ring.

6. Maintenance personnel's installation of a moisture seal in the horizontal stabilizer actuator deviated from the manufacturer's maintenance procedures and led to increased rotational friction between the clamp nut and eye bolt and likely interference with the clamp up of the top eye end and bearing assembly.

7. Clear and concise inspection and overhaul criteria regarding the assembly of the horizontal stabilizer actuator are critical to prevent its failure.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight unthreading of the clamp nut from the horizontal stabilizer trim actuator barrel due to a missing lock ring, which resulted in the horizontal stabilizer moving to an extreme trailing-edge-down position rendering the airplane's pitch uncontrollable.

4. Recommendations

4.1 New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the Federal Aviation Administration:

> Require operators of DHC-3 airplanes to install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut. (A-23-1)
>
> Require operators of DHC-3 airplanes to visually inspect both the horizontal stabilizer actuator lock ring and the associated torque seal at an interval that ensures safe flight or until a secondary retention feature is installed. (A-23-2)

To Transport Canada:

> Require operators of DHC-3 airplanes to install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut. (A-23-3)
>
> Require operators of DHC-3 airplanes to visually inspect the horizontal stabilizer actuator lock ring at an interval that ensures safe flight or until a secondary retention feature is installed. (A-23-4)
>
> Require operators of DHC 3 airplanes to install a torque seal on the horizontal stabilizer actuator clamp nut and lock ring and inspect the torque seal at an interval that ensures safe flight until a secondary retention feature is installed. (A-23-5)

To Viking Air:

> Develop inspection criteria for maintenance personnel to determine whether the horizontal stabilizer trim actuator lock ring is airworthy or needs to be replaced; the inspections should be performed at an interval that ensures safe flight. (A-23-6)
>
> Notify DHC-3 operators of the circumstances of this accident and instruct them to remove moisture seals that are installed within

horizontal stabilizer actuators and are not approved by Viking Air or a regulatory agency. (A-23-7)

Revise the DHC-3 aircraft maintenance manual to include inspection and overhaul procedures for the horizontal stabilizer actuator that specify how many holes can be drilled into the clamp nut and how to determine if the holes are airworthy, a proper torque value for installing the clamp nut, and how to install the lock ring and verify that it is properly seated and functions as intended. (A-23-8)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER HOMENDY
Chair

MICHAEL GRAHAM
Member

BRUCE LANDSBERG
Member

THOMAS CHAPMAN
Member

Report Date: September 29, 2023

Appendixes

Appendix A: Investigation

The National Transportation Safety Board (NTSB) was notified of this accident on September 4, 2022, and members of the investigative team arrived on scene the following day.

Investigative groups were formed to evaluate operations, airworthiness, and metallurgy. Also, specialists were assigned to perform a meteorology study, an airplane performance study, interview witnesses and examine witness videos, review maintenance records, and review the pilot's medical records and reports.

The Federal Aviation Administration, Northwest Seaplanes, and West Isle Air dba Friday Harbor Seaplanes were parties to the investigation. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Transportation Safety Board of Canada (TSB) participated in the investigation as accredited representative of the state of design and manufacture. As provided for in Annex 13, Viking Air Limited (the current type certificate holder for the DHC-3 airplane) participated in the investigation as a technical advisor to the TSB.

Appendix B: Consolidated Recommendation Information

Title 49 *United States Code* 1117(b) requires the following information on the recommendations in this report.

For each recommendation–

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the Federal Aviation Administration

A-23-1

Require operators of DHC-3 airplanes to install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.5, Secondary Retention Feature. Information supporting (b)(1) can be found on pages 35-37; (b)(2) is not applicable; and (b)(3) can be found on pages 36-37.

A-23-2

Require operators of DHC-3 airplanes to visually inspect both the horizontal stabilizer actuator lock ring and the associated torque seal at an interval that ensures safe flight or until a secondary retention feature is installed.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.5, Secondary Retention Feature. Information supporting (b)(1) can be found on pages 35-37; (b)(2) is not applicable; and (b)(3) can be found on pages 36-37.

To Transport Canada

A-23-3

Require operators of DHC-3 airplanes install a secondary retention feature on the horizontal stabilizer actuator clamp nut to ensure it remains secured to the barrel in the event the lock ring is not installed or otherwise fails to retain the clamp nut.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.5, Secondary Retention Feature. Information supporting (b)(1) can be found on pages 35-37; (b)(2) is not applicable; and (b)(3) can be found on pages 36-37.

A-23-4

Require operators of DHC-3 airplanes to visually inspect the horizontal stabilizer actuator lock ring at an interval that ensures safe flight or until a secondary retention feature is installed.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.5, Secondary Retention Feature. Information supporting (b)(1) can be found on pages 33-37; (b)(2) is not applicable; and (b)(3) can be found on pages 33-34 and 36.

A-23-5

Require operators of DHC 3 airplanes install a torque seal on the horizontal stabilizer actuator clamp nut and lock ring and inspect the torque seal at an interval that ensures safe flight until a secondary retention feature is installed.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.5, Secondary Retention Feature. Information supporting (b)(1) can be found on page 37; (b)(2) is not applicable; and (b)(3) can be found on page 37.

To Viking Air

A-23-6

Develop inspection criteria for maintenance personnel to determine whether the horizontal stabilizer trim actuator lock ring is airworthy or needs to be replaced, to be performed at an interval that ensures safe flight.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.4, Exemplar Lock Ring Examination and Experimental Testing. Information supporting (b)(1) can be found on page 35; (b)(2) is not applicable; and (b)(3) can be found on pages 33-34.

A-23-7

Notify DHC-3 operators of the circumstances of this accident and instruct them to remove moisture seals that are installed within horizontal stabilizer actuators and are not approved by Viking Air or a regulatory agency.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.2.6, Moisture Seal. Information supporting (b)(1) can be found on pages 37-39; (b)(2) is not applicable; and (b)(3) can be found on pages 33-34.

A-23-8

Revise the DHC-3 AMM to include inspection and overhaul procedures for the horizontal stabilizer actuator that specify how many holes can be drilled into the clamp nut and how to determine if the holes are airworthy, a proper torque value for installing the clamp nut, and how to install the lock ring and verify that it is properly seated and functions as intended.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3, Manufacturer Maintenance Guidance. Information supporting (b)(1) can be found on pages 39-41; (b)(2) is not applicable; and (b)(3) is not applicable.

References

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NTSB (National Transportation Safety Board). 2022. *Require Immediate One-Time Inspection of De Havilland Canada DHC-3 Horizontal Stabilizer Actuator.* AIR-22-08. Washington DC: NTSB.

TC (Transport Canada). 2022. "Missing or Improperly Installed Stabilizer Actuator Lock Ring." Civil Aviation Safety Alert (CASA) 2022-04. Ottawa, Canada.

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