

September 26, 2024

Aviation Investigation Report AIR-24-06

Mitigate Safety Concerns Involving Boeing 737 Airplanes with Collins Aerospace SVO-730 Rudder Rollout Guidance Actuators

Introduction

The National Transportation Safety Board (NTSB) is providing the following information to urge The Boeing Company and the Federal Aviation Administration (FAA) to take immediate action on the safety recommendations in this report concerning the potential for a jammed or restricted rudder control system on certain Boeing 737 airplanes. We identified these issues during our ongoing investigation of the rudder pedal anomaly involving a Boeing 737-8, N47280, while landing at Newark Liberty International Airport (EWR), Newark, New Jersey, on February 6, 2024.

On the basis of the results of postincident testing conducted in July 2024 and information from Boeing and Collins Aerospace, the NTSB is concerned that Boeing's mitigation to overcome a jammed or restricted rudder control system during landing could also result in a large input to the rudder pedals and a sudden, large and undesired rudder deflection sufficient to cause loss of control or departure from the runway. A jammed or restricted rudder scenario could become even more concerning if a high-crosswind or an engine-out condition were simultaneously occurring with a jammed or restricted rudder, not only because the amount of rudder available to respond to these conditions might be insufficient to maintain control of the airplane if the jam is not cleared—but also because excessive rudder input may result if the jam is cleared by responding with Boeing's mitigation. As a result, the NTSB is issuing two urgent safety recommendations to The Boeing Company and two urgent safety recommendations to the FAA.

Background and Analysis

On February 6, 2024, about 1555 eastern standard time, the flight crew of United Airlines flight 1539, a Boeing 737-8, N47280, experienced a rudder pedal

anomaly while landing at EWR.¹ In a postincident statement, the captain reported that, during the landing rollout, the rudder pedals were “stuck” in their neutral position and did not move in response to the “normal” application of foot pressure to maintain alignment with the runway centerline.² The flight was operating under the provisions of Title 14 *Code of Federal Regulations* Part 121 as a scheduled international passenger flight from Lynden Pindling International Airport, Nassau, Bahamas, to EWR.³

According to data derived from the flight data recorder, the flight crew applied approximately 32 pounds of force to the rudder pedals before touchdown which yielded no discernible effect on the rudder position or heading.⁴ The flight crew attempted to clear the jammed rudder controls immediately after touchdown, applying approximately 75 pounds of force to the rudder pedals when the airspeed was about 120 knots, again with no effect on the rudder position or heading.

With the airplane’s airspeed continuing to decrease during rollout, the flight crew applied approximately 42 pounds of force to the pedals, but the jam persisted. The captain elected instead to use the nosewheel steering tiller as the airplane slowed to a safe taxi speed. The captain stated that, after the airplane entered the assigned taxiway, he asked the first officer to check the rudder pedals on his side of the flight deck, and the first officer indicated that the same anomaly was occurring.

Data derived from the flight data recorder indicate that shortly after, with the airplane traveling at a groundspeed of less than 20 knots, the flight crew applied approximately 59 pounds of force on the rudder pedals, and the rudder pedals and rudder surface began to operate normally. The airplane taxied to the gate without further incident, and all airplane occupants (2 flight crewmembers, 4 cabin

¹ According to the captain, during preflight duties for the first flight leg of the day (the incident flight was the second flight leg), he noticed a previous maintenance note regarding the rudder pedals. The captain recalled that the writeup stated, “rudder pedals stuck at neutral position on short final and had to push hard.” The captain wrote in a postincident statement that he thought that the writeup “appeared to be resolved. During our first leg, we didn’t notice anything unusual with the rudder pedals during the after-start checklist, taxi out (during the rudder check), takeoff or landing.”

² According to Boeing, rudder pedal force ranges from 15 to 75 pounds (the latter at full pedal travel), with about 45 pounds as the average pedal force during rudder use.

³ Visit [ntsb.gov](https://www.ntsb.gov) to find additional information in the [public docket](#) for this ongoing NTSB investigation (case number [DCA24LA094](#)). Use the [CAROL Query](#) to search safety recommendations and investigations.

⁴ Values presented for amounts of force applied to the rudder pedals are approximations based on the data available.

crewmembers, and 155 passengers) deplaned without any injuries or damage to the airplane.

United Airlines received the incident airplane from Boeing on February 20, 2023. The airplane was equipped with a Collins Aerospace SVO-730 rudder rollout guidance actuator, which was electrically disabled based on the operator's delivery requirements for the autoflight system.⁵ Although the actuator was disabled, it remained mechanically connected to the upper portion of the airplane's aft rudder input torque tube by the actuator's output crank arm and a pushrod, as shown in figure 1.⁶

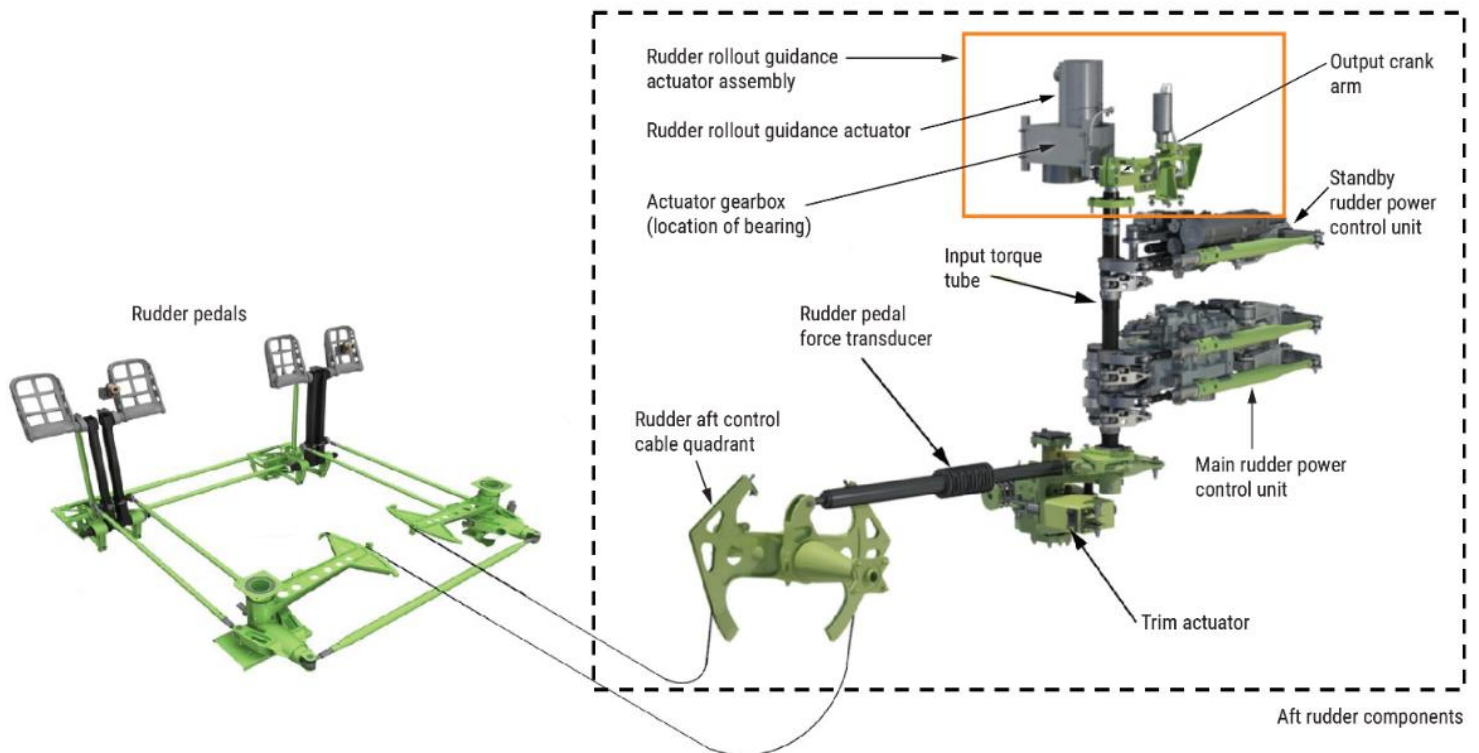


Figure 1. Rudder control system with rudder rollout guidance actuator (Source: Boeing. Image copyright Boeing. Reproduced with permission).

⁵ The Collins SVO-730 rudder rollout guidance actuator is installed only on Boeing 737NG and 737MAX airplanes equipped for category IIIB operations. (The incident 737-8 was a MAX variant.) United Airlines does not require category IIIB capability for its Boeing 737 fleet. According to FAA Advisory Circular 120-28D, category IIIB operations involve a precision instrument approach and landing with no decision height and a runway visual range less than 700 ft but not less than 150 ft.

⁶ Pilot control of the Boeing 737-8 rudder is transmitted in a closed-loop system from the pilots' rudder pedals in the cockpit, through a single cable system, an aft rudder quadrant, and a pedal force transducer, to the aft rudder input torque tube in the vertical stabilizer. Rotation of the torque tube provides the command inputs to the main and standby rudder power control units to move the rudder surface.

Postincident examination and testing of the incident SVO-730 rudder rollout guidance actuator found that the torque needed to rotate the actuator's output crank arm was 2.8 inch-pounds at room temperature; this torque value was within specified design limits. After the actuator was subjected to cold temperatures in a chamber for 1 hour, the output crank arm could not be rotated at the previous torque value. Increases in torque were incrementally applied. The torque needed for the output crank arm to start rotating was 520 inch-pounds, which significantly exceeded the specified design limits. Once the output crank arm started rotating, a torque of about 100 inch-pounds was required to sustain the rotation; this torque value also exceeded the specified design limits. Disassembly of the actuator revealed evidence of moisture within the unit, as shown in figure 2, which would account for the resistance observed in excess of specified design limits.

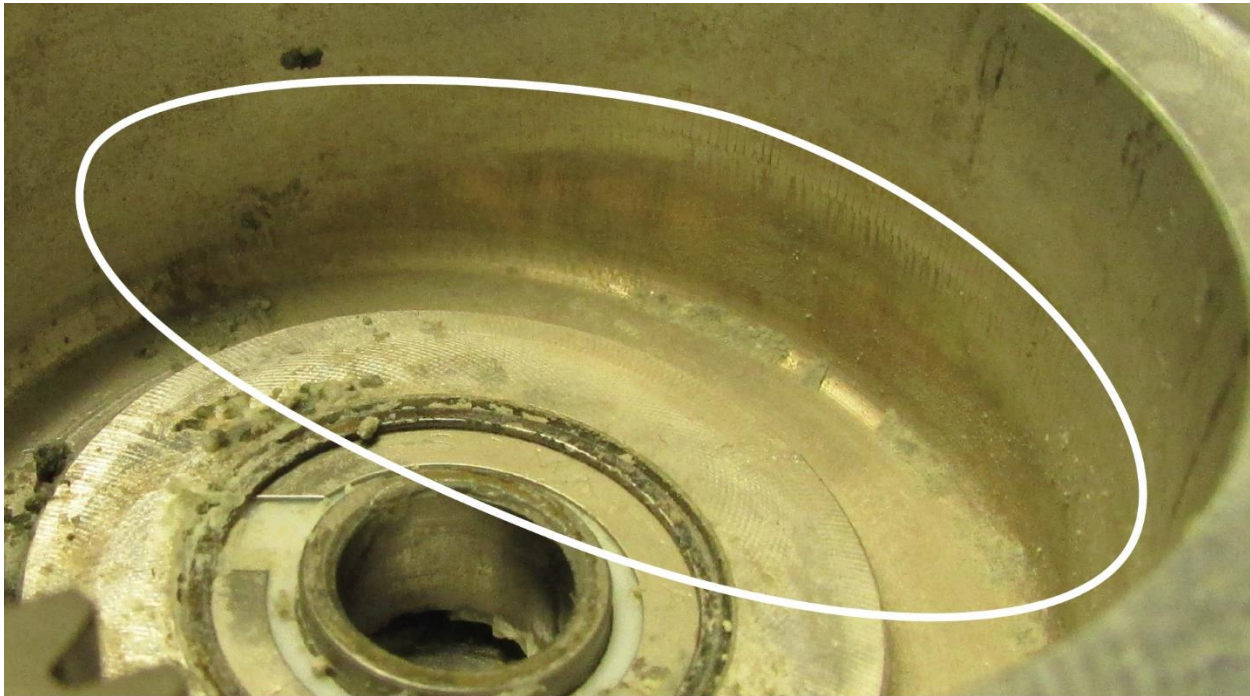


Figure 2. Incident actuator bearing with area of moisture (Source: Collins Aerospace).

Note: The image in the figure is magnified and not an accurate representation of its size.

Afterward, three additional SVO-730 rudder rollout guidance actuators were examined and tested in the same manner (cold soaking) as the incident actuator. One actuator was an in-service unit that United Airlines removed from another Boeing 737 airplane in its fleet as part of a removal service bulletin that the airline requested from

Boeing regarding the actuator as a result of this incident.⁷ The other two actuators were provided by Collins from its service center.

The test results were compared with those from the incident actuator. Results for one of the three actuators were similar to the incident actuator: The unit failed the cold chamber test, and the torque to move its output crank arm was substantially beyond the specified design limits when subjected to cold temperatures.⁸ Disassembly of this actuator found evidence of moisture and corrosion in the area adjacent to the pressure test port pinhole.⁹ Also, evidence of pooled moisture (staining/discoloration) was found inside this actuator on the bottom and sidewall of the actuator gearbox, which was the same area in which moisture was observed inside the incident actuator.¹⁰ The test results suggested the possibility that the pressure test port pinhole provided a path for moisture ingress.

During a postincident internal review, Collins determined that a sealed bearing in the incident actuator's clutch assembly was not assembled according to drawing requirements during the actuator's production. Specifically, Collins found that a clutch bearing on the upper gearbox assembly was inadvertently assembled with the seal facing toward the clutch teeth instead of the seal facing away from the clutch teeth. On August 12, 2024, Collins notified Boeing that 353 SVO-730 rudder rollout guidance actuators it had delivered to Boeing were affected.¹¹ Collins provided its

⁷ Nine of United Airlines' Boeing 737 airplanes had initially been configured for another operator with SVO-730 rudder rollout guidance actuators (including the airplanes with the incident actuator and the actuator referenced in this sentence). As with the incident actuator, the other eight actuators were electrically disabled (according to a service bulletin dated November 10, 2022) based on United's delivery requirements for the autoflight system. These eight actuators also remained mechanically connected to the upper portion of the aft rudder input torque tube by the output crank arm and pushrod. A service bulletin, dated May 6, 2024, provided instructions that allowed United to permanently remove the SVO-730 rudder rollout guidance actuators from its 737 airplanes.

⁸ This actuator was from Collins' service center. A second actuator also failed the test, but the results did not significantly exceed the specified design limits. A third actuator (which was previously installed on a United Airlines Boeing 737 airplane) passed the test.

⁹ According to Collins, the pressure test port is used to test production actuators before delivery. The pressure test port is on the upper gearbox, and the area with pooling is inside the lower gearbox.

¹⁰ Of the two actuators tested that did not fail, one was an actuator that United Airlines had removed from its fleet; during post-testing disassembly, it was observed that the bearing had been assembled incorrectly but showed no evidence of moisture ingress. The other actuator that did not fail was also subsequently disassembled; its bearing had been assembled correctly and did not show evidence of moisture ingress.

¹¹ Collins delivered this notice in a letter to Boeing with the subject "SVO-730 Clutch Bearing Installation."

safety assessment to Boeing that indicated the possibility of a hazard related to these 353 actuator units.

In response to this information, Boeing issued Multi Operator Message MOM-MOM-24-0442-01B on August 23, 2024, to both domestic and foreign operators. The message explained the issue of the clutch bearing's misassembly and stated that 353 affected actuator units were delivered to Boeing starting in February 2017.¹² The message also stated that the incorrect manufacture of the bearing made the actuator assembly "more susceptible to moisture ingress." Boeing stated in the message that it had determined the issue posed no immediate threat to safety. However, the multi-operator message stated that, to reduce "any unnecessary risk" in the 737 fleet, Boeing would develop a plan to remove the affected actuator units from the fleet and replace them with conforming units, which Collins would provide. Boeing indicated that its plan and the associated timeline would be shared when available with 737 operators.

The NTSB's investigation of this incident is ongoing. However, preliminary findings suggest that the rudder control system was stuck (as discovered during the landing rollout) as a result of moisture that previously entered the actuator through the pressure test port pinhole, migrated to the incorrectly assembled sealed bearing, and froze during flight. This scenario would explain why the incident captain had difficulty using the rudder pedals for directional control immediately after touchdown.

According to information from United Airlines' Boeing 737 flight manual (section 2.90.38, Non-Normals/Flight Controls), Boeing's mitigation for a jammed or restricted flight control in the yaw axis in flight or during landing is to "overpower the jammed or restricted [rudder control] system."¹³ As previously stated, Collins determined that 520 inch-pounds of torque was required to move the actuator's output crank arm due to the restriction that resulted after the actuator was subjected to cold temperatures and the moisture (via cold soaking) had frozen.

Boeing subsequently calculated that the 520 inch-pounds measured during the testing would correlate to about 87 pounds of force applied to the rudder pedals. However, this amount of force applied during landing or rollout could, in clearing a

¹² Collins moved its manufacturing facility from Melbourne, Florida, to Mexicali, Mexico, in February 2017. The 353 actuator units that Collins and Boeing identified were all manufactured in the Mexicali facility.

¹³ The United Airlines' Boeing 737 flight manual also stated to "use maximum force, including a combined effort of both pilots, if needed. A maximum two-pilot effort on the controls will not cause a cable or system failure." This section implied that pilots should apply as much force as they would be capable of exerting.

jam or restriction, also result in a large input to the rudder pedals and a sudden, large, and undesired rudder deflection that could unintentionally cause loss of control or departure from a runway. Accordingly, the NTSB is concerned that Boeing's mitigation for a jammed or restricted rudder control system—to apply maximum force to overcome the jam or restriction as indicated in the *Boeing 737 Quick Reference Handbook*—might not be appropriate during a landing or rollout for the same reason.

The NTSB notes that, because the flight crew's substantial applications of force to the rudder pedals during landing and immediately after touchdown were insufficient to clear the restriction, a large, sudden, and undesired rudder input and its likely consequences did not occur during these critical phases of flight.^{14,15}

During the investigation of this incident, the NTSB learned that, in general, United Airlines was unaware that the rudder rollout guidance actuator was installed on nine of its Boeing 737 airplanes, each of which had an autoflight system that had been reconfigured from category IIIB to category IIIA capability.¹⁶ The NTSB is therefore concerned that Boeing 737 flight crews might not be aware that (1) some 737 airplanes are equipped with a rudder rollout guidance actuator that remains mechanically engaged even when electrically disconnected, and (2) some of these actuators might become restricted in flight or during landing due to a manufacturing defect that allows moisture to accumulate inside it and freeze. The NTSB is also concerned that Boeing 737 flight crews might not be aware of the appropriate response if this condition were encountered in flight or during landing.

The NTSB is unaware of any simulator training for Boeing 737 flight crews in which a large force input is needed to overcome a restricted rudder control system. In response to a 1999 NTSB safety recommendation, the FAA stated that its inspectors were required to determine whether operators of Boeing 737 airplanes were providing initial and recurrent training on the "jammed or restricted rudder

¹⁴ The output crank arm of the Collins SVO-730 rudder rollout guidance actuator includes shear pins that are designed to break with substantially greater pedal force than the flight crew applied in this incident if a jam or restriction occurs within the actuator, which would allow normal operation of the rudder control system to resume.

¹⁵ In a postincident statement, the captain explained, "I did not want to push too hard on the rudder pedals in case it released suddenly."

¹⁶ The rudder rollout guidance actuator is not required for United Airlines' category IIIA operations. FAA Advisory Circular 120-28D defines category IIIA as a precision instrument approach and landing with a decision height lower than 100 ft or no decision height and a runway visual range not less than 700 ft.

procedures” in the Boeing 737 operations manual.¹⁷ However, only general procedures for jammed or restricted flight controls are provided in the Boeing 737 *Airplane Flight Manual* and *Flight Crew Operating Manual*, and the rudder rollout guidance actuator is not mentioned as a potential source for a jam or restriction in the rudder control system. Among these procedures, flight at a warmer altitude—if the flight crew suspects that frozen water has caused a jam—is recommended only after the crew is advised to first attempt applying “maximum force, including a combined effort of both pilots” to “overpower the jammed or restricted system.”

Although the incident flight crew was able to respond successfully to the restricted rudder control system without knowledge about the failure mode related to the rudder rollout guidance actuator, other flight crews would benefit from advance notification about the possibility of encountering a restricted rudder control system in flight or during landing. The NTSB concludes that informing Boeing 737 flight crews of (1) the potential for a restricted rudder control system in airplanes equipped with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings and (2) the appropriate mitigations if such a situation were to occur in flight or during landing would help prevent undesired rudder input and its likely consequences during these critical phases of flight.

As a result, the NTSB recommends that Boeing instruct operators of 737NG and 737MAX airplanes with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings to notify flight crews that the rudder control system might become jammed or restricted in flight or during landing due to moisture that could accumulate and freeze in the actuators.

The NTSB also recommends that Boeing determine, for 737NG and 737MAX airplanes with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings, appropriate flight crew responses, besides applying maximum rudder pedal force, if the condition described in Safety

¹⁷ On April 16, 1999, the NTSB issued Safety Recommendation A-99-25, which asked the FAA to “require all 14 Code of Federal Regulations part 121 air carrier operators of the Boeing 737 to provide their flight crews with initial and recurrent flight simulator training in the ‘uncommanded yaw or roll’ and ‘jammed or restricted rudder’ procedures in Boeing’s 737 operations manual.” On October 1, 2001, the FAA stated that it issued (in December 2000) Joint Flight Standards Information Bulletin for Air Transportation 00-16A, which directed flight standards district offices, certificate management offices, and principal operations inspectors to ensure that all Part 121 air carriers that operate Boeing 737 airplanes provide their flight crews with initial and recurrent flight simulator training in the uncommanded yaw or roll and jammed or restricted rudder procedures contained in the Boeing 737 operations manual. On January 3, 2002, the NTSB classified this recommendation Closed–Acceptable Action. According to United Airlines, no simulator training is done for a jammed rudder (or other flight control), but the United Airlines manager of flight standards stated that simulator training is conducted for upset recovery, some of which could fulfill the requirement for uncommanded yaw or roll training.

Recommendation A-24-27 were encountered in flight or during landing and then notify operators to disseminate this information to flight crews of these airplanes.

In an August 28, 2024, email to the NTSB, Boeing provided preliminary information indicating that 25 US-registered airplanes have or had an affected SVO-730 rudder rollout guidance actuator installed. Boeing also indicated that, of the 25 airplanes, 9 airplanes were part of United Airlines' Boeing 737 fleet and that, as stated previously, the rudder rollout guidance actuators installed on those airplanes had already been removed. Boeing added that the remaining 16 US-registered airplanes were leased to foreign operators. On the basis of that information, Boeing stated that no US operators appeared to be currently affected by the recently discovered safety issues involving SVO-730 rudder rollout guidance actuators.

The NTSB recognizes that the information Boeing provided was preliminary, and while Boeing identified 25 affected actuators delivered on Boeing 737 airplanes, there remains uncertainty about how many affected actuators sent directly to operators and installed after delivery are currently on airplanes. As a result, there could be additional Boeing 737 airplanes beyond those 25 delivered by Boeing that have incorrectly assembled bearings in their SVO-730 rudder rollout guidance actuators, and it is essential that this possibility is clearly addressed. Further, the NTSB is concerned that foreign operators have Boeing 737 airplanes equipped with the affected actuators. In addition, the NTSB is concerned about the amount of time that it would take for Boeing 737 operators to remove all affected rudder rollout guidance actuators, for Collins to provide conforming units, and for the operators install them (if the operator wants to maintain the ability to perform Category IIIB landings).

A restricted rudder control system resulting from frozen moisture in an incorrectly assembled actuator bearing could increase a flight crew's workload during a critical phase of flight. For example, a flight crew would not likely diagnose the non-normal condition involving jammed or restricted rudder pedals until attempting to make a rudder pedal input while on approach or during the landing rollout and realizing that the pedals are jammed or restricted. This situation could become even more critical if a high-crosswind or an engine-out condition were simultaneously occurring with the jammed or restricted rudder because the amount of rudder available to respond to these conditions might be insufficient to maintain control of the airplane if the jam is not cleared. Furthermore, the force required to clear the jam

may result in a large, sudden, and undesired input to the rudder.¹⁸ Without the appropriate pilot response, a loss of airplane control could result.

Boeing has indicated that 737 airplanes can be safely flown without the rudder rollout guidance actuator installed. The NTSB recognizes that Boeing 737 operators would be precluded from performing category IIIB approaches without the actuators. The NTSB concludes that the removal of Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings from Boeing 737 airplanes would eliminate a potential cause of a restricted rudder control system on those airplanes.

Thus, the NTSB recommends that the FAA determine whether Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings should be removed from Boeing 737NG and 737MAX airplanes and, if so, direct US operators to remove the actuators until acceptable replacement actuators become available for installation. The NTSB also recommends that the FAA, if they determine the affected Collins Aerospace SVO-730 rudder rollout guidance actuators should be removed, notify international regulators that oversee operators of Boeing 737 airplanes about the safety issues involving the SVO-730 rudder rollout guidance actuator and encourage them to require the removal of actuators with incorrectly assembled bearings from 737NG and 737MAX airplanes until an acceptable replacement actuator becomes available for installation.

Conclusions

Findings

Informing Boeing 737 flight crews of (1) the potential for a restricted rudder control system in airplanes equipped with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings and (2) the appropriate mitigations if such a situation were to occur in flight or during landing would help prevent undesired rudder input and its likely consequences during these critical phases of flight.

¹⁸ Unrelated to this incident, the FAA issued Airworthiness Directive (AD) 2024-03-04 after receiving a report of a missing nut and washer and a migrated bolt in the aft rudder quadrant of a Boeing 737 airplane. The AD, which became effective on February 28, 2024, stated that, if a loss of rudder control via the rudder pedals were to occur, "rudder surface position would then be based only on the rudder trim and yaw damper systems." Further, the AD stated that, "with the limited rudder trim authority, there would not be enough rudder control to counter an engine-out scenario during takeoff/climb out or to counter a high crosswind (above 20 kts) during landing. This condition, if not addressed, could result in the loss of continued safe flight and landing."

The removal of Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings from Boeing 737 airplanes would eliminate a potential cause of a restricted rudder control system on those airplanes.

Recommendations

To The Boeing Company:

Instruct operators of Boeing 737NG and 737MAX airplanes with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings to notify flight crews that the rudder control system might become jammed or restricted in flight or during landing due to moisture that could accumulate and freeze in the actuators. (A-24-27) (Urgent)

For 737NG and 737MAX airplanes with Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings, determine appropriate flight crew responses, besides applying maximum rudder pedal force, if the condition described in Safety Recommendation A-24-27 were encountered in flight or during landing and then notify operators to disseminate this information to flight crews of these airplanes. (A-24-28) (Urgent)

To the Federal Aviation Administration:

Determine whether Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings should be removed from Boeing 737NG and 737MAX airplanes and, if so, direct US operators to remove the actuators until acceptable replacement actuators become available for installation. (A-24-29) (Urgent)

If you determine the Collins Aerospace SVO-730 rudder rollout guidance actuators with incorrectly assembled bearings should be removed, notify international regulators that oversee operators of Boeing 737 airplanes about the safety issues involving the SVO-730 rudder rollout guidance actuator and encourage them to require the removal of actuators with incorrectly assembled bearings from 737NG and 737MAX airplanes until an acceptable replacement actuator becomes available for installation. (A-24-30) (Urgent)

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Report Date: September 26, 2024

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