**Serious Incident**

| | |
|---|---|
| **Aircraft Type and Registration:** | ATR 72-202, G-NPTF |
| **No & Type of Engines:** | 2 Pratt & Whitney Canada PW121 turboprop engines |
| **Year of Manufacture:** | 1990 (Serial no: 192) |
| **Date & Time (UTC):** | 7 March 2023 at 0138 hrs |
| **Location:** | Belfast International Airport |
| **Type of Flight:** | Commercial Air Transport (Cargo) |
| **Persons on Board:** | Crew - 2 Passengers - None |
| **Injuries:** | Crew - None Passengers - N/A |
| **Nature of Damage:** | None reported |
| **Commander's Licence:** | Airline Transport Pilot's Licence |
| **Commander's Age:** | 45 years |
| **Commander's Flying Experience:** | 6,750 hours (of which 92 were on type)<br>Last 90 days - 65 hours<br>Last 28 days - 25 hours |
| **Information Source:** | AAIB Field Investigation |

**Synopsis**

During the flare to landing at Belfast International Airport the co-pilot, who was PF, discovered that the rudder was extremely difficult to move. The commander immediately took control of the aircraft and used the nosewheel steering for directional control on the runway. Examination of the aircraft on the following day showed that the rudder was almost immoveable from either set of rudder pedals in the cockpit or by physically pressing on the rudder outside the aircraft.

A number of faults with the rudder control system were uncovered during the investigation but the major cause of the extreme rudder stiffness was the degradation of the steel rudder rear quadrant support bearings due to corrosion. The sealed nature of the bearings and their installed location precluded visual inspection of their condition. Moisture ingress in the vicinity of the bearings had likely contributed to their degraded condition. The installation of the rudder damper may also have contributed to the rudder stiffness, albeit to a lesser extent.

A Service Bulletin which recommended replacement of all flight control bearings with corrosion-resistant stainless steel bearings had not been embodied on the aircraft.

The operator took actions to ensure the continued airworthiness of its ATR fleet. The manufacturer also took, or has committed to taking, a number of safety actions to address issues identified during the investigation. These include updating the Illustrated Parts Data for some flight control bearings to specify stainless steel equivalents as the preferred part number, updating troubleshooting guidance and publishing a communication to remind operators of the existing recommended Service Bulletin.

**History of the flight**

The flight crew reported for duty at 2320 hrs on 6 March 2023 to fly G-NPTF from East Midlands Airport to Belfast International Airport. The aircraft had been flown into East Midlands by another crew arriving at 2035 hrs. Having completed their pre-flight preparations and with the cargo loaded, the aircraft engines were started. The aircraft departed the stand at 0024 hrs on 7 March 2023. The aircraft checklist required the flight crew to complete a full and free movement check of the controls. During this check both the commander and the co-pilot commented that the rudder seemed to be very stiff to move. The co-pilot noted that the rudder seemed stiffer than the other aircraft in the fleet that he had flown. There was then a discussion about whether to continue with the flight, which included a conversation about the likely crosswind at the destination. They concluded that since both crew members could move the rudder (albeit with significant effort), and that the crosswind was very slight, they would continue with the flight.

The flight to Belfast was uneventful with cloud and icing encountered during the climb for around 15 minutes before the aircraft emerged into clear skies. The weather in Belfast was CAVOK with light winds. The co-pilot flew an ILS approach to Runway 25, disconnecting the autopilot at 700 ft aal. The co-pilot reported that as he flared the aircraft for landing, what little wind there was started to cause the aircraft to drift very slightly to the left of the centreline. He attempted to apply rudder to stop the drift but found the rudder pedals almost impossible to move. Having realised there was a problem, the commander immediately took control and placed the aircraft on the ground, rapidly de-rotating the nosewheel to allow him to use the nosewheel steering.

Once the aircraft was safely at taxi speed, both pilots tried the rudder pedals and described them as barely moving. At 0141 hrs the aircraft arrived at the parking stand, where it was shut down and the cargo was unloaded. Once the unloading was complete, the aircraft was moved to a remote stand. At this point the flight crew found the rudder pedals would not move at all.

**Relevant checklist items**

The flight crew were required to check the rudder for full and free movement as it was part of the flight controls check item on the before takeoff checklist. The Flight Crew Operations Manual (FCOM) for the ATR 72-200/210 requires the occupant of the left seat to '*move the rudder pedals to full travel in both directions and verify freedom of movement.*' The check is the final opportunity to identify a possible problem with the flight controls before the takeoff begins.

In flight the FCOM, which is applicable for G-NPTF, contains an Abnormal Procedure for use when the crew detects a rudder jam.

▶ DIFFERENTIAL POWER.................................. USE TO MINIMIZE SIDESLIP
● For approach
▶ STEEP SLOPE APPROACH (≥ 4.5 °) : PROHIBITED
▶ LAND AT AIRPORT WITH MINIMUM CROSSWIND
▶FLA
PS.........................................................................................................30
● At touchdown before power reduction below FI
▶NOSE..........................................................................................DOWN

With the aircraft in the flare when the crew identified there was a problem with the rudder, the applicable checklist item is to put the nose down in order to be able to use the nosewheel steering for control of the yaw.

**Meteorology**

On the night of 6/7 March 2023 there was a cold front in the area of East Midlands Airport. The temperature was around 3°C during the period G-NPTF was on the ground and there was no precipitation shown on the METARs. The aircraft would have entered cloud after takeoff between 4,000 and 5,000 ft amsl. It would then have climbed through layers of cloud up to 18,000 ft amsl. These layers of cloud would have presented a moderate risk of icing. As the aircraft flew north of the Isle of Man it would have entered clear conditions which remained for the approach and landing at Belfast International Airport.

Conditions at Belfast were good with no cloud detected and a light north-westerly wind (less than 5 kt). The temperature was -2°C when the aircraft landed and remained below freezing until around 1000 hrs. It returned to below freezing overnight on 7/8 March 2023.

The aircraft was parked in Guernsey from 4 March 2023 to 6 March 2023, when it flew to East Midlands ready for the flight on which the event occurred. The temperature during this period had been around 5°C with some rain showers reported.

**Airfield information**

The aircraft landed on Runway 25 with the wind given to the crew when they were cleared to land as 320 at 5 kt. This gave a crosswind component of less than 5 kt.

**Recorded information**

Recordings from the aircraft's flight data and cockpit voice recorders were downloaded and analysed. The CVR recording corroborated the crew's recollections of the event. The FDR data, however, was unhelpful as there was no recording of forces detected by the force detector rod linked to the rudder pedals (see *Aircraft description* section). For 200 series ATR 42s and 72s manufactured since 2008, there is an option to record rudder pedal and other control forces. For all 600 series ATRs, these control forces are recorded as standard.

## Aircraft description

The ATR 72-202 is a twin-engine turboprop, short-haul regional airliner.

*Rudder and rudder control*

Yaw control on the ATR 72 is achieved by a mechanically-actuated rudder linkage system, composed of quadrants, bellcranks, pulleys, rods and cables (Figure 1). Pilot inputs are made via two sets of rudder pedals in the flight deck. The rudder pedals are linked to a force detector rod which produces movement of the forward quadrant. A cable loop, which runs under the flight deck floor, vertically up behind the flight deck, above the cabin compartment ceiling panels and through the rear pressure bulkhead, links the forward and rear rudder quadrants.

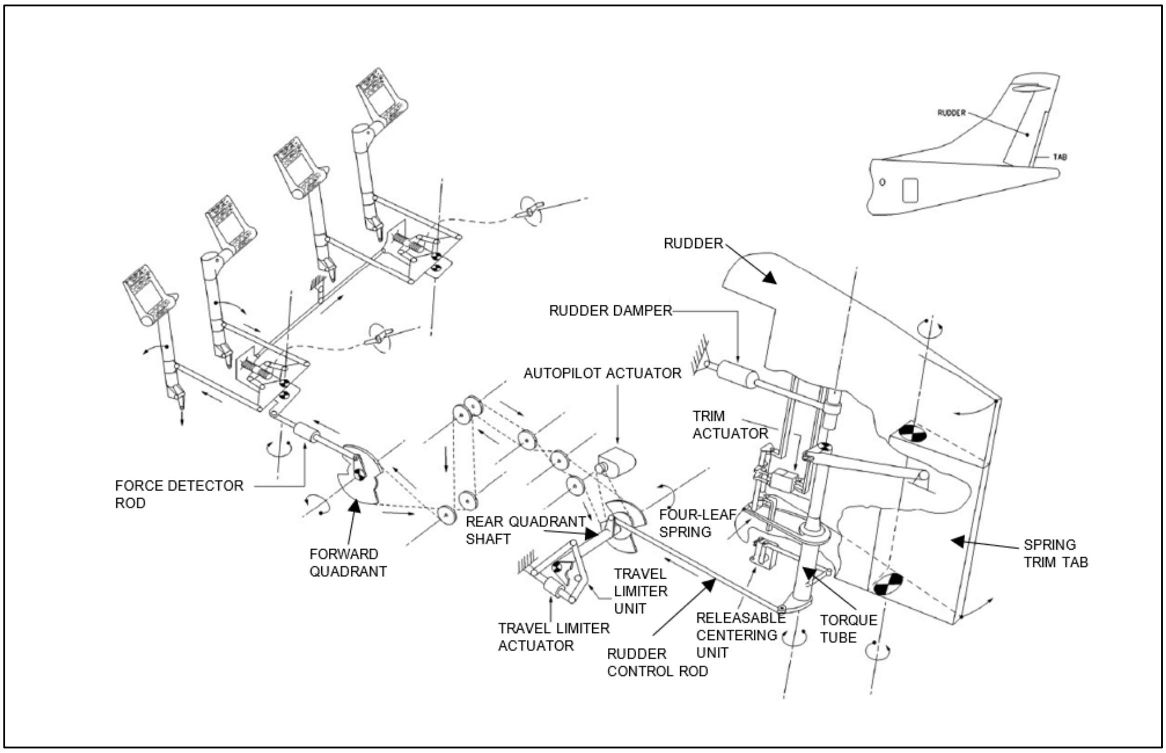


**Figure 1**

High-level schematic of ATR 72 rudder control system
(image modified and used with permission)

The linear movement of the cable loop drives a bellcrank mounted on the rear quadrant shaft, to rotate the shaft (Figure 2). Shaft rotation produces linear movement of the rudder control rod, which runs between a lever mounted on the rear quadrant shaft and the bottom pivot at the base of the rudder torque tube. Movement of the rudder torque tube acts directly on the spring trim tab, and via a four-leaf spring, on the rudder itself.

Autopilot yaw commands are transmitted to a yaw damper actuator (or autopilot actuator), which is connected to the rear quadrant by means of a short cable loop and a separate bellcrank mounted on the shaft. This rotates the shaft in the same way as the pedal bellcrank, to generate movement of the rudder surface.

The force detector rod linked to the pedals includes a microswitch which changes state when a 30 daN load is applied to the rudder pedals. This causes the yaw damper function, and consequently the autopilot, to disengage.

The yaw control system also contains a Travel Limitation Unit (TLU), a Releasable Centering (sic) Unit (RCU), a rudder damper and a trim system. The TLU mechanically limits rudder deflection to ensure that the rudder is not damaged by large inputs when the aircraft is flying at high speeds. The TLU system includes an electrical actuator, two v-shaped cams mounted on the rear quadrant shaft, and two rollers mounted on a pivoting bracket, which moves in response to actuator extension and retraction.

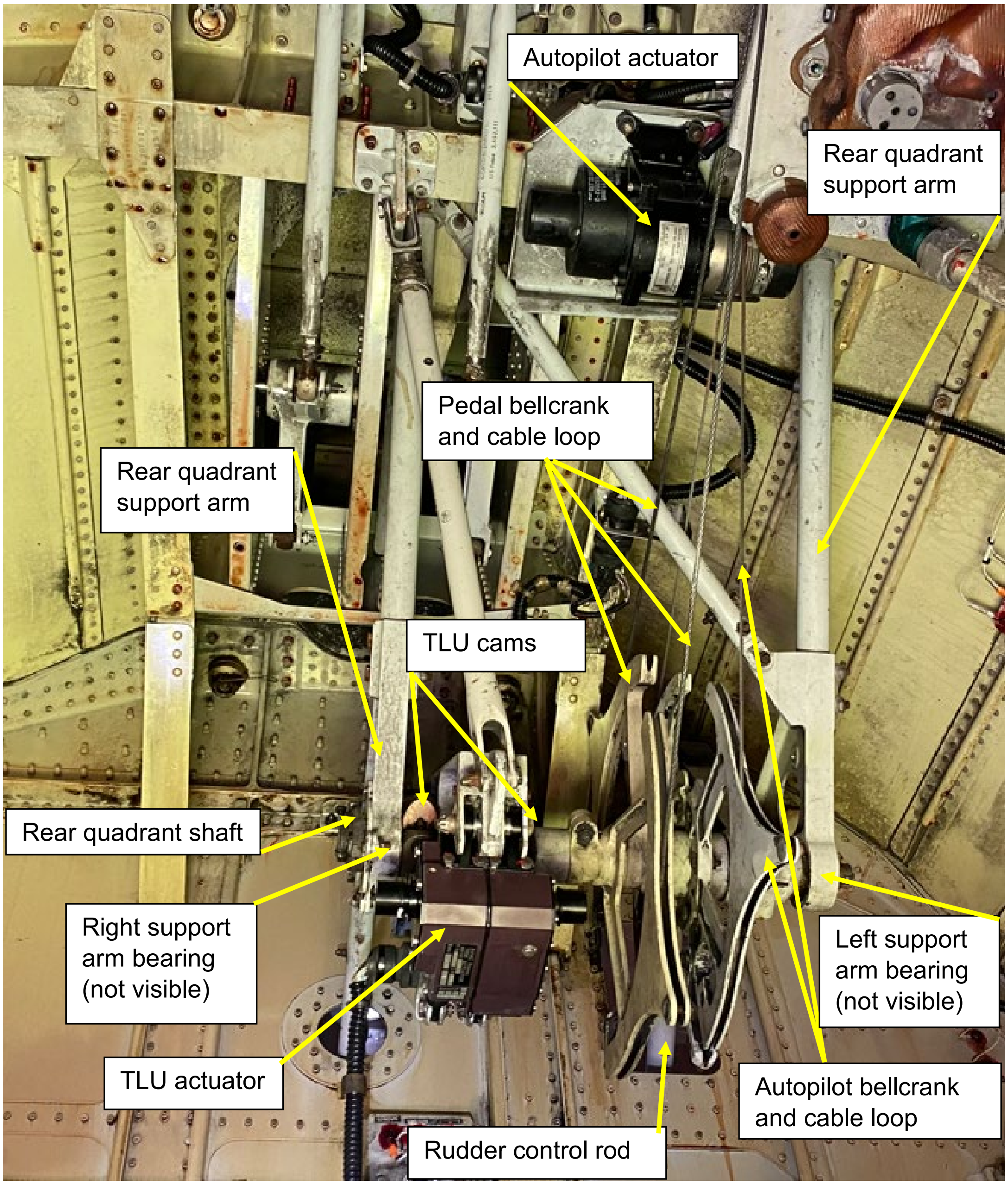


**Figure 2**

G-NPTF's rudder rear quadrant (view looking aft)

The RCU is installed in the tail cone, between the rudder and the linkage to the pilot pedals. It stabilises the rudder position when no action is applied on the pedals. This device is automatically centred on the linkage position every time a trim control command is applied and is inhibited when the yaw damper is active.

The rudder is linked to the aircraft structure by a rudder damper. This limits rudder travel speed when the aircraft is airborne and, when the aircraft is on the ground, it damps excessive rudder movement in response to wind gusts, preventing damage to the structural stops. When the aircraft is on the ground, the rudder is unrestrained and should move downwind with the trim tab in line with the rudder.

Yaw trim control is electrically controlled by the pilots using a control on the centre console. Use of the trim offsets the zero position of the trim tab on the rudder.

The rudder is hinged on the vertical stabiliser rear spar by means of four hinges (pivot points).

**Initial aircraft examination**

Initial examination of the aircraft in Belfast showed that the rudder was extremely difficult to move either using the rudder pedals or by hand on the rudder surface. The rudder pedals did not return to neutral after being displaced and the rudder did not appear to move in response to external wind inputs.

The rear bay, directly underneath the vertical stabiliser, and in which the rudder rear quadrant is located, appeared dry and there was no evidence of moisture or ice accumulation. The internal surfaces of the rear bay, rear quadrant shaft support structure and bellcranks were dirty, with a light film of old grease/dirt (Figure 2).

The rear quadrant shaft appeared to rotate in response to pedal inputs but there was a rubbing noise evident during parts of the quadrant's travel. The rudder pedal cable was observed to be rubbing against the right hand cable guide of the pedal bellcrank, but this did not appear to be the source of the noise.

The rudder control rod was disconnected at the rear quadrant shaft to isolate the 'command' side (rudder pedal circuit) of the system from the 'actuation' side (rudder circuit aft of the rear quadrant). In this configuration, considerable stiffness remained within the pedal circuit. While some stiffness remained in the rudder circuit, it appeared to be less than before.

The rudder pedal circuit pulleys and cables were inspected and found to be clean and free from debris, but there was no evidence of recent lubrication. The autopilot and rudder pedal cable tensions were checked and were within, or very close to, the normal range.

**Detailed aircraft examination**

After several days parked outside, the aircraft was moved to a hangar to allow a more detailed examination, with assistance of flight control and structural specialists from the aircraft manufacturer.

*Command/rudder pedal circuit*

When the rear bay door was opened a large volume of water which had been trapped above the door fell on the hangar floor. The entire bay was wet, with condensation present on all surfaces, including the rear quadrant shaft. Although a drain hole was located on the forward edge of the door moisture had accumulated in this area, indicating that the drain hole was not providing effective drainage.

The rudder pedals remained very difficult to move. Although not representative of normal rudder pedal operation, the force required to move the pedals by hand was measured using a hand-held dynamometer. A maximum of 97.7 lbf (43.4 daN) was measured, but it was not possible to achieve full pedal travel in this way.

With both sides of the rudder system isolated by disconnecting the rudder control rod at the rear quadrant shaft, the rudder pedals still did not move freely. The rubbing noise remained evident when the rudder rear quadrant shaft was operated and some dark coloured debris was noted at the left rear quadrant shaft support bearing.

The rudder pedal and autopilot yaw cables were disconnected from their respective bellcranks to remove any tension from the shaft. It was then possible to operate the rudder pedal cables freely using only finger pressure and the rudder pedals moved freely in response. This confirmed that the friction originated at the rear quadrant shaft.

*Actuation/rudder circuit*

The aircraft's tail cone was removed to allow inspection of the rudder torque tube. Moisture was present at the bottom of the torque tube and on the lower parts of the bulkhead. In places, the pooled moisture was clear and jelly-like in consistency. The sealant on the torque tube bottom pivot was broken in places, and it was softened or dis-bonded in others.

Some light resistance was detected by the flight controls specialist when attempting to manually move the rudder from the bottom of the torque tube, which was not particularly obvious to others in the investigation team; ordinarily the rudder should move freely. In order to remove any friction from other bearings in the system and assess rudder movement, the rudder control rod was completely disconnected from the torque tube, RCU arm and the bottom pivot. The light resistance was still evident when manually moving the rudder.

A subsequent torque check of rudder damper attachment bolts revealed that the torque on the forward attachment bolt (vertical stabiliser side) was within limits (allowable 8-10 daNm). However, the aft attachment bolt (rudder side) had been over-torqued and required more than 10 daNm to loosen it (allowable 4 – 6 daNm). When the bolt was removed, moisture was present on the bolt shank and within the attachment lugs and the bushing was seized to the bolt. There was no evidence of grease present at either attachment.

Having disconnected the rudder damper, the rudder then moved completely freely, without any resistance. The rudder continued to move freely when the RCU arm was reconnected and the RCU appeared to operate correctly to centre the rudder. This indicated that the rudder damper installation had also contributed to stiffness within the rudder circuit.

Examination of the four rudder pivot points showed some evidence of fresh grease (green/blue colour) on the grease nipples. However, only small amounts of fresh grease were present within the joints at the pivot points, with most of the grease being brown/red in colour and thick and lumpy in appearance. Moisture was present at all the pivot points, including on the surface of the grease. The gaps at the rudder pivot point locations were checked and found to be within limits.

External visual examination of the vertical stabiliser showed that sealant was absent at several locations on the top rib, which may have provided a path for moisture ingress to the rear bay.

*Rear quadrant shaft*

The rear quadrant shaft and its support bearings were removed, with some difficulty, for further examination. There was evidence of light distress on the left and right bearing surfaces on the rear quadrant shaft. The inner face of the right cable guide on the rudder pedal bellcrank displayed cable contact marks. There was evidence that the right TLU cam had been fouling against mounting bracket for the TLU actuator, and an adjacent conical washer appeared to be seized to the shaft.

The left support arm bearing was intact and could not initially be rotated. Later it could be rotated but was rough to turn. Some mechanical damage was evident on one face of the bearing which was probably caused during removal. The right support arm bearing was intact and was also rough to turn. The installed components on the rear quadrant were dirty; the side walls of both bearings were dirty and caked with a mixture of old grease and dirt.

**Rudder rear quadrant support bearings**

Both rudder rear quadrant support bearings, manufactured by Fafnir, were self-aligning bearings, although each bearing achieved this in a different way. Bearing No 1, was a conventional KSP10 self-aligning bearing with a grooved inner race and a spherical outer race, to allow for shaft misalignment. This type of bearing can self-align during service to accommodate movement of the shaft axis.

By contrast, self-alignment in bearing No 2, a KP16BS, was provided by an external self-aligning ring which had an internal spherically ground surface matched to the external spherically ground surface of the outer race. This type of bearing is designed to compensate for initial misalignment during installation.

The raceways and balls of both bearings were made from 52100 grade steel which does not have significant corrosion resistance. The exposed surfaces, the bore, cap and seals were cadmium-plated.

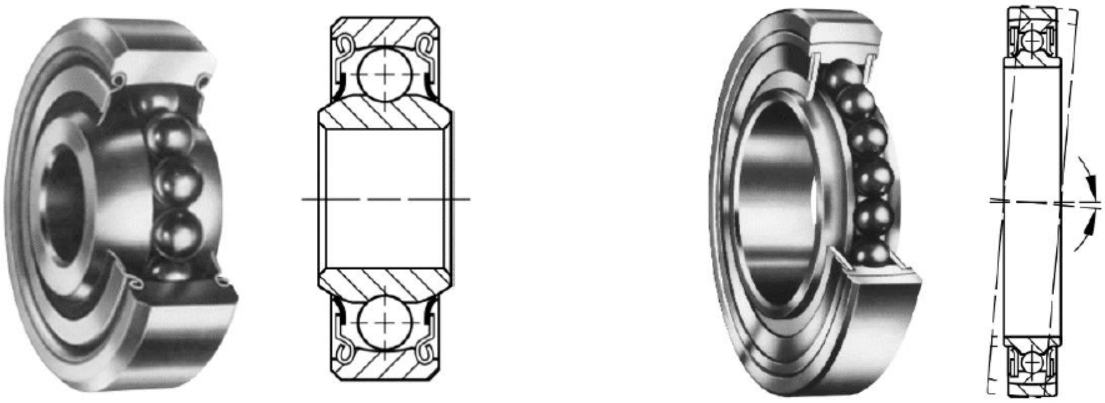

**Figure 3**

Original production standard rear quadrant shaft support bearings fitted to G-NPTF

**Metallurgical examination of rudder rear quadrant support bearings**

*Visual examination*

Bearing No 1 from the left support arm felt rough during rotation, while bearing No 2 from the right support arm was completely seized.

Deformation and scoring was present on the retaining ring of the seal on bearing No 1. This mechanical damage, which was fresh and consistent with contact from a hard object such as a tool. This likely occurred during removal of the bearing from the support arm, as the engineers encountered difficulty removing it. The bearing contained a full complement of balls, with balls and raceways appearing well greased.

Bearing No 2 displayed corrosion and a brown deposit on the outer surface. It contained a full complement of balls which appeared to be extensively corroded. No grease was present, although there was a thick brown deposit throughout, which appeared to be a combination of corrosion product and dried grease residue (Figure 4).


**Figure 4**
Rear quadrant support arm bearings from G-NPTF

After cleaning, visual examination of the inner surfaces of bearing No1 showed axial marks consistent with the ball positions and circumferential marks around the approximate mid-point of the outer race (Figure 5).

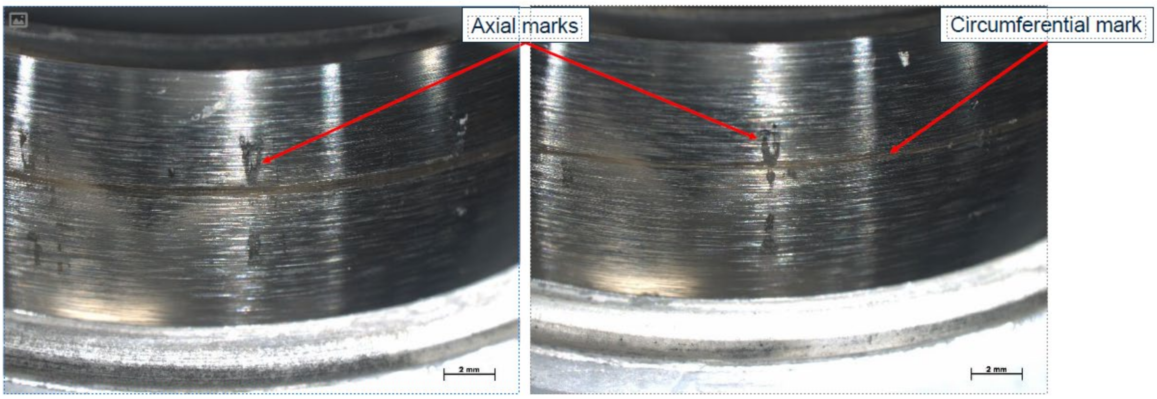


**Figure 5**
Bearing No 1 axial and circumferential marks

Axial misalignment, measured at 2.9º, was noted between the outer ring and outer race of the bearing No 2 (Figure 6).

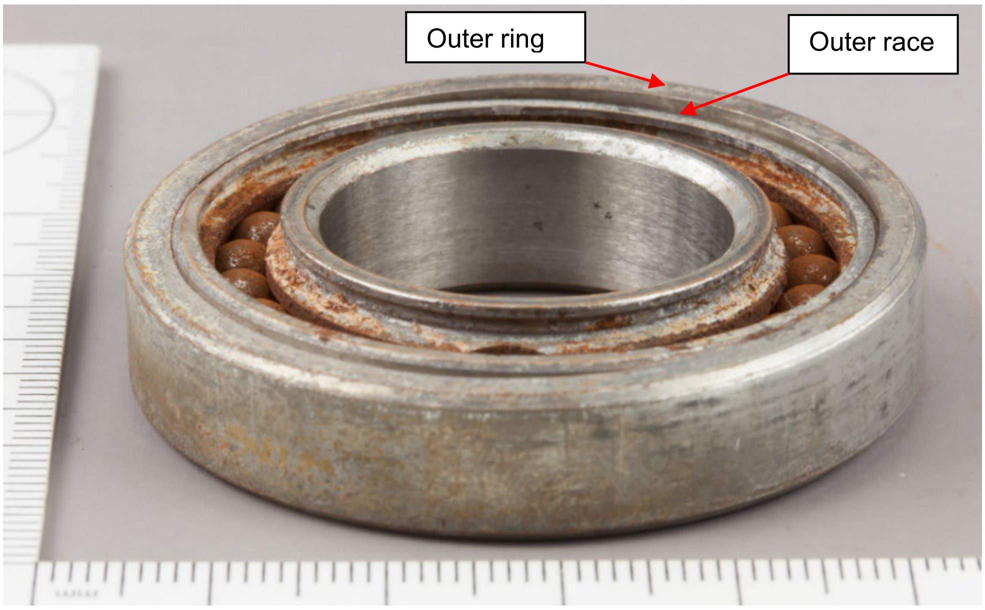


**Figure 6**
Bearing No 2 misalignment

After cleaning, extensive corrosion pitting was evident on the inner and outer bearing races and balls of bearing No 2 (Figure 7).

**Figure 7**
Bearing No 2 corrosion and pitting (outer race shown, inner similar)

*Detailed examination*

Examination of the bearing No 1 outer race in the scanning electron microscope (SEM) showed that the axial marks had resulted from a combination of corrosion and sliding in the axial direction. The track of circumferential marks had resulted from a combination of corrosion and wear. Within this track was a line where the machining marks on the outer race had been polished flat. This was considered consistent with the type of wear that occurs with in-service bearings. However, within this track, patches of corrosion were also observed, which is not typical. The corrosion is likely to have contributed to the rough running of the bearing.

Axial wear marks were observed at evenly spaced positions around both the inner and outer races of bearing No 1. The marks appeared to be the result of axial sliding of the balls. On the outer race, the axial wear coincided with corrosion damage. Corrosion damage was not observed at the axial marks on the inner race.

The spacing between the corrosion/axial marks was consistent with the ball spacing suggesting that the corrosion had occurred while the balls had been stationary for some time. The axial sliding damage had also occurred at fixed positions indicating that relative axial movement between the inner and outer races had occurred while the bearing was not rotating. It is possible that this axial damage occurred during removal of the bearing from the support arm.

Energy dispersive X-ray analysis of metallic swarf retrieved from left support arm adjacent to bearing No 1 identified it as aluminium alloy. Debris on the swarf contained multiple elements consistent with the corrosion deposit of a cadmium-plated steel component, such as would result from the corrosion of the steel bearings, which had cadmium plating on the exposed surfaces. The source of the aluminium swarf was not identified, but the left support arm was not examined by the laboratory.

Bearing No 2 was not examined in the SEM because of the extensive pitting corrosion that was observed during the visual examination.

**Rudder rear quadrant examination**

The rear quadrant shaft from G-NPTF was mounted in a test rig, using donor support bearings so that it could be rotated.[1] The findings from the aircraft examination were confirmed and in addition the following observations were made.

Closer examination of fouling/interference between one of the TLU cams and the TLU support arm revealed that while there was some paint loss on the TLU support arm, there was no damage to the underlying metal. The TLU support arm bearing felt somewhat rough to turn and had migrated slightly from its housing, probably contributing to the interaction with the adjacent TLU cam.

The rollers on the TLU pivoting bracket were seized and there were visual indications that the rollers had not turned for some time. Minor damage was also observed on the TLU actuator attachment points. Despite these observations, when a donor TLU actuator was installed and electrically powered, it functioned as expected to locate the rollers in the TLU cams. However, the test conditions were not fully representative of the installed aircraft configuration, because the shaft was isolated from the rudder linkage and therefore was not loaded.

**Footnote**

1 The donor bearings were from aircraft serial number 98, which had the same original production standard steel bearings as G-NPTF. These bearings were in good condition and turned freely.

The rear quadrant shaft was disassembled and a dimensional check performed on all parts. Comparison with production drawings revealed no dimensional anomalies.

Based on the observed condition, the rear quadrant shaft and its associated components were declared unserviceable by ATR.

## Aircraft maintenance history

G-NPTF was built in 1990 and entered service as a passenger aircraft. It was converted to its present cargo configuration in 2014. It had been in service with the operator since 28 May 2022, having previously been operated on the Spanish register by another organisation in the same group as the operator[2]. During its service with the previous operator there were no periods of long-term parking or storage. At the time of the occurrence G-NPTF was the third oldest ATR 72 in operation in the global fleet.

*Previous reports of rudder stiffness on G-NPTF*

Some of the operator's ATR pilots said that G-NPTF was known to have a much stiffer rudder than the other ATRs on the fleet. The rudder had been reported in the technical log on three previous occasions. These reports and the rectification action taken are shown in Table 1:

| Date of entry | Wording of technical log entry | Rectification action |
|---|---|---|
| 4 February 2023 | Rudder is significantly harder to move than any other fleet ATR. | Operational test of rudder control and spring tab – all found to be operating as expected.<br>Rudder damper fluid level checked and found to be in accordance with requirements.<br>Rudder cable runs checked and found to be satisfactory. |
| 7 February 2023 | Rudder unusually heavy. Significant pressure required to move. | Rudder damper replaced. |
| 9 February 2023 | Left rudder pedal input on finals almost impossible to move. Tried from left and right side. Can be moved on ground but still rather stiff. | Aircraft on ground for 10 days while extensive maintenance troubleshooting performed TLU, rudder damper and RCU replaced.<br>Substantial troubleshooting input from ATR. |

**Table 1**

Previous G-NPTF technical log report and rectification action

**Footnote**

2 The aircraft was operated by the previous operator between June 2009 and 1 June 2011 and from 17 August 2012 until it left the fleet in 2022.

The rudder stiffness report on 9 February 2023 was reported to the AAIB, which monitored correspondence relating to the maintenance troubleshooting performed but did not open an investigation.

The troubleshooting and rectification work was undertaken at a maintenance facility in Guernsey. Various operational tests were performed including tests of the RCU and TLU; both units were replaced as a result. During a check of the rudder damper (which had been replaced two days previously) the engineer noted different stiffness in the rudder control between when the rudder damper was connected and disconnected. The rudder damper was therefore replaced once again, after which the engineer perceived that the rudder stiffness appeared to be reduced compared to the initial finding on 10 February 2023 but could still be considered more stiff (ie the rudder pedals were "heavier") than on other aircraft he had maintained. The worksheet relating to the replacement of the rudder damper correctly noted the applicable torque range for the forward and aft attachment points.

The operator contacted the manufacturer for assistance on 14 February 2023 asking for additional information to allow it to assess whether the perceived heavier feel of the rudder pedals was considered within an acceptable tolerance for aircraft operation or whether it could be indicative of an underlying problem.

The troubleshooting recommendations provided by ATR detailed various rudder system functional tests and visual inspections, amongst which were visual inspections of the rudder mechanical control[3] and the rudder control cables[4]. Both inspections require the flight crew seats to be removed for access.

The rudder mechanical control visual inspection states: '*To correctly examine the mechanical parts, operate the rudder controls from stop to stop…Do a visual check of the rudder control mechanical-parts-assembly: rudder pedals, rods, torque shaft, bellcranks. Make sure that assembly shows no signs of corrosion, cracks or defects in surface protection (flaked paint).*'

The rudder control cable circuit visual inspection includes the instruction: '*To fully examine cables, pulleys, quadrants and regulators, operate rudder pedals from stop to stop.*'

In correspondence relating to the troubleshooting, the maintenance engineer performing the rudder mechanical control and rudder cable visual inspections reported that no faults were evident.

The troubleshooting guidance and visual inspections did not specifically mention the rudder rear quadrant shaft or its support bearings.

ATR also recommended isolating the command and actuation sides of the rudder control system and performing a full rudder travel, first with the rudder pedals and then manually to identify which side of the system the stiffness originated from. The maintenance engineer reported that the rudder could be moved by hand and that the rudder pedals had no resistance.

**Footnote**

3 AMM Task MP ATR-A-27-21-XX-00001-281A-A.
4 AMM Task MP ATR-A-27-21-XX-01001-281A-A.

*G-NPTF rudder pivot point lubrication*

The ATR 72 maintenance program requires that lubrication of the flight control pivot points (including the rudder and rudder tab hinge points) is performed every 3,000 flight hours. ATR maintains a Consumable Material Data (CMD) document which lists all consumable products (including fuels, oils, grease etc) approved for use on ATR aircraft. It includes applicable material specifications, usage notes and approved alternatives.

Maintenance records were reviewed for the previous four flight control lubrication tasks performed on G-NPTF. These were carried out in March 2018, March 2019, May 2020 and November 2021 at third party maintenance providers in Bulgaria and Hungary. The grease used alternated between Mobil Aviation Grease SHC-100 (CMD item 04-004C) in March 2018 and May 2020, and Aeroshell Grease 33 (CMD item 04-024A) in March 2019 and November 2021. SHC-100 is red in colour while Aeroshell 33 is green/blue. The grease observed on the G-NPTF rudder pivot points following the occurrence was visually consistent with a mixture these two grease products[5].

Of the two types of grease used on G-NPTF, only Aeroshell 33 was intended for use on flight control pivot points.

Similar products are grouped together within the CMD. When a new item is added it is given a five-digit item reference eg 04-004. When a similar, but not identical or interchangeable, product is added to the CMD, the original five-digit reference is retained but emptied. The initial product is transferred to a new reference based on the five digits but with an 'A' suffix eg 04-004A. The new product is created with the same five-digit reference but with a 'B' suffix eg 04-004B etc.

As the CMD evolved over time, AMM job instruction cards (JICs) which called up consumable items were not amended to take account that the original reference no longer referred to the expected consumable. Prior to January 2020, the AMM JIC for ATR 72 AMM task ATR-A-12-22-27-00001-240A-A *'Lubrication of flight controls pivot points'* called for consumable item 04-004. In the CMD there are three consumables with a 04-004* reference, including item 04-004C - SHC-100.

Separately, due to a historic absence of written guidance on how to interpret the CMD, there was an assumption within ATR and externally that items with a number-only reference referred to a family of consumables and therefore any product based on that number could be used interchangeably. For example, it was assumed that if item 04-004 was called up then any item with a 04-004* reference could be used. This was not the intention.

ATR identified this issue and in January 2020 the JICs for AMM task ATR-A-12-22-27-00001-240A-A were updated to reflect the correct and originally intended consumable: item 04-004A -MIL-G-23827 Type 1 grease (for which Aeroshell 33, item 04-024A was an approved replacement item).

**Footnote**

[5] Samples of grease were collected from the rudder pivot points but the small sample sizes and the fact that more than one grease type was present would have prevented full analysis of the lubrication properties or conformance to specification. Therefore, the samples were not subjected to detailed laboratory analysis.

In the CMD usage notes for items 04-004A and 04-024A, it states that in the case where a replacement grease product was used, the two types of grease should not be mixed, the old grease should be completely purged by the new grease and the servicing interval should be temporarily reduced, for instance by half, for around 3 to 4 services. There is no evidence that this was done on G-NPTF.

Following this occurrence, the operator fully purged and regreased all the flight control pivot points on G-NPTF and its other ATR 72s, to reset the flight control lubrication status in accordance with best practice. Additionally, it instructed the organisation which provides its continuing airworthiness management organisation function to specify Aeroshell 33 as the only grease to be used for lubrication of the flight control pivot points.

## Aircraft maintenance procedures

*Rear quadrant shaft*

At the time of the occurrence there were no prescribed maintenance procedures or inspections specifically relating to the bearings on the rear quadrant shaft. The area is subject to general visual zonal inspections and a scheduled detailed visual inspection of the rudder control cable circuit is required to be performed every eight years[6]. This is the same visual inspection of the rudder control cable circuit performed during the troubleshooting following the 9 February 2023 report of rudder stiffness. Prior to that, it was most recently performed on G-NPTF as routine inspection on 9 February 2022, one year before the first crew reports of rudder stiffness. A review of the associated maintenance workpack for that inspection did not reveal any defects or discrepancies.

The manufacturer stated an expectation that this inspection should be able to detect friction in the rear quadrant support bearings.

*Rear damper installation*

The ATR 72 maintenance manual[7] tasks for removal and installation of the rudder damper refer to a figure which includes an overview on sheet 1, showing the location of the rudder damper. Sheet 2 (Figure 8) shows a detailed view of the rudder damper and its attachment points, specifying the allowable torque values. While the overview on sheet 1 includes an orientation arrow to show the forward direction, the detailed view on sheet 2 does not include any orientation arrows, to differentiate the forward and rear aft attachment points and the detailed view is shown in the opposite orientation to the overview.

**Footnote**

6 Maintenance Review Board Report (MRBR) task 272100-01 relating to AMM Task MP ATR-A-27-21-XX-01001-281A-A

7 Revision number 006 dated January 01/23.

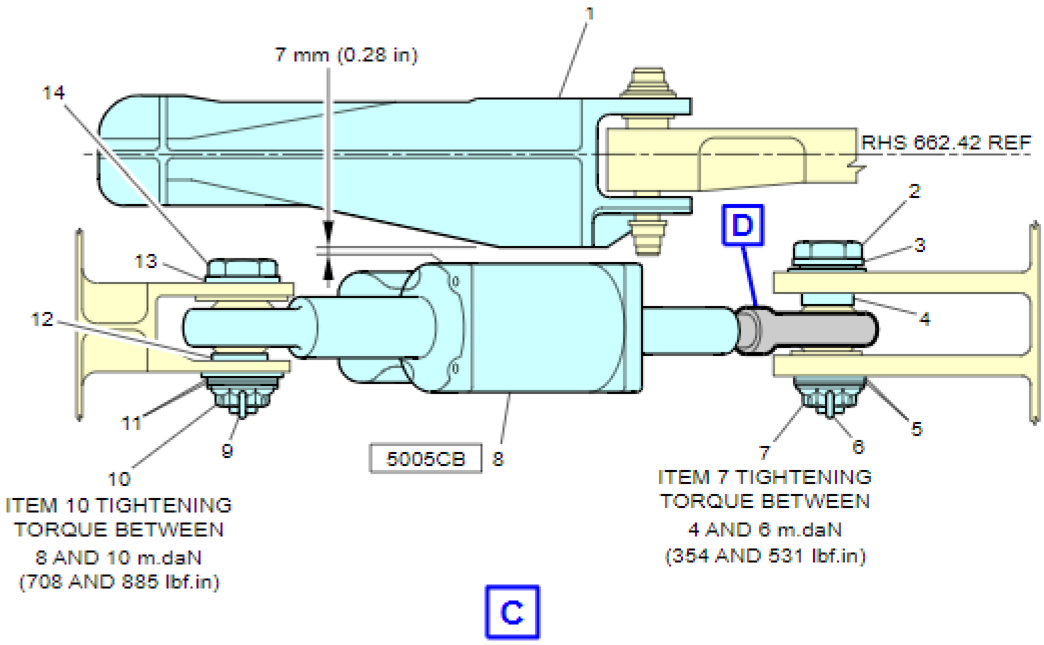


**Figure 8**

Extract from ATR 72 AMM figure showing rudder damper attachment allowable torque values

*Rear bay drainage*

Two routine inspections of the fuselage drain ports existed. Maintenance Planning Document (MPD) 122111-CLN-10000-1 task *'Fuselage drains (external)'* describes *'cleaning of draining holes/filters located on door thresholds and check for obstruction of holes of lower fuselage drain valves – external.'* The inspection interval was every two A check period/ nine months and it was last performed on G-NPTF on 1 July 2022.

MPD task 122112-CLN-10000-1 *'Fuselage drains (internal)'* describes *'cleaning of draining holes/filters located on door thresholds and check for obstruction of lower fuselage drain valves and drain pipes – internal.'* The inspection interval was every two C check/ four years and it was last performed on G-NPTF on 9 February 2022.

Both tasks instruct the engineer to ensure the drain hole is cleaned of debris and unobstructed. The manufacturer considered that any obstruction of the rear bay draining holes should have been detectable when performing these routine inspections.

In addition, the manufacturer referred to several other relevant sources of published guidance relating to moisture ingress. Among these were Technical Progress Status[8] (TPS) reports 30-11-002 and 55-36-001 which relate to protecting the tail cone from fluid ingress/ limiting glycol contamination for operators using de-icing fluids, installing a water deflector (SB ATR72-53-1052) and sealing vertical tailplane rear spar access panels with removable sealant. The manufacturer also published a Corrosion Improvements Booklet.

**Footnote**

[8] ATR TPS is a communication platform on the ATR online customer portal, on which the manufacturer advises the status, mitigations and corrective or improvement plan for known technical issues

**G-NPTF rear bay drainage**

ATR indicated that from in-service experience it is not unusual to have moisture ingress in the rear bay. It confirmed that according to the original design drawings, the rear bay access door drain hole should align with a corresponding drain hole on the fuselage door frame.

The drain hole on the rear bay door appeared to be correctly located in accordance with the design drawings. But when the rear bay door was closed, the door drain hole was entirely obscured by the fuselage door frame preventing effective drainage of any accumulated water. During a subsequent base maintenance check in 2024 after the aircraft had returned to service, the operator's maintenance organisation conducted a detailed survey of this area of the aircraft. It determined that the corresponding drain hole on the fuselage door frame was absent. It noted that there were 17 fastener holes in the door frame to retain a P-seal, when there should be 16. It appeared that an additional fastener hole had been added at some point in place of a drain hole. At the time of publication of this report, it had not been determined whether the drain hole was omitted at the time of production, or as a result of a post-production repair. ATR advised that it had no records of communication relating to a repair at this location on this airframe.

**Flight control bearing modification**

The rear quadrant shaft support bearings fitted to G-NPTF were the original bearings fitted at the time of manufacture. They complied with the original design standard for the ATR 72, which called for steel bearings in all flight control and engine systems.

In 1990, Aerospatiale[9] (which at that time provided the engineering function) launched modification 3102 which replaced the steel bearings with cadmium-plated, corrosion-resistant, stainless steel bearings, in all areas outside the pressurised fuselage. This was embodied at production for ATR 42 and 72 aircraft from serial number 332 onwards. Introduction of the modification followed a report of a seized flight control bearing due to corrosion on an in-service aircraft. ATR records did not indicate whether the seized bearing was on the rudder, aileron or elevator axis and there was no corresponding entry in its continuing airworthiness database.

Service Bulletin SB 72-27-1020 '*Flight controls … replace existing steel bearings by stainless steel bearings*' was published on 1 March 1993, to address bearing replacement for ATR 72 aircraft already in service[10]. As part of the process to introduce the Service Bulletin, the failure condition of a seized flight control bearing was classified as MAJOR and therefore did not prompt mandatory action. The Service Bulletin was categorised as RECOMMENDED and embodiment was therefore optional for operators.

**Footnote**

9 ATR was formed in 1981 as a joint venture between Aerospatiale of France (succeeded by Airbus) and Aeritalia of Italy (now Leonardo).

10 Corresponding SB 42-27-0060 for the ATR 42 was also published at the same time.

As of December 2023, SB 72-27-1020 was applicable to 78 ATR 72 aircraft, of which 43 were in operation[11] and SB 42-27-0060 was applicable to 248 ATR 42 aircraft, of which 88 were in operation. ATR records showed that accomplishment had been reported only on six aircraft, although it acknowledged that not all operators report accomplishment of Service Bulletins.

Full compliance with SB 72-27-1020 requires replacement of all flight control bearings, 47 in total (10 on the aileron, eight on the rudder and 29 on the elevator system), and therefore probably could only be accomplished at a major overhaul. But SB 72-27-1020 accomplishment instructions indicate that it can be embodied *"Partially, as required, on one or more specific component(s) of a control"* or *"Fully on a specific control (part A or B or C)"* where parts A, B and C refer to the aileron, rudder and elevator systems respectively. This information was probably included at the time to give operators flexibility to be able to partially embody the SB on an attrition basis.

ATR's preferred philosophy is to favour full accomplishment of an SB to ensure full traceability; it is not possible to track partial embodiment at fleet level and ATR considers an SB either fully embodied or not embodied. Accomplishment of any part of the SB requires each replaced bearing to be identified with a new part number, therefore partial accomplishment could be tracked by operators at an aircraft level.

Based on its 'full accomplishment' philosophy, during the investigation ATR indicated that partial compliance of SB 72-27-1020 was not permitted and that there was no interchangeability between pre and post-mod bearings.

Following this occurrence, G-NPTF's rear quadrant shaft and bearings were replaced prior to its return to service. As SB 72-27-1020 had not been embodied on G-NPTF, only the original standard steel bearings were approved for installation and so pre-modification bearings were re-fitted.

Since then, based on the findings of this investigation ATR has undertaken action to ease the replacement of rudder rear quadrant bearings by adding the post-mod bearings as the preferred part number, providing interchangeability. SBs 72-27-1020 and 42-27-0060 list six types (A to F) of bearing installations found in the flight control systems; the rudder rear quadrant shaft support bearings are Type F 'free-to-rotate' bearings. ATR considered that the replacement of free-to-rotate bearings can be relatively easily accomplished by operators. Therefore, in January 2024 the ATR 72 and 42 maintenance Illustrated Parts Data (IPD) was updated for Type F bearings covered by SBs 72-27-1020 and 42-27-0060, to include the post-modification corrosion-resistant stainless steel bearings as a preferred alternative part.

ATR indicated that following the G-NPTF event, the airworthiness classification for the failure condition of a seized flight control bearing remained as MAJOR and therefore the highest classification of the SB 72- 27-1020 is RECOMMENDED.

**Footnote**

[11] Based on ATR's fleet database.

**Previous reports of bearing failure/corrosion**

ATR indicated that in-service reports of problems with the rudder rear quadrant shaft support bearings are extremely rare. Its records showed that prior to this occurrence on G-NPTF, it was aware of only one previous in-service report of rudder stiffness where corrosion of the rear quadrant shaft support bearings was identified as the root cause. It was also aware of two reports of corrosion having been identified in steel bearings within the elevator system.

The investigation determined that this knowledge was not fed into the troubleshooting guidance on G-NPTF following the 9 February 2023 report of rudder stiffness, nor the investigation troubleshooting performed following the occurrence on 6 March 2023. ATR indicated that in its experience, reports of friction or stiffness within the rudder control system are typically related to the rudder damper, RCU or TLU and therefore these components were prioritised in the troubleshooting philosophy. It stated that it understood the relevance of this historic modification from steel to stainless steel bearings only when the AAIB shared the findings of the metallurgical examination of the bearings from G-NPTF.

**Safety assessment considerations**

ATR's flight controls System Safety Assessment (SSA), produced during the ATR 42 certification process and periodically reviewed[12], did not specifically include rudder stiffness as a failure scenario but did include a rudder jam failure condition, which takes account of a rudder jam within the normal rudder deflection range. A seized flight control bearing could lead to a rudder jam. The safety effects of this failure are described as: *'This loss can be the consequence of a single failure as [sic] jamming. Based on flight test results, the control of the aircraft is performed through roll axis.'*

This failure scenario does not meet the regulatory criteria for an unsafe condition and was therefore classified as having MAJOR[13] consequences. To arrive at a MAJOR categorisation, control of the aircraft must be demonstrated during flight test and for the ATR 72 an approach and landing were performed with a simulated rudder jam at approximately 5° deflection. Additionally, ATR published a specific operational procedure for the rudder jam case which requires the flight to land at an airport with minimum crosswind. ATR consider that the rudder jam failure condition is more conservative than the reported rudder stiffness scenario, and on that basis, it does not intend to review or update the SSA in response to this occurrence.

**Footnote**

[12] The ATA 27 (flight controls) SSA for the ATR 72 was originally produced during the certification for the ATR 72-101/201/101/202. ATR document reference 420.0101/95 Issue 1, dated 4 April 1995, documents the flight controls SSA as updated for ATR 42-500 certification. At the same time this document also became applicable to the ATR 72. This document was subsequently updated in April 2023 (new document reference EYG-3049/22) but the update was neither related, nor relevant to the occurrence to G-NPTF.

[13] Failure conditions are classified according to their severity. Classifications include: CATASTROPHIC, HAZARDOUS, MAJOR, MINOR and NO SAFETY EFFECT. The certification basis for the ATR 72 was Joint Aviation Regulation (JAR) 25 change 11, which in section 25.1309 defined MAJOR failure conditions as those which: '*would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries*'.

**Testing and examination of rudder system components**

No operational or functional checks were performed on the rudder system components during the onsite investigation, as initial findings indicated substantial mechanical resistance within the system. Checks performed during the subsequent return to service maintenance on G-NPTF did not indicate any anomalies with the TLU, RCU or rudder damper (other than that already noted) fitted at the time of the occurrence that could have contributed to the rudder stiffness encountered.

The rudder system components previously removed from G-NPTF during the troubleshooting for the rudder stiffness report on 9 February 2023 were sent to the respective manufacturers for examination and testing.

Minor discrepancies were noted on both the TLU actuator and the RCU, consistent with normal wear, but the units were otherwise functional and in good condition. The findings did not explain why the TLU failed the operational test during the 9 February 2023 troubleshooting.

The rudder damper was mildly out of tolerance in some respects but was also assessed as being in good condition. In summary, no issues were identified with these components that could have contributed to the history of rudder stiffness on G-NPTF.

**Analysis**

*Background to the occurrence*

Over a period of approximately one month several of the operator's pilots had intermittently reported stiffness within G-NPTF's rudder system on three occasions. Each report appeared to indicate the degree of stiffness was increasing over time, despite prompt maintenance intervention on each occasion. The resulting maintenance ranged from functional and operational tests to replacement of the rudder damper and, following the most recent occurrence, replacement of the TLU, RCU and the rudder damper for a second time and an extensive period of troubleshooting which included guidance from ATR. The operator indicated that these actions had, at least to some extent, alleviated the perceived stiffness in the rudder system.

*Flight crew's acceptance of aircraft for flight*

ATR indicated that the primary mitigations for any stiffness, resistance or jamming in the rudder control system are the full and free control check conducted before flight and the rudder jam procedure, if the condition is encountered in flight. The rudder jam procedure had limited relevance in this case, as the aircraft was already in the landing flare when the rudder stiffness was encountered.

During the full and free movement check of the flight controls after engine start, both flight crew commented that the rudder was very stiff to move. Despite this observation they continued with the flight. This meant that the last chance to prevent the aircraft flying with the stiff rudder was missed. Had the crew opted to return the aircraft to the stand, it is possible that further engineering investigations might have identified there was a significant issue with the rudder control system. However, the previous extensive engineering attention and the repeated clearance of the system as having no faults meant the flight crew were ready to accept the aircraft for the flight to Belfast despite feeling that the rudder was very stiff.

*Condition of rudder control system following the occurrence*

Examination of the aircraft the day after the occurrence confirmed the presence of significant resistance in the rudder system, with the rudder being extremely difficult to move both when using the rudder pedals and by hand. While there was no moisture or ice accumulation evident in the rear bay during the initial aircraft examination, subsequent examination after the aircraft had been parked outside for several days revealed an accumulation of water and condensation in the rear bay.

By isolating the command and actuation sides of the rudder system and disconnecting the rudder pedal and autopilot yaw cables from the rear quadrant, the predominant source of the stiffness/friction was determined to originate from the rudder rear quadrant shaft. Removal of the shaft revealed that both rear quadrant shaft support arm bearings were in a degraded condition.

Some residual stiffness remained in the rudder/actuation circuit and the investigation identified that the aft attachment bolt for the rudder damper had been over-torqued. Its installation had contributed to stiffness with the rudder circuit, albeit to a much lesser degree that the degraded bearings.

Additionally, examination of the rudder and vertical stabiliser identified the presence of moisture and degraded sealant, and the grease on the rudder pivot (hinge) points had a degraded appearance.

*Rear quadrant support bearings*

The predominant source of stiffness/friction in the rudder system was determined to be the degradation of the rear quadrant support bearings. Both bearings showed evidence of corrosive attack. The No 2 bearing was completely seized when examined in the laboratory and there was a complete absence of fresh grease, despite being a sealed bearing. The No 1 bearing was rough when rotated and had also suffered from corrosion, although to a lesser extent.

The degradation of the bearings would have substantially reduced or prevented their ability to rotate freely and thus resisted the movement of the rear quadrant shaft, which would have resulted in the difficulties reported in the rudder operation.

SB 72-27-1020 was issued by ATR in March 1993 recommending replacement of steel flight control bearings with corrosion-resistant stainless steel bearings but had not been embodied on G-NPTF.

Following this event, ATR took steps to ease the installation of some post-mod flight control bearings, including the rudder rear quadrant bearings, as an alternative to the SB. This change took effect in February 2024. This means that it will be possible for operators to replace the original steel bearings on the rear quadrant shaft and in other flight control Type F bearing locations, on an on-condition/opportunity basis, without the need to embody the entire SB.

*Moisture ingress*

While G-NPTF's flight control bearings were not corrosion-resistant, many older aircraft in the ATR 42/72 fleet similarly equipped with the original steel bearings, continue to operate without reported problems. Regardless of whether original steel or the post-mod corrosion-resistant bearings are installed, bearings perform better when operated in a mostly dry environment.

Ordinarily, internal bearing components should not be exposed to moisture since the bearings are sealed and covered with grease; in this case, the presence of excessive moisture in the rear bay undoubtedly contributed to the corrosion on the bearings. The rear bay is not intended to be a fully sealed area and it is not unusual to encounter moisture here, but not to the extent observed on G-NPTF. Degraded and missing sealant on the vertical stabiliser provided a path for moisture ingress.

The horizontal and vertical stabilisers and the rudder are areas of the aircraft subject to external de-icing, and pressurised jets are sometimes used to ensure de-icing fluid reaches the upper part of the rudder. ATR is aware of reports de-icing fluid residue being found in the rear bay in the past. Some of the moisture accumulations in G-NPTF's tailcone area had a gel-like consistency, visually consistent with a mixture of water and glycol-based de-icing fluid. It is therefore probable that de-icing fluid entered this area as well as rain and could also have contributed to the corrosion.

Once in the rear bay, accumulated water/de-icing fluid was unable to effectively drain away due to an absent drain hole in the door frame, which obscured the corresponding drain hole in the door. An additional fastener hole had been added instead of the drain hole, at some point in the aircraft's history, but the investigation did not determine when. The resulting trapped moisture would have created an environment conducive to corrosion.

The manufacturer considered that any obstruction of the rear bay drain holes should have been detectable by two routine inspections of fuselage drain ports, which required ensuring that drain holes were clear of debris and unobstructed. While these inspections had been performed on G-NPTF, the inspection tasks assume that the drain holes are present and correctly located. On G-NPTF, it is feasible that the absence of the drain hole in the door frame would not have been detected, particularly if the inspections were performed with the rear bay door in the open position.

Following the occurrence, the operator resealed the vertical stabiliser on G-NPTF and restored the drain hole in the rear bay door frame. ATR has undertaken to remind operators of existing maintenance requirements and best practice regarding rear bay sealing to minimise moisture ingress and glycol contamination in a customer communication.

*Why was the cause of the rudder stiffness not identified sooner?*

The first crew report of rudder stiffness was made on 4 February 2023. Given the extent of the corrosion exhibited on the rear quadrant shaft support bearings, it is likely that this degradation would have developed over an extended period of time. Despite this, it seems that it was only in the month leading up to the incident flight that the condition of the bearings became such that the friction in the rudder control system was detected by flight crew. The most recent routine visual inspection (of the rudder cable circuit) was performed approximately one year earlier, under the previous operator's tenure with no issues identified.

Neither the rudder rear quadrant shaft nor its support bearings were specifically examined or considered during the maintenance interventions which took place in response to the history of rudder stiffness reports on G-NPTF. Initial troubleshooting by the operator's maintenance organisation following the 9 February 2023 report of rudder stiffness was perceived to have had reduced the stiffness in the rudder system.

Further troubleshooting performed in response to guidance provided by the manufacturer, did not result in the identification of any findings which explained the rudder stiffness. This guidance was in-part informed by the operator's feedback from the troubleshooting, which did not include information about the overall maintenance condition of the rear bay, as observed post-incident. The guidance did not specifically direct the operator or its maintenance organisation to look at the rear quadrant shaft bearings. While corrosion/degradation of the bearings was an issue historically known to ATR and addressed by SB 72-27-1020, the absence of numerous or recent in-service reports of difficulty with these bearings together with the lack of findings from the troubleshooting, meant that it was not included as a consideration in the ATR troubleshooting process for reports of stiffness within the rudder system. The operator was not aware of SB 72-27-1020 and therefore did not consider it in the troubleshooting for G-NPTF.

The manufacturer considered that the visual inspections of rudder mechanical control/rudder cable circuit (either performed routinely or during troubleshooting) should have identified the friction at the quadrant shaft. The manufacturer indicated its expectation that the maintenance condition of the rear bay, in combination with the reports of rudder stiffness should have prompted further examination.

The investigation noted that neither of the visual inspections directly referred to the rear quadrant shaft or its support bearings. They did not require the rear quadrant shaft to be rotated by hand, but rather operated by moving the rudder surface or the pedals.

The investigation considered that even a detailed visual inspection, without further examination, may not identify any problems with the bearings. The sealed nature of the bearings and their installed location on the rear quadrant shaft precludes visual inspection of their condition without some level of disassembly. It's likely that friction or degradation in the bearings may therefore only be reliably detected by rotating the rear quadrant shaft by hand, after isolating it from the rest of the rudder control system and confirmed by removal/inspection of the bearings.

Both inspections required the flight crew seats to be removed, so operation of the pedals would not be performed in the normal manner. ATR did not specify a maximum permissible force on the rudder pedals and the force sensed by the force detector rod was not recorded on G-NPTF's DFDR. While the force to move the pedals could be measured by a hand-held dynamometer during the aircraft examination, this is not representative of how the force would be applied to the pedals in normal use. There was therefore an element of subjectivity in the perception of the force required to move the pedals before and after the maintenance interventions and during the post-incident aircraft examination.

As a result of the findings of this investigation, ATR has proposed to create a new Aircraft Fault Isolation (AFI) task to be followed by operators in the event of a problem with the rudder command. The point of entry to the AFI will be an unsatisfactory pre-flight check, for example a hard point detected on the rudder command. The instructions will provide a troubleshooting sequence based on the most probable root causes eg disconnect the rudder control system to isolate the fault on the command or actuation side of the system, RCU, rudder dampers, check the condition of the rear quadrant support bearings, TLU etc. ATR plans to implement this change in the next revision of ATRNavX[14] scheduled for January 2025.

ATR has also launched a review of the rudder mechanical control/rudder cable circuit visual inspection tasks.

*Rudder damper*

The bolt attaching the rudder damper to the rudder surface was found to be over-torqued, a bushing was seized to the bolt shank and there was absence of grease at both rudder damper attachment points. During the aircraft examination it was noted that the rudder damper installation created some subtle but detectable resistance in the rudder/actuation circuit, which disappeared after the bolt was loosened.

The rudder damper had most recently been replaced following the 9 February 2023 report of rudder stiffness. The investigation therefore concluded that this was the only opportunity during which the over-torque could have occurred.

ATR indicated that it did not fully understand how an over-torqued bolt could contribute to stiffness in the rudder circuit, but due to difficulty in obtaining a rudder damper for testing, had not at the time of publication of this report taken action to test or model the possible effects of this condition.

At the time the rudder damper was replaced, the detail view on the relevant AMM figure which showed the allowable torque at each attachment bolt, did not include an arrow to indicate direction or orientation to differentiate the forward and rear aft attachment points. The orientation of the detail view was also opposite to that presented in the overview of the same AMM figure. While it is not known if this directly contributed to the maintenance engineer's understanding of the required torque at each attachment point when the rudder

**Footnote**

14 ATR's electronic maintenance data application.

damper was replaced, the investigation considered that the presentation of information on the figure could lead to uncertainty. As a result, ATR has amended the AMM figure to include an orientation arrow and this change was incorporated in the AMM in January 2024.

*Rudder pivot point lubrication*

Examination of the rudder pivot points showed that while there was some evidence of fresh grease on the grease nipples, most of the grease within the joints was thick, lumpy and degraded in appearance and was brown/red in colour. Additionally, there was evidence of moisture at all the pivot points, including on the surface of the grease.

A review of G-NPTF's maintenance records showed that two different grease products, Aeroshell 33 and SHC-100 had been used alternately on the previous four occasions that the rudder pivot point lubrication task had been performed. Of these, only Aeroshell 33 was approved and intended for use on flight controls, while the other was approved for use in wheel bearings. The grease observed on the G-NPTF rudder pivot points was visually consistent with a mixture of these two grease products, but the presence of water or de-icing fluid may also have contributed to its appearance.

Historical inconsistencies between the numbering convention for consumable items in the ATR CMD and how consumables were called up in AMM tasks created a situation where ATR and maintenance organisations believed consumable items with similar item numbers were interchangeable, when that was not the intent.

The ATR CMD indicated that when a replacement grease product is used, the two types of grease should not be mixed, the old grease should be completely purged and the servicing interval should be temporarily reduced for around 3 to 4 services. There is no evidence that this was done on G-NPTF. Old or degraded grease can develop hygroscopic properties, where it actively attracts water.

It was not determined to what extent, if at all, the degraded, moisture-saturated grease found on G-NPTF's rudder pivot points contributed to the rudder stiffness encountered by the flight crew. No discernible effect was observed during the on-ground examination in a hangar environment but given the in-flight temperatures the aircraft encountered during the occurrence flight the potential for any moisture to freeze could not be discounted.

The condition of the grease indicated that pivot points had not been lubricated in accordance with best practice. Following this occurrence, the operator took steps to ensure that all old grease will be purged on its ATR fleet and that only Aeroshell 33 grease would be used for lubrication of the flight controls. The intent of this standardisation is to ensure a consistent lubrication philosophy and avoid the need for third party maintenance providers to interpret the approved products in the ATR CMD, and thereby reduce the chance of different grease products being mixed.

*Other observations*

The rudder stiffness was detected by the crew at stages of flight during which the TLU would not have been active. When tested, neither the TLU actuator, RCU or rudder damper fitted to the aircraft during the occurrence, or those fitted during the previous occurrence on 9 February 2023, revealed any defects which could have contributed to the rudder stiffness.

Several mechanical anomalies were noted on the TLU system components during examination of the rear quadrant shaft, including that the rollers were seized. While this appeared to have no negative impact on the operation of a donor TLU actuator, the investigation did not rule out that these mechanical discrepancies influenced the result of the TLU operational test during the 9 February 2023 troubleshooting. While in some cases the condition of the components was consistent with operating in a high moisture environment, the investigation determined it had no, or negligible, contribution to the rudder stiffness. But the condition of the rear quadrant shaft and its installed components was such that the ATR declared it unserviceable.

Cable fouling noted on the pedal bellcrank could have resulted from the observed misalignment on the outer ring on bearing No 2, the migration of the TLU support arm bearing, a cable routing issue or a combination of these. But in any case, stiffness or friction imparted to the rudder system as a result of the cable fouling would have been negligible.

*Safety assessment and continuing airworthiness considerations*

ATR indicated that the primary consequence of rudder stiffness such as that resulting from corrosion in the rear quadrant shaft bearings did not result in an unsafe condition and was already covered by the more conservative RUDDER JAM failure condition. It further stated that the very low number of reports of rudder stiffness or corrosion in the rear quadrant support bearings did not indicate a fleetwide unsafe condition.

It therefore stated that there was no evidence to consider upgrading the SB from its existing status of RECOMMENDED, nor to revise the SSA.

**Conclusion**

Following an extensive history of reports of stiffness within the rudder control system, the flight crew experienced rudder stiffness during the full and free control check prior to the flight. Aware of the recent maintenance interventions which were considered to have resolved the problem, the flight crew elected to continue with the flight. They subsequently encountered excessive rudder stiffness during the landing flare which rendered the rudder pedals almost immovable.

Two support bearings on the rudder rear quadrant shaft were found to be corroded. Trapped moisture in the aircraft's rear bay probably contributed to the condition of the bearings. Unable to rotate freely, the bearings would have resisted the movement of the rudder rear quadrant shaft leading to the stiffness. Other anomalies observed in the rudder control system may have contributed to the stiffness, but to a lesser extent.

A Service Bulletin published in 1993 existed to replace the affected bearings with corrosion-resistant equivalents, but had not been embodied on G-NPTF. In February 2024 the manufacturer updated the IPD to allow interchangeability for some flight control bearings (including those on the rudder rear quadrant) with corrosion-resistant bearings, as an alternative to the Service Bulletin.

The manufacturer will also issue an operator communication emphasising existing operational and maintenance procedures to prevent reoccurrence.

## Safety actions

*Manufacturer completed safety actions*

ATR has amended the figure referenced in the AMM tasks for removal/installation of the rudder damper, to include an orientation arrow. This change was incorporated in the AMM in January 2024.

ATR took steps to ease the installation of some post-mod flight control bearings, including the rudder rear quadrant bearings, so that they can be replaced on an on-condition/opportunity basis, without the need to embody the entire SB 72-27-1020. This change took effect in January 2024.

*Manufacturer planned safety actions*

ATR has launched a review of the rudder mechanical control and rudder cable circuit visual inspections.

ATR has committed to publish an operator communication which will emphasise existing operational and maintenance procedures to prevent reoccurrence, including MRBR tasks and recommended Service Bulletins. The OIM will incorporate recommendations on maintenance procedures and reiterate in-service experience.

ATR has launched the creation of a new AFI task to apply in cases of rudder stiffness, with an unsatisfactory flight control check as the entry point. The troubleshooting instructions will include, among other potential causes, consideration of the condition of the rear quadrant shaft support bearings.

*Operator safety actions*

Following this occurrence, the operator undertook the following safety actions:

- Resealed all gaps and areas of degraded sealant on G-NPTF's vertical stabiliser.
- The operator's CAMO issued instructions to specify Aeroshell 33 as the only grease to be used for lubrication of the flight control pivot points to ensure a consistent lubrication philosophy and avoid mixing different products. It took steps to ensure this change was implemented during maintenance planning, by the organisation it subcontracts to provide partial CAMO services.

*Published: 28 November 2024.*