SERIOUS INCIDENT

Aircraft Type and Registration:	ATR72-202, EI-SLG
No & Type of Engines:	2 x Pratt and Whitney PW124B turboprop engines
Year of Manufacture:	1990
Date & Time (UTC):	15 March 2011 at 2130 hrs
Location:	Near Edinburgh Airport
Type of Flight:	Commercial Air Transport (Non-Revenue)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	4,092 hours (of which 3,500 were on type) Last 90 days - 72 hours Last 28 days - 29 hours
Information Source:	AAIB Field Investigation

Synopsis

On the first flight following a maintenance check, the aircraft experienced an uncommanded yaw resulting in a roll to the left as it accelerated through 185 kt. Directional control was regained and subsequent cockpit indications identified a fault with the rudder Travel Limitation Unit (TLU). The aircraft returned to Edinburgh Airport, where it landed safely. The investigation into this serious incident was conducted in conjunction with the Air Accident Investigation Unit (AAIU) of Ireland and the 'Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile' (BEA) of France. The investigation established that a cam on the rudder TLU mechanism had been removed and incorrectly refitted during the maintenance check. As a result of this incident AAIB Special Bulletin S1/2011, containing three Safety Recommendations, was published on 15 April 2011. Since this incident the aircraft manufacturer and the engineering organisation have taken safety actions to minimise the possibility of a similar event recurring. Two further Safety Recommendations are made in this final report.

History of the flight

The aircraft had undergone routine maintenance at an engineering facility at Edinburgh Airport immediately prior to the incident flight. The crew were due to position the aircraft to Paris on the afternoon of the incident, departing at 1600 hrs. However, on arrival they were informed that the aircraft would not be ready until 1830 hrs due to outstanding work required. They

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returned at 1830 hrs to be informed that it was still not ready, but they proceeded to the aircraft nevertheless to commence their preparation, expecting only a short delay. In accordance with company procedures, the co-pilot carried out the internal cockpit preparation whilst the commander carried out the external inspection. With the exception of two minor issues in the cockpit that were quickly resolved, the preparation proceeded normally and the aircraft was ready for operation by 2057 hrs.

The crew completed the pre-flight checks, all of which appeared normal. These included, as part of the 'Before Takeoff' checks, a check of the flying controls for full and free movement, during which the crew were able to monitor the roll control surfaces visually and observe the spoiler operation on a cockpit indication. The crew could not see the empennage and the aircraft was not fitted with a control position indicator.

The aircraft took off from Runway 24 at 2122 hrs with the co-pilot acting as the handling pilot. It was dark, with a reported broken cloud base at 1,700 ft and a light, westerly surface wind. After carrying out a standard instrument departure, the crew climbed the aircraft to FL230 at an airspeed of 170 kt with the autopilot engaged. As the aircraft levelled and accelerated through about 185 kt, the crew felt it roll to the left by about 5° to 10° and they noticed that the slip ball was indicating fully right. The co-pilot disengaged the autopilot and applied right rudder in an attempt to correct the sideslip, and right aileron to correct the roll. He reported that the rudder pedals felt unusually "spongy" and that the aircraft did not respond to his rudder inputs. He had to maintain 15° to 20° of right bank to hold a constant heading with the speed stabilised above 185 kt and applied a small amount of aileron trim to assist. The co-pilot commented that he was reluctant to use more aileron trim due to the varying amount of bank required. Shortly after regaining directional control a FLT CTL caption appeared on the Crew Alert Panel (CAP) and a FLT CTL fault light illuminated on the overhead panel, indicating a fault with the rudder TLU. In light of the control problems the commander requested radar vectors from ATC for a return to Edinburgh, later declaring a PAN. The co-pilot assessed that he had very little control authority to make right turns, so the commander requested that only left turns be given.

Having commenced a return to Edinburgh, the crew carried out the required QRH procedure (Figure 1). In following the procedure they established that both Air Data Computers (ADC) were operating before setting the TLU switch to the LO SPD position, believing that the aircraft had by then slowed below 180 kt. The co-pilot reported that on LO SPD being selected additional roll control input was required to hold the bank angle and that roll authority to the right was further reduced. The commander therefore decided to return the TLU switch to AUTO and the required roll control input reduced. The

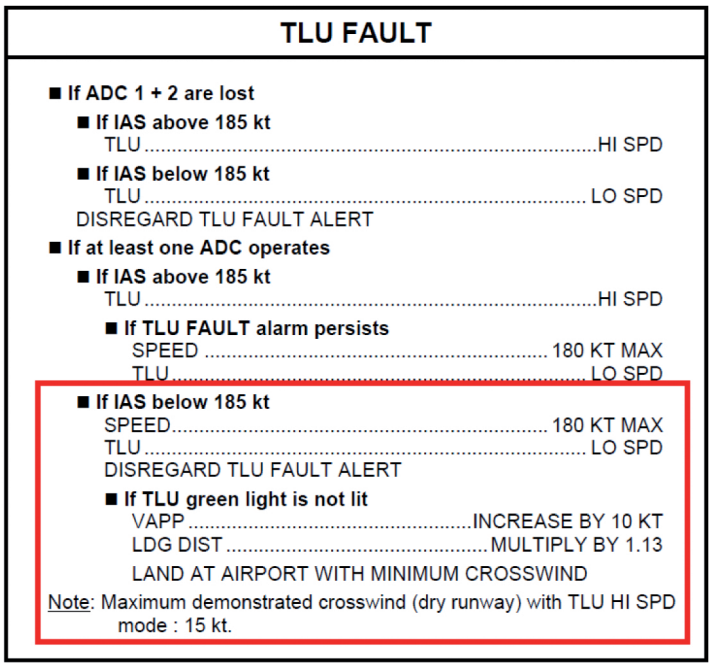


Figure 1

ATR 72 QRH Section 2.22 A - TLU Fault

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green LO SPD light did not illuminate and the crew added 10 kt to their approach speed, in accordance with the QRH.

The co-pilot was able to position the aircraft as directed by ATC, descending at a speed of approximately 180 kt, with a rate of descent of between 1,000 and 1,500 ft/min. The weather for the flight remained good, with a surface wind of 250° at 5 kt and the aircraft remained in VMC throughout the approach. It was established on the ILS for Runway 24 and configured for a full flap landing. The rudder trim, which appeared to be inoperative, was also centred. The co-pilot required both hands on the flight controls in order to maintain directional control and so the commander operated the power levers late on the final approach. The co-pilot reported that although the aircraft became slightly more difficult to control as the speed reduced, it remained controllable.

The aircraft touched down at 2203 hrs just to the left of the runway centreline and the commander took control, applying reverse thrust. The aircraft had landed right main wheel first and during the subsequent rollout, despite applying full right rudder pedal, it diverged towards the left edge of the runway. The commander was finally able to establish directional control using the steering wheel tiller and the aircraft was slowed to taxi speed. The commander was then able to taxi the aircraft clear of the runway and back to the engineering facility for inspection, the aircraft responding normally to steering commands.

Maintenance inspections following the incident

The maintenance organisation examined the aircraft on the morning after the incident to determine the cause of the uncommanded roll and FLT CTL fault reported by the flight crew. An operational test of the TLU was performed during which an asymmetric rudder pedal restriction was noted when the TLU moved towards the reduced authority position[1]. A subsequent visual inspection of the TLU confirmed that one of the cams on the rudder rear quadrant shaft had been incorrectly installed, such that it was misaligned with the other cam. The maintenance organisation immediately commenced a maintenance error investigation, suspending the approvals of the engineers concerned.

Flight Recorders

The aircraft was fitted with a 25-hour magnetic tape Flight Data Recorder (FDR) and 30-minute magnetic tape Cockpit Voice Recorder (CVR). These were removed from the aircraft following the incident for the data to be downloaded and analysed by the AAIB. The 30-minute duration of the CVR meant that the voice recording during the initial stages of the incident was overwritten with later recordings. Also, the FDR recording was of such poor quality that the data was unreliable and therefore unusable. However, the aircraft was also fitted with a Quick Access Recorder (QAR) that had recorded the same flight data. A copy of the QAR data was obtained by the AAIB.

A history of salient (and available) parameters from the QAR for the incident flight is shown in Figure 2. Highlighted (in pink) is the portion of the flight during which the aircraft had accelerated through 185 kt (2126:25 hrs) and then decelerated to below 180 kt (2141:54 hrs). In normal operation, during this period, the TLU would have been in the reduced authority position.

As the aircraft accelerated through 185 kt, the rudder position moved to 2° left (ie aircraft nose-left) at a

Footnote

[1] In the reduced authority (or high speed) position, rudder deflection is mechanically limited by the TLU. In the full authority (or low speed) position, rudder deflection is not limited.

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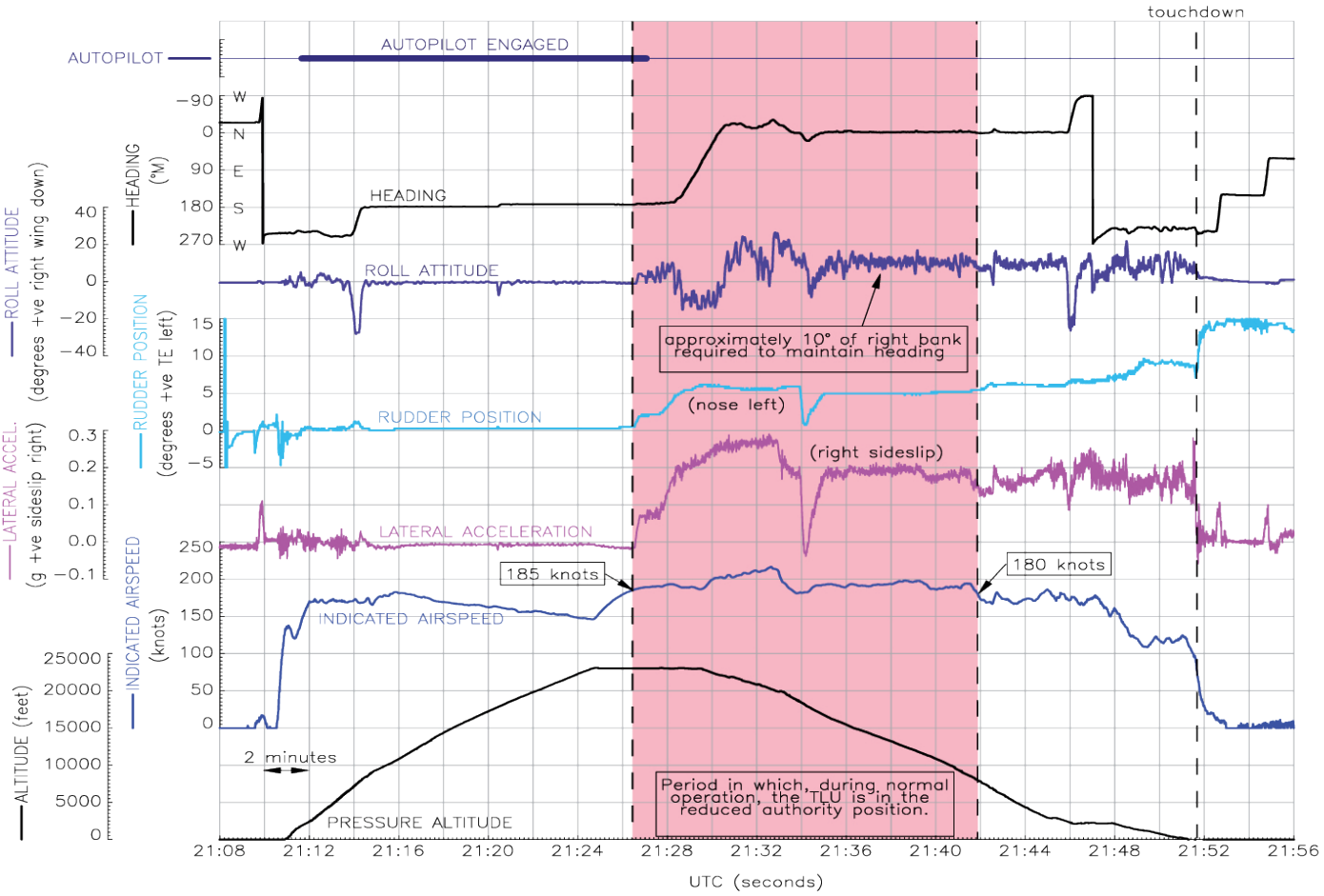


Figure 2

Salient QAR parameters

constant rate of 0.12°/s causing the aircraft to sideslip to the right. The autopilot then rolled the aircraft 4° right-wing-down to maintain the heading. The autopilot was disengaged shortly thereafter.

Over the next two minutes the rudder deflected further to the left (to 6°), during which time the aircraft was turned through 180° for a return to Edinburgh. At 2134 hrs, the rudder deflection decreased rapidly to below 1° left (0.55°/s) following a reduction in airspeed to 180.75 kt[2], before deflecting back to 5° (at 0.07°/s). The rudder remained in this position, with approximately 10° of right bank required to maintain heading, until the aircraft airspeed decreased to below 180 kt, seven minutes later (2141:54 hrs). At this point the rudder gradually deflected further to the left, reaching 8° at touchdown. Coincident with the touchdown, rudder deflection increased up to 15° left, where it remained until the end of the QAR recording.

An inspection of the FDR installation found that the rubber mounts, designed to isolate the FDR from excessive vibration to maintain a good contact between the record head and the magnetic tape media, were degraded and in need of replacement. The operator reported that there were no specific inspection requirements for these mounts in the aircraft manufacturer's maintenance programme. As a result,

Footnote

[2] The sample rate for the indicated airspeed was 1 sample per second with a resolution of 0.25 kt.

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they introduced a specific two-yearly inspection task on their ATR fleet to check the integrity of the FDR mounts.

Rudder travel limitation unit

The rudder linkage on the ATR 72 is a mechanical system composed of quadrants, pulleys, rods and cables. The TLU, installed on the rudder rear quadrant shaft (Figure 3), reduces the range of available rudder deflection at airspeeds above 185 kt, in order to limit the structural loads on the rudder. In the full authority (or low speed) position, rudder deflection is not limited; in the reduced authority (or high speed) position, rudder deflection is mechanically limited by the TLU.

The TLU mechanism comprises an electrical actuator which drives a pivoting bracket on which two rollers are mounted (Figure 4). In the reduced authority position the actuator retracts, engaging the rollers in two v-shaped cams mounted on the rudder rear quadrant shaft, to limit the rudder deflection mechanically. In the full authority position the actuator extends, disengaging the rollers from the cams and rudder deflection is no longer limited. A green LO SPD indicator light illuminates in the cockpit centre console when the TLU is in the full authority position.

The TLU is controlled by a guarded three-position (HI SPD/AUTO/LO SPD) selector switch on the overhead panel. In normal operation the switch is in AUTO. The actuator automatically retracts when both ADCs signal that the airspeed is greater than 185 kt and automatically extends when at least one ADC signals that the airspeed is less than 180 kt. The actuator stroke duration in automatic mode is approximately 15 seconds.

The TLU actuator position is monitored by the Multifunction Computers (MFC) and compared with the airspeed signal from the ADCs. In the case of a disagreement, the FLT CTL fault light on overhead panel and FLT CTL caption on the Crew Alert Panel (CAP) will illuminate; the master caution light and single aural chime are also triggered.

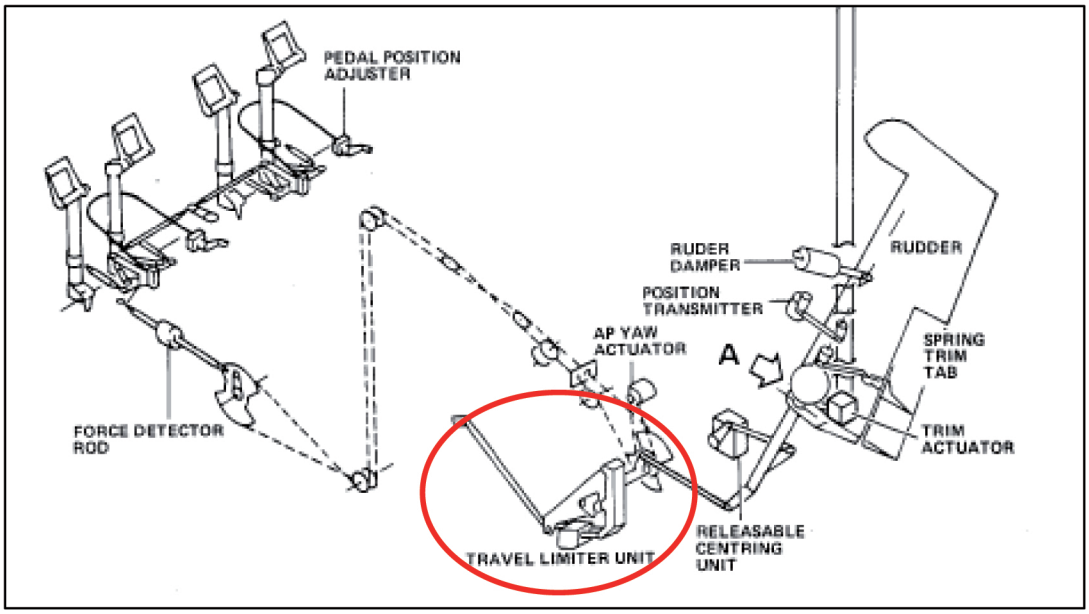


Figure 3

ATR 72 Rudder control system

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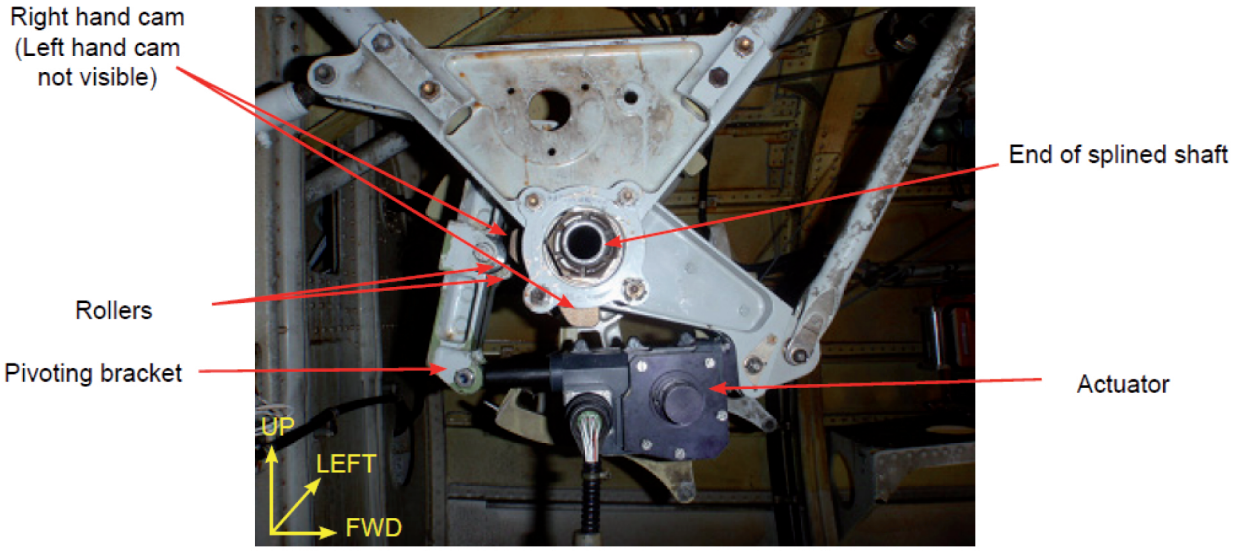


Figure 4

Rudder Travel Limitation Unit

In the case of a FLT CTL fault the actuator extension and retraction may be manually selected by setting the selector switch to HI SPD or LO SPD, according to the aircraft speed. The duration of the actuator stroke in manual mode is approximately 30 seconds.

Maintenance history

Between 19 February 2011 and 15 March 2011 the aircraft had undergone a planned '2-year'[3] maintenance check at a Part 145 approved maintenance organisation in Edinburgh. During the check it was determined the TLU actuator had to be replaced due to excessive moisture indications in the actuator desiccant cartridge. This was completed on 7 March 2011 and, as required in the Aircraft Maintenance Manual (AMM) task, an operational test of the TLU was performed. This work was certified by a licensed aircraft engineer (LAE), who will be referred to as 'Cert A'. As the actuator replacement involved disturbance of a flight control system, independent (duplicate) inspections of the installation and the operational test were required; this was carried out on 9 March 2011. The first part of the independent inspection was performed by Cert A, and the second by the check leader.

While conducting a final check of the area for any loose items following completion of the independent inspections, Cert A observed that the rudder cables seemed very tight and he raised a Non Routine Job Card (NRC) for the cable tensions to be checked. He also noted some play in the bearing of the TLU support arm. As this defect was discovered at a late stage in the check, Cert A discussed his findings with the check leader who referred him to the production manager. The production manager advised Cert A to remove the TLU support arm for closer examination. Cert A referred to AMM job card 27-23-30 RAI 10000-001 *'Removal and Installation of TLU Mechanism Assembly'* which involved relaxing the rudder control cables, removing the TLU actuator and partially disassembling the rudder rear quadrant shaft. It was the first time he had performed this task.

Footnote

[3] A '2-year' check is a heavy base maintenance check that can take two to three weeks to complete.

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Upon examination of the TLU support arm, Cert A and the production manager concluded that the bearing housing was showing signs of wear which was allowing the bearing to migrate. However they considered the wear to be minor and unlikely to prevent the bearing from functioning correctly. As the aircraft was due to leave the hangar in four days, the production manager considered that there would be little chance of obtaining a replacement part without delaying the aircraft, but he did not perform a stock check to verify this. Instead, he advised Cert A to reinstall the TLU support arm and suggested the fitting should be 'peened' to prevent further movement of the bearing.

Both considered that peening (using a centre-punch to create a small lip at a number of locations around the edge of the bearing housing) was a standard engineering practice to retain loose bearings. They did not consult the ATR 72 Structural Repair Manual (SRM) or AMM to determine if this practice was an approved repair on the TLU support arm. Neither document contains reference to such a repair. Cert A asked the production manager if an NRC should be raised to document the defect and the subsequent rectification, but the production manager decided to proceed without raising the appropriate repair documentation.

Cert A reassembled the TLU mechanism on the following day. He was deputising for the check leader and was the only certifying engineer working on EI-SLG that day. With the aircraft due to leave the hangar in three days, he was interrupted from the reassembly task numerous times to perform check leader functions. Having initially installed the TLU support arm, spacers and the left cam on the rudder rear quadrant shaft and checked that both cams were correctly aligned, Cert A was unsure of the order in which two of the spacers should be fitted, as this was not very clear in the AMM diagram. He removed the spacers and laid them out to compare them with the AMM diagram. The right cam also came off and he inadvertently placed it back on the shaft in the incorrect orientation. Cert A reported that the cam slid easily onto the shaft and he was confident that it was correctly aligned because he believed that the master locating spline on the rudder rear quadrant shaft was specifically intended to prevent misalignment of the cams. Once satisfied with the order in which the components had to be fitted, he completed the reassembly of the TLU mechanism up to the point where the next step was the rigging and tensioning of the rudder cables, for which he had previously raised a separate NRC. Following this step, the AMM task also required a functional test of the rudder control, an operational test of the rudder control and spring tab and an operational test of the TLU to be performed. As no job card had been raised for the repair, Cert A made a mental note to perform an operational test of the TLU at a later stage but he omitted to do this. None of the required functional checks on the TLU were performed. Cert A performed check leader functions for the remainder of the day. No further work was carried out on the TLU during the remainder of the check. The NRC raised for rigging and tensioning the rudder cables was completed and signed off on 13 March 2011 by the opposite shift and did not require any disturbance of the TLU system.

Organisational information

General

The maintenance organisation had previously been owned by the aircraft operator but both were now sister companies and part of a larger group. Two of the operator's aircraft had recently experienced significant delays at the Edinburgh facility, a situation which had caused frustration within the maintenance organisation, the operator and at group level. Another of the operator's aircraft was planned in for maintenance

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immediately following EI-SLG. The management at the maintenance organisation considered that another delayed aircraft would have been viewed as a major failure on their part and would result in loss of revenue if the following aircraft could not be accommodated. The production manager stated that these factors directly influenced his decision not to delay the EI-SLG check by ordering a replacement TLU support arm and not to record the work carried out on this system.

Management of maintenance inputs

A check leader was assigned to manage each aircraft maintenance check. This role involved allocation of job cards and manpower, ordering of spares and reporting on the progress of the check. A number of mechanics and LAEs were assigned to each aircraft, and the senior LAE would deputise for the check leader in his absence.

Working hours

The shift patterns for the engineers were 4 days on followed by 4 days off, working 12 hours per day from 0700 to 1900 hrs. On the day the TLU cam was incorrectly installed, Cert A was working his fifth twelve-hour day in a row. He did not consider that he felt physically tired. However, he stated that he may have been mentally fatigued as a result of the heavy workload, the time pressure towards the end of the check and the additional stress of deputising for the check leader.

Material supply to maintenance checks

This operator had a policy of directly purchasing parts from the aircraft manufacturer, and forwarding them to the maintenance organisation. The maintenance organisation considered that this practice would often result in delays, causing a backlog of work towards the end of the maintenance check.

Maintenance personnel

Cert A had worked for the organisation for 3½ years, initially as a technician before undertaking his licence exams. He was awarded a 'B1' category licence in November 2009 and an ATR 72 type rating and company approvals in May 2010. Despite being recently licensed, he was considered within the organisation to be a very capable engineer, frequently assisting the check leader and often deputising in this role.

The production manager was an experienced engineer who had worked for the organisation for two years. He was a 'C1' category LAE, and held a type rating for the ATR 72. In this time he had been promoted to the role of check leader and was subsequently appointed as production manager, responsible for the overall management of the maintenance facility. This post also entailed acting as the Accountable Manager for the company's Part 145 maintenance organisation approval. In addition to this he also held the post of line maintenance manager.

The responsibilities of the Accountable Manager are stipulated in the maintenance organisation's Maintenance Organisation Exposition (MOE) and these include: ensuring that maintenance carried out meets the standards required by EASA and the UK CAA; establishing and promoting the safety and quality policy; enforcing any rectification that may be required to eliminate non-conformance; and ensuring compliance with the procedures contained in the company's MOE and Maintenance Procedures Manual.

Repair procedures

The procedures for standard repairs on the ATR 72 are contained in the aircraft manufacturer's Structural Repair Manual (SRM). If no standard repair exists, the maintenance organisation's technical services

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department must contact the aircraft manufacturer to obtain a repair scheme. The production manager stated after the incident that he should not have become involved in the decision about the repair to the TLU support arm and should have instead referred Cert A to technical services.

Independent inspections

In accordance with applicable regulations, when work is performed on safety critical systems (flight controls, engine controls, etc) an independent (duplicate) inspection must be performed. This requirement was reflected in the maintenance organisation's MOE.

Maintenance documentation

AMM job card 27-23-30 RAI 10000-001 *'Removal and Installation of the TLU Mechanism Assembly'* did not include any specific instructions regarding the orientation of the cams or include any warnings about the possibility of incorrect installation. However it did specifically state that only the right hand cam should be removed. This task required functional tests of the rudder and an operational test of the TLU following reassembly.

AMM job card 27-23-00 OPT 10000 *'Operational Test of the Rudder TLU'* checks that rudder pedal travel is not limited when the TLU is in the full authority position and that it is limited when the TLU is in the reduced authority position. It also checks that the TLU responds correctly to the speed signals from each ADC. A test switch in the cockpit can be selected to send a high speed signal to the TLU actuator during ground testing. When a Press-To-Test (PTT) button is depressed the TLU actuator retracts to the reduced authority position. Rudder deflection and rudder pedal travel are limited accordingly.

Post-incident testing

Incorrect installation of the TLU cam

The rudder rear quadrant shaft has a master locating spline which is intended to prevent rotational misalignment between the two TLU cams. Testing demonstrated that if a cam was removed and transposed through 180° (such that the inboard face of the cam then faced outboard) it could be installed without encountering any resistance, resulting in misalignment between the two cams (Figure 5). This is because the master spline is not located centrally between the two lobes on each cam, but is offset to one side. There are no markings on the cams to indicate their correct orientation.

Although the misalignment of the cams is evident in Figure 5, this is a side-on view of the TLU. Figure 6 is representative of the view that Cert A would have had when reassembling the TLU mechanism. The cam lobes are not visible from this perspective, and although evident, the misalignment between the two cams is more difficult to detect.

Effect of misaligned cam

With the right cam incorrectly installed, it was demonstrated that when the TLU was actuated towards the reduced authority position, both rollers were prevented from engaging in the cams. Instead, the right roller was observed to push upwards on the upper lobe of the right cam, causing the rudder rear quadrant shaft to rotate, deflecting the rudder surface and pedals. The maximum rudder deflection produced during testing on the ground (in the absence of flight loads) was 21°.

A condition could be produced where the right roller was pushing up against the upper lobe of the right cam and the left roller was pushing down against the lower lobe of the left cam, effectively creating a condition

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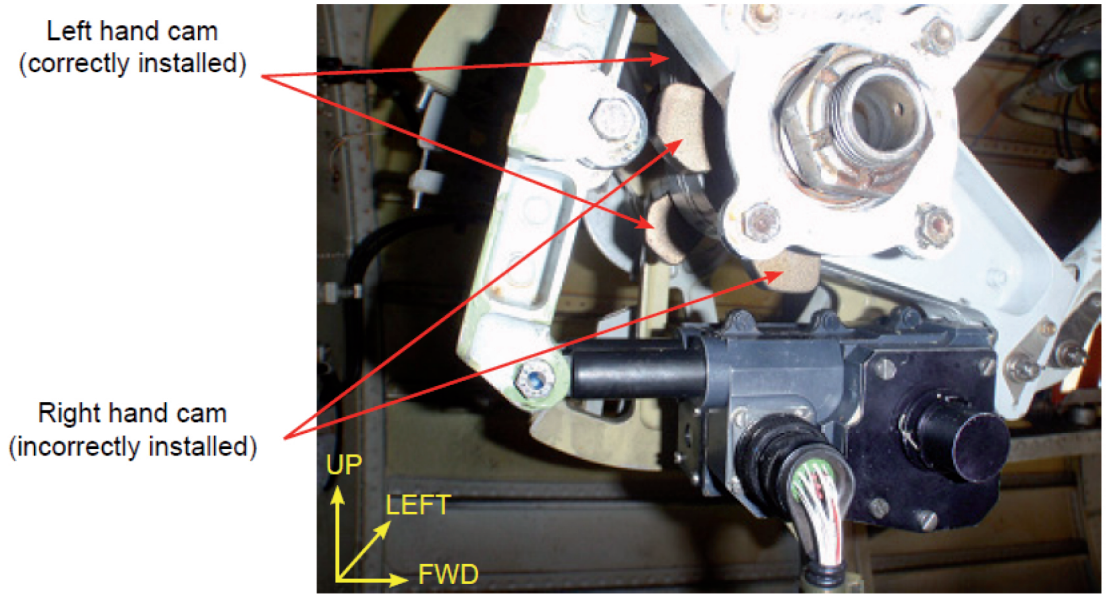


Figure 5

TLU with right cam incorrectly installed

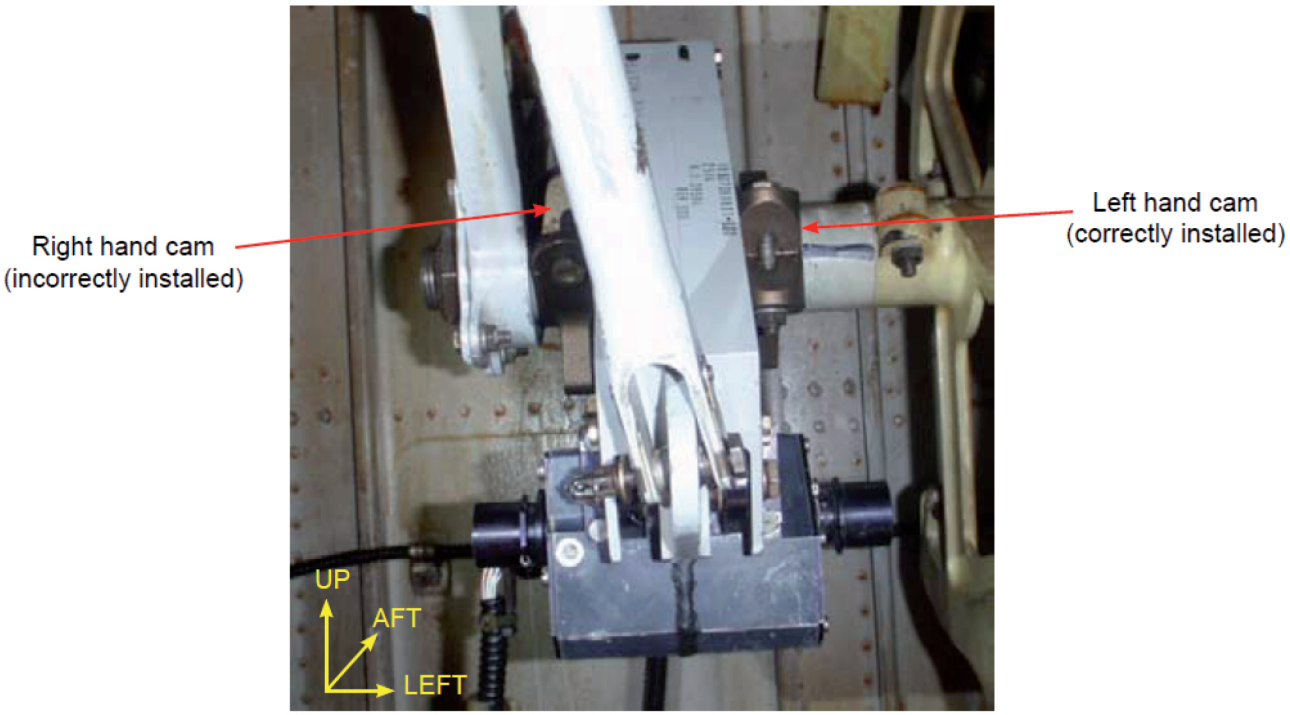


Figure 6

View looking aft on TLU – right cam incorrectly installed

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where the rudder surface and pedals were jammed in the deflected position (Figure 7).

TLU operational test

The AMM operational test was performed with the right cam incorrectly installed. During the test rudder pedal travel was found to be restricted in an asymmetric sense. A FLT CTL fault light illuminated, correctly indicating the disagreement between the aircraft speed configuration and actuator position, but only when the test button was depressed for a minimum of 25 seconds. The AMM task did not state how long the test button should be depressed.

Actuator testing

The TLU actuator was tested at the manufacturer's facilities to determine if there were any anomalies which may have contributed to the uncommanded rudder deflection; none were noted.

Analysis

Incorrect installation of the TLU cam

Inadequate staffing levels on the day of the maintenance error led to a situation in which a recently licensed engineer was working as the only certifying engineer on the aircraft and deputising for the check leader in a high workload environment. The associated distractions, time pressure and the possibility of fatigue are likely to have been detrimental to his focus on the task of reassembling the TLU. Tasks involving reassembly of components are more vulnerable to error than disassembly tasks as they require a greater reliance on memory and attention to the task.

The design of the TLU made it possible for the cam to be installed incorrectly. However the AMM contained no specific reference to the orientation of the cams and there were no markings on the cam to identify the correct orientation. The following Safety Recommendation is therefore made:

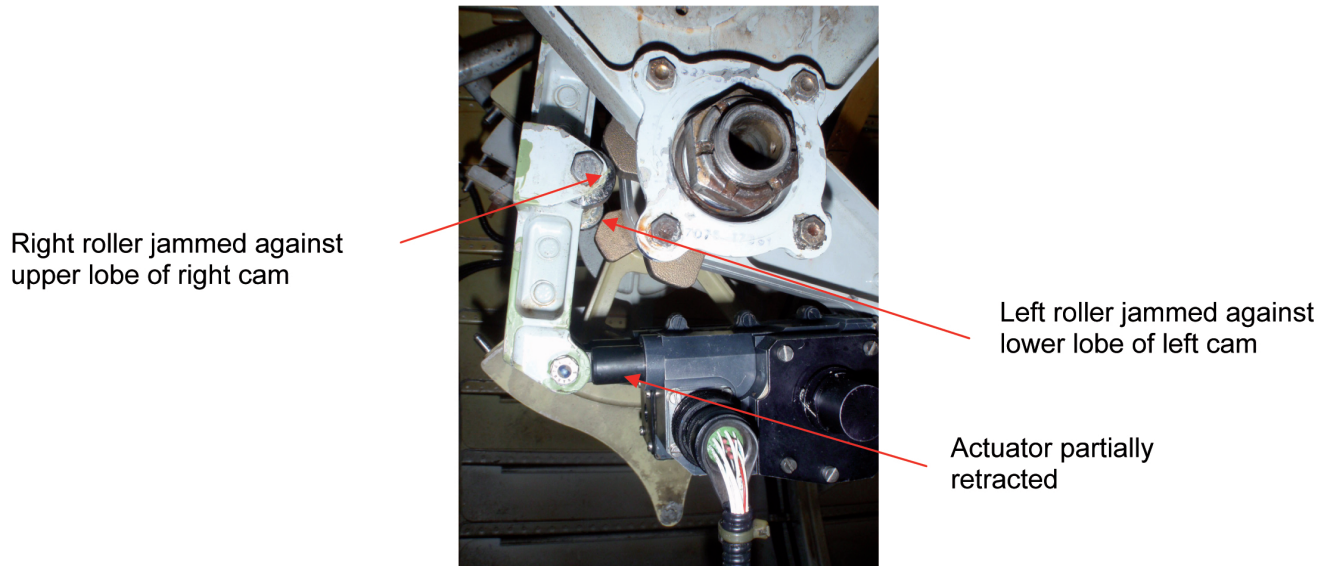


Figure 7

TLU partially retracted – rollers jammed against cams

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Safety Recommendation 2012-002

It is recommended that the European Aviation Safety Agency require ATR to modify the cams on the rudder Travel Limitation Unit on all applicable aircraft, to reduce the risk of incorrect assembly.

Failure to detect the incorrectly installed cam

If an NRC had been raised to document the defect with the TLU support arm, the requirements for an operational test and an independent inspection of the TLU would have been raised. The decision not to record this maintenance resulted in these protections being removed and the maintenance error remaining undetected.

It was considered imperative by the management at the maintenance organisation that EI-SLG's check was completed on time. The relationship between the maintenance organisation and the operator, the associated time pressure, and the potential financial implications were all influencing factors in the production manager's decision to instruct the unapproved and unrecorded repair to be carried out on the TLU. This situation represented a conflict of interest between the production manager's commercial priorities and his obligations as the Accountable Manager. Further, these decisions were not challenged by Cert A.

Unapproved repair

Although the repair on the TLU support arm prompted the disassembly and reassembly of the TLU, the repair itself was not relevant to the operation of the TLU during the incident flight. The decision to proceed with this repair demonstrated non-adherence to both the aircraft manufacturer's and maintenance organisation's procedures.

Effect of incorrect cam installation on TLU operation

The misalignment of the two cams prevented the TLU rollers from engaging normally when the TLU was automatically actuated towards the reduced authority (high speed) position. The interaction between the rollers and cams instead caused the rudder rear quadrant shaft to rotate, resulting in a deflection of the rudder and rudder pedals. A review of the flight data shows the rudder deflection increased from 0° to 6° left as the aircraft accelerated through 185 kt. While actioning the QRH checklist the crew manually selected the TLU selector switch to the LO SPD position. They believed this action to be ineffective as the co-pilot perceived greater roll inputs were required to control the aircraft and the green LO SPD light did not illuminate. However, from the flight data the rudder deflection is observed to reduce rapidly towards 0° in response to this selection. Selecting the TLU switch to LO SPD places the TLU in manual mode, in which the actuator stroke takes 30 seconds. It is therefore likely that the TLU switch remained in the LO SPD position for less than the 30 seconds required to illuminate the green LO SPD light. Had the TLU switch remained in the LO SPD position, the rudder control restriction would have disappeared as the actuator reached the fully extended position, and the return to Edinburgh could have been completed without any further rudder control restrictions.

Having reduced the airspeed below 185 kt, the corresponding action in the QRH checklist did not contain any requirement for the TLU switch to be returned to the AUTO position. Neither did it contain reference to the fact that the green LO SPEED light would take up to 30 seconds to illuminate. The following Safety Recommendation is therefore made:

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Safety Recommendation 2012-003

It is recommended that ATR amend the ATR 72 QRH section 2.22 A to state that the green LO SPD light should illuminate after 30 seconds, when the rudder Travel Limitation Unit switch is manually selected to the LO SPD position.

Returning the switch to the AUTO position caused the rudder deflection to increase to 5° left. As the airspeed subsequently reduced to below 180 kt the TLU actuator would have been expected to extend automatically, removing the control restriction; however instead, the rudder deflection began to increase gradually, reaching 8° left at touchdown. One scenario to explain this is that the TLU rollers became jammed between the two cams, such as occurred during ground testing, and the TLU actuator could not overcome the resistance. Another scenario is that the crew inadvertently placed the TLU switch in the HI SPD position rather than the AUTO position as reported. Subsequent testing of the actuator revealed no anomalies, so it was not possible to draw any firm conclusions on the actuator behaviour.

As only the resultant rudder surface deflection was recorded by the QAR, it was not possible to determine whether any rudder pedal inputs made by the crew throughout the event influenced the amount of rudder deflection.

Operational issues

The rudder control restriction would not have been evident to the flight crew during either the aircraft walkround checks or the pre-flight control checks and the first indication occurred as the aircraft accelerated through 185 kt.

The commander's decision to request ATC to give all turns to the left was based on the limited remaining control authority to the right, as significant right control inputs were required to maintain directional control. However in turning in the direction of the uncommanded roll they faced the possibility that there may have been insufficient control authority remaining to arrest the manoeuvre and avoid an uncontrolled roll departure to the left. Therefore, despite the limited control authority to the right, it may have been more prudent to have made all turns to the right.

The decisions made by the flight crew were based on the limited information they had available at the time while facing a problem of unknown origin which they were unable to resolve, and a desire to land the aircraft as soon as possible.

Safety actions

Aircraft manufacturer

The AAIB made the following Safety Recommendations to ATR in Special Bulletin S1/2011:

Safety Recommendation 2011-10

It is recommended that ATR immediately informs all operators of ATR aircraft equipped with a Travel Limitation Unit that it is possible to install the cams on the rear rudder quadrant shaft in the incorrect orientation.

Safety Recommendation 2011-11

It is recommended that ATR amends all relevant Aircraft Maintenance Manual tasks to include a warning to highlight that the cams on the rear rudder quadrant shaft can be installed incorrectly.

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Safety Recommendation 2011-12

It is recommended that ATR amends the Aircraft Maintenance Manual task *'Operational Test of the Rudder Travel Limitation Unit'* to state that: (1) the test should be carried out for a minimum of 30 seconds and (2) should an asymmetric restriction of the rudder pedals be detected or if the FLT CTL light illuminates, further inspection of the TLU system should be conducted.

In response to these Safety Recommendations, ATR issued an All Operators Message (AOM) on 19 April 2011, to advise operators of this incident and to emphasise the importance of performing an independent inspection after any maintenance is performed on a flight control system. ATR have also updated the AMM task *'Removal and Installation of TLU Mechanism Assy'* to include a requirement to record the position of the right hand cam before removal. In addition, the AMM task *'Operational Test of the Rudder Travel Limiter Unit'* has also been amended to reflect the intent of Safety Recommendation 2011-12.

Maintenance organisation

A new Accountable Manager was appointed with immediate effect following the incident. As a result of their maintenance error investigation, the maintenance organisation identified a requirement for additional training of the two engineers involved, prior to reinstatement of their company approvals. Both engineers have since undertaken training courses on 'Aviation Legislation' and 'Human Factors' delivered by a Part 147 approved training organisation. The details of this incident have also been incorporated in the syllabus of the maintenance organisation's annual recurrent Human Factors training course.

As a result of the issues identified with the lack of adequate staffing cover of certifying engineers, the maintenance organisation has implemented a change in shift patterns. The hangar now operates a Monday to Friday operation, with two shifts: 0700 to 1600 hrs and 1000 hrs to 1900 hrs, in order to ensure there are more certifying engineers available during peak hours. In addition, a minimum of two certifying engineers are assigned to each aircraft in addition to the check leader. Where a certifying engineer deputises for the check leader, handovers are completed in writing and the production manager will step into the role of check leader if the number of certifying engineers on the check is compromised.

Conclusion

The incident was caused by the incorrect fitment of a cam on the rudder TLU mechanism which was not detected by maintenance personnel. This resulted in rudder control restriction which caused the aircraft to enter an uncommanded roll to the left when the airspeed increased above 185 kt. The required independent inspection of the work and the operational test of the TLU system were not carried out. Commercial pressure was identified as the most significant factor which influenced the decision to perform unapproved and unrecorded maintenance on the TLU system. A contributory factor was the design of the TLU cams, which allowed them to be installed in the incorrect orientation.

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