SERIOUS INCIDENT

Aircraft Type and Registration:	BAe ATP, SE-LPS	
No & Type of Engines:	2 Pratt and Whitney Canada PW126A turboprop engines	
Year of Manufacture:	1991 (Serial no: 2043)	
Date & Time (UTC):	9 April 2021 at 0519 hrs	
Location:	Ronaldsway Airport, Isle of Man	
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:	54 years	
Commander's Flying Experience:	5,415 hours (of which 2,964 were on type) Last 90 days - 44 hours Last 28 days - 20 hours	
Information Source:	AAIB Field Investigation	

Synopsis

SE-LPS was on approach to Ronaldsway Airport, Isle of Man with the co-pilot as PF. As the aircraft approached the minimum descent altitude, the co-pilot attempted to disengage the autopilot. There was no audio tone to indicate the disengagement and the co-pilot felt there was resistance in the flying controls. Both pilots checked the cockpit indications which seemed to show that the autopilot had disengaged. The commander took control and also felt resistance in the flying controls. He pressed and held the synchronisation (SYN) button on the control column which he felt released the controls and was able to land the aircraft normally.

A definite cause could not be found for the autopilot not disengaging as designed. The manufacturer responsible for the design of the autopilot identified a possible scenario where the autopilot servomotors could remain engaged after the autopilot disengaged. This would result in higher-than-normal forces at the cockpit controls.

On 2 December 2021, another autopilot occurrence on an ATP, registration SE-MAJ, was reported to the AAIB. The results of this investigation are included in this report.

Safety action was taken by the CAA to include additional testing of the autopilot system as part of the continued airworthiness programme of the ATP. The operator took safety action to reconfigure their fleet so that either pilot could override either autopilot via the SYN button on

their respective control wheel. The operator also initiated remedial action to try and prevent water ingress into the cockpit.

Two Safety Recommendations have been made to the CAA regarding the use of magnetic tape recorders.

History of the flight

The aircraft departed East Midlands Airport at 0428 hrs for the flight to Ronaldsway Airport, Isle of Man. The co-pilot was PF and was using Autopilot 2 (AP2). The flight was uneventful until the final stages of the approach, apart from the chime which sounds in the flight deck to alert the flight crew that they are approaching the altitude they have set in the Electronic Flight Instrument System (EFIS) Control Panel. Every time the chime sounded, throughout the flight, it lasted for 12 seconds rather than the usual one second.

The crew were radar vectored for an ILS approach to Runway 26 at Ronaldsway. AP2 remained engaged for the approach in localiser and glideslope modes and the crew completed their landing checks. As the aircraft reached the decision altitude, the co-pilot attempted to disengage AP2 using the autopilot disconnect button[1] on his control column. There was no audio warning of a disengagement and when the co-pilot attempted to roll the aircraft to line up with the centreline of the runway, he felt resistance in the movement of the controls.

The co-pilot alerted the commander to the problem and both pilots checked their respective primary flying displays (PFDs) which both indicated the autopilot was disengaged. The commander took control and attempted to adjust the aircraft in pitch and roll, he also felt resistance as if the autopilot was still engaged. The commander then used the SYN button on his control column. He immediately felt the controls were no longer resistant to movement. The commander held the SYN button until the aircraft landed at 0517 hrs.

The commander taxied the aircraft to the parking stand where the autopilot disconnect audio warning began to sound continuously and could not be cancelled by any actions the crew took. It finally silenced when the audio warning unit 'timed out'.

Previous flight

The aircraft's previous flight was on 2 April 2021. The flight was uneventful, but the commander noted that the yaw damper indication on the flight controller panel had extinguished at some point. Prior to shutting the aircraft down, the commander tried to engage each autopilot in turn to see if the anomaly was an indication fault (broken bulb), or a system fault. A post-flight entry in the aircraft technical log stated:

> *'AP controller yaw damper not indicating. AP disconnect sounded continuously after landing. Cannot select AP on ground.'*

Footnote

[1] The following terms are used in this report for consistency but are sometimes referred to by other terms in manuals or checklists:
Autopilot disconnect button (also referred to as pilot disconnect button or disengage switch)
Control column (also referred to as control wheel or control handwheel)
Go around button (also referred to as go around switch)
Flight controller (also referred to as autopilot controller or AP controller)

A replacement autopilot control panel was fitted, and the operator's maintenance facility subsequently found that the yaw damper indication bulb was broken. The aircraft technical log recorded that a replacement AP2 computer was installed.

Recorded information

The aircraft was fitted with a CVR, FDR and a QAR. The data recorded by the QAR was in an identical format to that in the FDR. The AP engaged parameters for AP1 and 2 were the only autopilot parameters recorded. The recording shows AP2 was in use during the approach and disengaged just prior to the decision altitude.

The CVR recording was of high quality and two hours in duration. While it captured the end of the occurrence flight, it remained powered during the initial engineering work and so recordings from the start of the flight, including the pre-flight checks of the AP systems were overwritten. However, the autopilot warnings that triggered after the flight while the aircraft was on the ground were captured. Extracts of the QAR and CVR recordings are shown in Figure 1.

The co-pilot was the PF during the descent. Passing through 250 ft amsl the commander called "DECIDE" and the automatic "MINIMUMS" call was triggered. The data shows that AP2 disengaged, followed by the co-pilot stating that it was "...NOT DISENGAGING..." No cavalry charge audio, normally associated with an autopilot disengagement, was captured by the CVR. This was followed by a brief discussion between the flight crew, during which the PF commented that he felt the AP had not disengaged. Passing approximately 150 ft amsl, the commander stated that he had control, and that he was "IN SYNC MODE". The descent continued and the aircraft landed normally. The commander stated that the aircraft "FELT WEIRD" but that he was in control.

After the aircraft landed, and whilst on the stand, the CVR recorded the crew reviewing the event. The co-pilot stated that he had attempted to disengage the autopilot using the 'button' and also the trim but it had not disengaged. He recalled that he tried to roll the aircraft but that he felt resistance against his attempt to move the control column. The commander stated that it had showed DISCONNECTED on his side.

After the data recorders had stopped, the CVR recorded the pilot saying, "TRY THIS", followed by a series of 24 cavalry charge tones. The co-pilot later recalled that he had engaged AP2 on the ground. The co-pilot then said "YAW DAMPER" which was followed by a series of 11 cavalry charge tones. Shortly after, a series of 255 cavalry charge tones was recorded which the crew seemed unable to stop; the trigger for this was not established.

The CVR stopped recording and started again, capturing engineering discussions about the reported fault. They could not fault the autopilot system, and the normal cavalry charge audio alerts were recorded multiple times. They also stated that the use of the commander's SYN button should not have worked with AP2 engaged.

The only other anomalous system behaviour identified in the recordings were that the altitude alerts recorded by the CVR during the flight were approximately 12 seconds long, which was significantly longer than the expected duration of approximately one second.

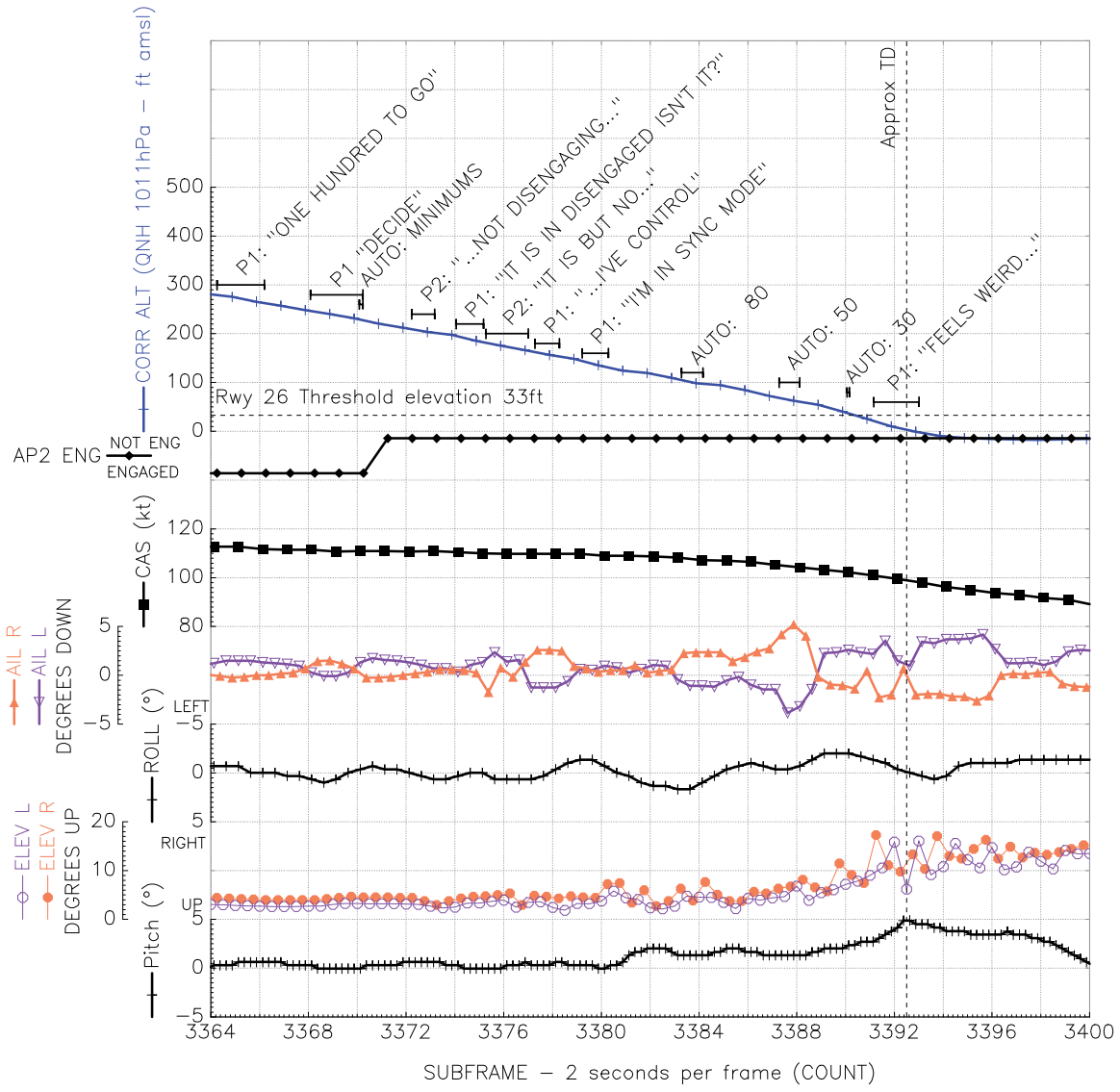

Figure 1

QAR and partial CVR extracts

System descriptions

Automatic Flight Control System

The ATP is fitted with two independent autopilots that share a common flight (autopilot) controller, servo clutches and mechanical drive assemblies. Flight director functions can be selected by each pilot but only one autopilot can be engaged at any one time. The autopilot is a two-axis system (pitch / roll) with a yaw damper and controls the aircraft using three primary electrically actuated servomotors (servos). A separate pitch trim servo operates automatically when the autopilot is engaged or through manual electric trim switches on the control columns. Two independent mode controllers in the centre sloping instrument panel allow the pilots to select autopilot/flight director modes.

Primary servos (aileron, elevator, and rudder)

The three primary servos consist of a drive mechanism with two electric motors (one for each autopilot). The motors are engaged by an electric solenoid clutch that is controlled by the autopilot (flight) controller. A slipping clutch in the servo output lever assembly allows the pilot to override the servo in an emergency. This requires the pilot to apply force on the control column in the direction of the desired movement. For the ailerons this requires a force at the controls of 44 lb (20 kg) and for the elevators a force at the controls of 50 lb (22.7 kg).

Flight controller

The flight controller is fitted to the rear of the centre console and allows the selection of the autopilot system (AP system selector), engagement of the selected autopilot (AP switch) as well as yaw damper disengagement, turbulence mode and ½ bank angle selection. There is also a TURN knob and PITCH wheel which allows the pilot to adjust the aircraft attitude whilst the autopilot is engaged to a new datum or required heading. The controller has an annunciator window that shows the selected functions in green. The controller is shown at Figure 2.

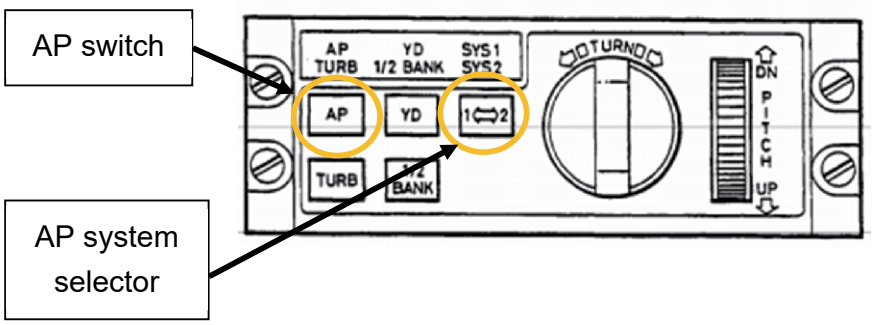

Figure 2
Flight controller © BAE Systems

The AP switch is used to engage the autopilot, but it cannot be used to disengage it. The autopilot will disengage if the AP system selector switch is pressed, because it deselects the active autopilot system and selects the alternate system but in a disengaged state.

Control column

The two aircraft control columns have switches fitted for the control of the autopilot (Figure 3). The co-pilot's control column is similar to the commander's, but with the switches mounted on the opposite side.

The autopilot disconnect button is the primary means for the pilots to disengage the autopilot. Operation of single or both manual electric trim switches on either control column will also disengage the autopilot.

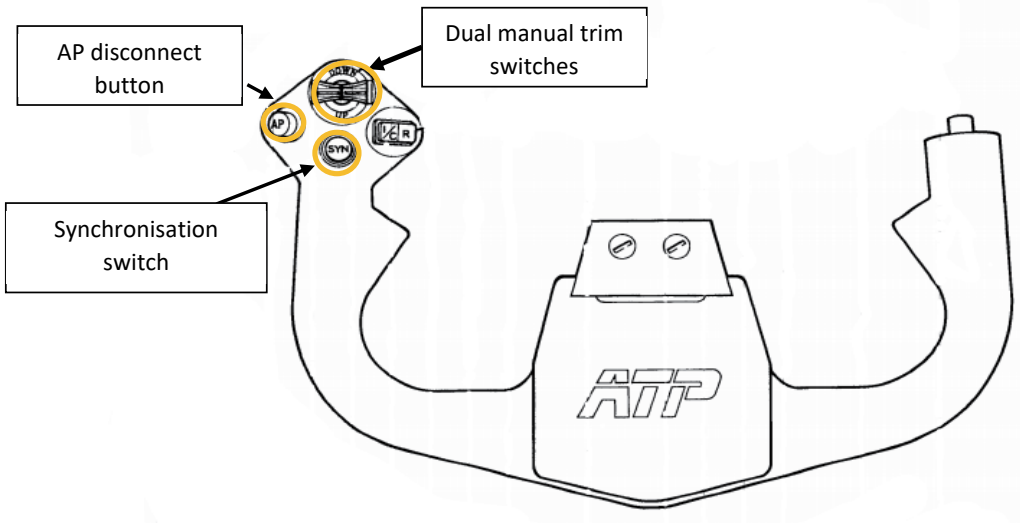

Figure 3

Commander's control column © BAE Systems

The SYN switch is a press button which when depressed will de-clutch the aileron, elevator and pitch trim servos. Any selected autopilot modes will be deselected whilst the switch is depressed. The aircraft may then be manoeuvred to a new attitude with electric trim available without disengaging the autopilot. When the switch is released, the servos re-engage with the flying controls and the autopilot resumes control. Any selected pitch modes are replaced with the basic pitch mode[2] although the previously selected roll mode will reengage if the roll attitude has remained at or less than 6°. The original design of the system allowed either SYN button to de-clutch the servos of either autopilot, allowing either pilot to operate this function regardless of which autopilot system was engaged.

Synchronisation switch

Service Bulletin (SB) 22-14 was issued on 27 April 1990 after an operator request to separate the two SYN buttons so that they only work with their respective autopilot. The operator cited events where the PNF had inadvertently operated the SYN button, disengaging autopilot modes that the PF had previously selected. The SB was optional.

Embodiment of the SB means that the left control column SYN button only works when AP1 is engaged, and the button on the right control column will only work when AP2 is engaged. This SB had been embodied on SE-LPS before the current operator acquired the aircraft, and at the time of this event their ATP fleet consisted of a mixture of modified and unmodified aircraft.

Autopilot engagement and disengagement

The autopilot is engaged by depressing the AP switch on the flight controller (Figure 2). The switch must be depressed for 0.75 seconds to allow for a self-check of the integral safety

Footnote

[2] If there are no flight director modes engaged, PITCH is shown on the PFD, which is a basic mode commanding a hold of the current pitch attitude.

circuit to be completed. Once engaged, the status of the autopilot is displayed on the pilot's PFD. If autopilot 1 is engaged, then AP1 in green is displayed in the top centre of the left PFD with AP1 in white on the right PFD. If autopilot 2 is engaged, then AP2 is displayed in green on the right PFD and in white on the left PFD.

The autopilot cannot be disengaged using the AP switch on the controller but can be manually disengaged by the pilots using the following methods:

- AP disconnect button on either aircraft control column (Figure 3)
- Operation of the manual electric trim on either aircraft control column
- Pressing the AP system selector button on the flight controller (Figure 2)
- Pressing either go around switch on the engine power levers

Manual disengagement of the autopilot is indicated by the removal of the displayed AP1 or AP2 on the PFD and by the sounding of an aural warning (cavalry charge) for one second.

The autopilot will disengage automatically if certain failure conditions are detected, or specific aircraft attitude limits are exceeded. If this happens, the cavalry charge will sound continually until the crew press either of the autopilot disconnect buttons, or the cavalry charge sounds 255 times without being cancelled.

Standby Control System (SCS)

The SCS is an emergency system that provides a means of operating the flying controls via the autopilot servos if the primary mechanical flying control circuits are jammed or severed. The SCS control logic is in each autopilot computer so there are two independent systems. The SCS is armed when electrical power is applied to the autopilot circuits, but it is inhibited whilst the autopilot is engaged.

Each SCS has independent channels to control the ailerons, elevator and the rudder. Each channel has a position input sensor (synchro) at the pilot's controls, which is continuously compared with a position feedback sensor (synchro) at the control surface. If the difference between the synchros exceeds a pre-determined limit, and the autopilot is not engaged, the SCS will operate. Under these conditions the relevant servo(s) will be driven to follow the pilot's control demands.

Audio warnings

Audio warnings including the cavalry charge and altitude alert are generated by the audio warning unit. The warning unit is fitted in the cockpit, behind the sidewall trim below the right Direct Vision (DV) window, which can be opened on the ground.

When the autopilot disengages, the audio warning unit generates the cavalry charge tone in response to an electrical input from the autopilot computer. The altitude alert system is active when approaching the selected altitude to within 1,000 ft or if the aircraft deviates from it by 250 ft. If these criteria are met, an amber light illuminates on the altimeter, and the cockpit speaker emits an audible warning tone. The tone is generated by the audio

warning unit in response to an electrical input from the air data computer. The tone is 12 seconds long, but it will only sound for the duration of the electrical input, which should be one second. If the electrical input remains active for more than one second, the warning will sound until the input is removed, or the warning unit 'times out' after the tone sounds 255 times.

Aircraft examination

The aircraft operator tested the autopilot, SCS and audio warning system, but no faults were found. The following components were removed for further investigation:

- Flight (autopilot) controller
- Autopilot computer No 1
- Autopilot computer No 2
- Audio warning unit
- Audio summing unit

Equipment testing

Flight controller

The flight controller was tested in accordance with the component maintenance manual and no faults were found. The external cover was removed and there was no visible evidence of any anomalies.

Audio warning unit

The electrical connector was found to be corroded when the audio warning unit was disconnected (Figure 4). The unit is located in the area beneath the DV window and the operator advised that moisture (water) ingress through the DV windows was a known problem with ATP aircraft.

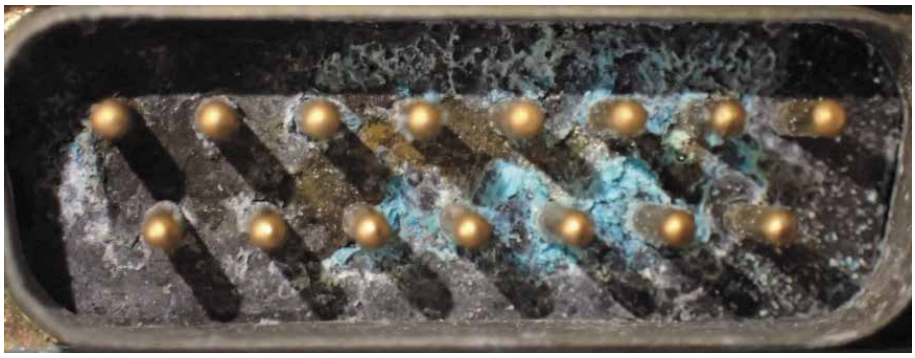

Figure 4

Contamination and corrosion on the audio warning unit connector

No faults were found when the warning unit was tested. It was dry when disassembled, but corrosion deposits were found on one of the three printed circuit boards (PCBs). Most of

the corrosion was in the area where the external electrical connector was soldered to the PCB, but deposits were also found on other areas of the circuit board (Figure 5).

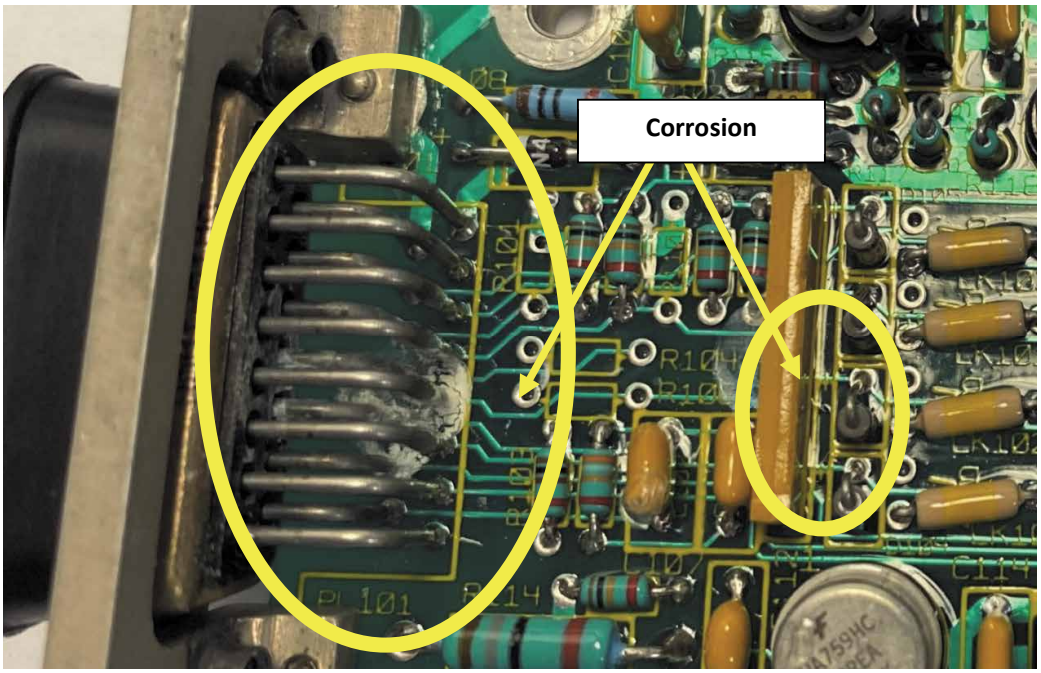

Figure 5

Corrosion deposits inside the audio warning unit

Previous autopilot events and AAIB investigations

The AAIB is aware of three other occasions where flight crews were unable to disengage the autopilot on an ATP aircraft:

- On 27 May 1991 the commander of G-BTPJ was unable to disengage the autopilot. It was eventually disengaged when the crew pulled the autopilot circuit breaker, and a fault was found in the co-pilot's electric trim switch. The AAIB did not investigate this occurrence, and the rationale for the link between the trim switch and the reported symptoms is unclear.
- On 26 January 2016 the crew of G-BUUR reported that the cavalry charge did not sound when the autopilot disconnect button was pressed and control forces suggested that the autopilot was still engaged. The AAIB investigated this occurrence[3] but the cause could not be found. The FDR data indicated that the autopilot disengaged on selection, but the CVR had been over-written.
- On 14 December 2017 the crew of SE-MHF reported that the cavalry charge did not sound when the autopilot disconnect button was pressed

Footnote

[3] Serious Incident on G-BUUR, AAIB Bulletin 9/2016, https://www.gov.uk/aaib-reports/aaib-investigation-to-bae-atp-g-buur [accessed August 2022].

and control forces suggested that the autopilot was still engaged. The control forces were relieved when the co-pilot pressed the SYN button. The AAIB investigated this occurrence[4] but the cause was not found. The FDR data indicated that the autopilot disengaged on selection, but the CVR had been over-written. The aircraft manufacturer reviewed the emergency checklist and a memory item[5] was added stating that if the autopilot does not disengage, the SYN button should be pressed and held whilst manoeuvring the aircraft until it is safe to continue with the rest of the checklist. After the occurrence on SE-LPS, it was noted that the revised checklist did not mention the service bulletin that separates the two SYN buttons so that they will only work if their respective autopilot is engaged. The manufacturer found that this design change had not been identified when the checklist was amended because of an omission during a technical publication amendment in the 1990s. They considered this to be an isolated event that would no longer occur because of subsequent procedural changes.

Review of the autopilot engagement logic

The manufacturer responsible for the design of the autopilot[6] reviewed the engagement logic and identified a possible scenario where an intermittent failure could result in the autopilot computer disengaging whilst the autopilot servo solenoids remain energised.

Each autopilot computer provides the autopilot status signal. The computer that is activated during autopilot engagement indicates the engaged state via this signal. When either of the autopilot disconnect switches are pressed, both autopilot status signals are interrupted, and this interrupt starts the autopilot disengagement sequence.

The autopilot disconnect switches are push buttons that use metallic electrical contacts. These contacts do not connect or disconnect instantaneously but generate an output that indicates that the connection is bouncing until it settles in the final switch state. A debounce circuit is normally used to filter the output so that it represents the desired button status ie ON or OFF.

If the debounce circuit was ineffective, multiple electrical pulses could be produced very rapidly. This phenomenon could be intermittent and could be caused by degradation of electrical components in the debounce circuit or the push button mechanism and contacts.

The autopilot disconnect switches are connected to the autopilot controller, which monitors their status and uses analogue logic gates to control the autopilot computers and servo solenoids (Figure 6).

Footnote

[4] Serious Incident on SE-MHF, AAIB Bulletin 12/2018, https://www.gov.uk/aaib-reports/aaib-investigation-to-bae-systems-operations-ltd-atp-se-mhf [accessed August 2022].

[5] A memory item is an immediate action that should be completed without needing to refer to the emergency / abnormal checklist

[6] The manufacturer responsible for the design is not the Original Equipment Manufacturer

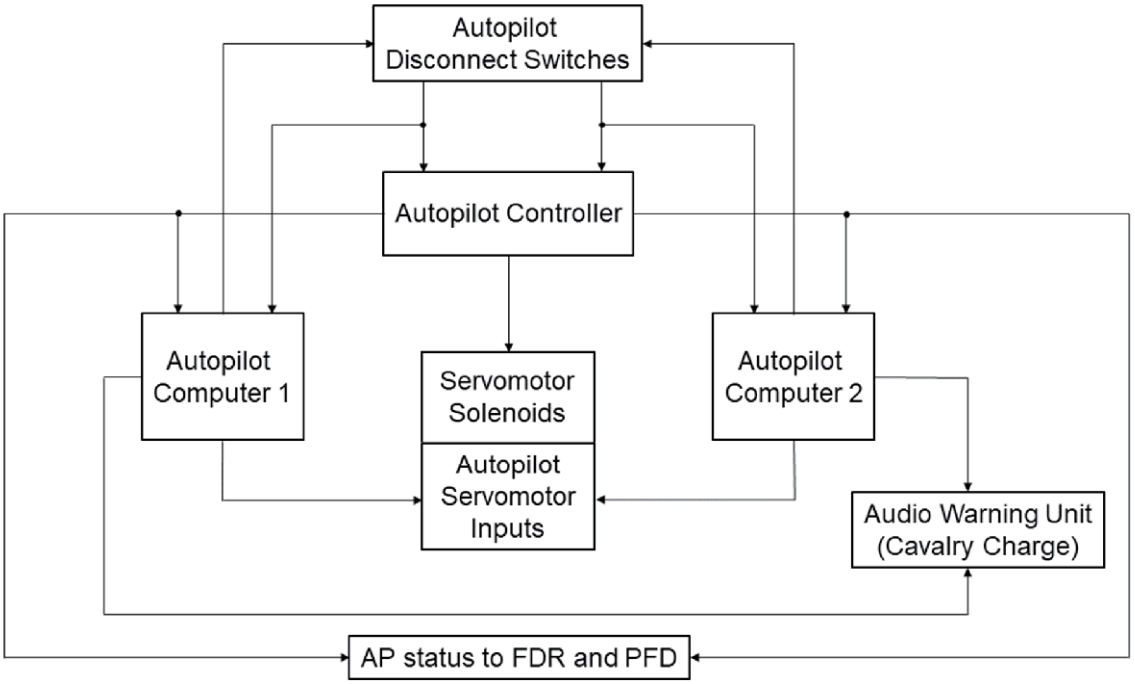

Figure 6

Simplified autopilot schematic (not all components and interactions are depicted)

Unlike digital control circuits, which operate on two voltage levels to indicate ON or OFF, analogue logic gates operate with continuously variable voltage levels, where ON and OFF are represented by specific voltages. These voltages may differ for different components in the circuit, and some components will operate faster than others. Theoretical analysis identified that multiple rapid changes in switch state could potentially result in the autopilot controller logic disengaging the autopilot computer, but not the servo solenoids. The FDR and PFDs would indicate that the autopilot was not engaged, but the crew would experience higher than normal control forces because the servos would still be engaged, but no longer driven by the autopilot. The rapid outputs from the autopilot disconnect switch could cancel the audible cavalry charge before it is generated.

Further attempts to disengage the autopilot using the disconnect buttons or trim switches would have no effect because the autopilot computer would already be disengaged. The only options available to the crew would be to overpower the autopilot servos using the slipping clutches, remove the electrical power by pulling the appropriate circuit breaker, or to de-energise the servo solenoids by pressing the autopilot SYN button.

Meteorology

The weather at Ronaldsway was good with few clouds at 1,500 ft aal and a north-westerly wind of 9 kt. The wind gave a slight crosswind from the right for an aircraft approaching Runway 26. At the time of the occurrence, it was daylight at Ronaldsway, with sunrise occurring at 0531 hrs.

Crew

The commander had significant experience on type and was very familiar with the autopilot system. He had also recently read the AAIB report into a similar occurrence and had spent some time considering his actions should he experience something similar.

Organisational information

Operator procedures

The operator had introduced procedures for checking the disengagement of the autopilots as part of the pre-flight procedures. This was in response to previous occurrences on the aircraft type. This procedure was performed on SE-LPS before the flight and no faults were noted.

Abnormal and emergency checklist procedures

The aircraft Abnormal and Emergency Checklist has a procedure for the crews to follow in the event of an autopilot not disengaging. This checklist was modified after the SE-MHF investigation to include the use of the SYN button. The checklist takes no account of SB 22-14 and does not include any instructions on which SYN button to use if the modification is embodied.

'AUTOPILOT FAILS TO DISCONNECT/MALFUNCTIONS

CAUTION: THE FLIGHT CONTROLS SHOULD BE RESTRAINED DURING DISENGAGEMENT OF THE AUTOPILOT, AS AN OUT-OF-TRIM CONDITION MAY EXIST

If the autopilot does not disengage when the control column disconnect button is pressed:

Memory Actions

Control column SYN button ..... Press and hold

Manoeuvre aircraft until safe to continue with the drill

To disconnect the autopilot carry out the following actions until the autopilot disconnects – confirm EFIS PFD AP annunciation extinguishes:

Electric trim	*Operate*
Other control column disconnect button	*Press*
Go-around button	*Press*
SYS1/SYS2 switch	*Press*
Relevant circuit breaker (see c/b list)	*Pull*

DO NOT RE-ENGAGE THE AUTOPILOT'

Occurrences involving SE-MAJ

2 December 2021

On 2 December 2021 the commander of SE-MAJ, who was also the commander of SE-LPS, reported to the AAIB that the altitude alerts sounded too long, and the cavalry charge did not sound when he pressed the autopilot disconnect button. He recalled that the PFD showed that the autopilot was still engaged after he tried to disengage it. He pressed the disconnect button again, with no effect, before instinctively pressing the SYN button. When he checked the PFD again, the autopilot status showed disengaged. No faults were found when the operator tested the autopilot and audio warning systems, but they replaced several components as a precautionary measure.

Recorded data

QAR, FDR and CVR recordings were analysed and discussed with the crew. The data shows the autopilot disconnected at the point the commander stated he initially attempted to disengage the autopilot, at about 100 ft above the decision altitude. The CVR recording confirmed that no autopilot-disconnect audio alert sounded. The CVR also captured the altitude alerts from earlier in the flight, each sounding for approximately 12 seconds, rather than the normal duration of 1 second. Crew discussions after landing captured by the CVR corroborated the commander's recollection that there was no abnormal resistance to control inputs throughout the event. No other audio alert anomalies were identified from the CVR recording.

29 October 2021

On 29 October 2021 the operator conducted an investigation on SE-MAJ after the crew reported that the altitude alert sounded for too long, and the cavalry charge did not work; the autopilot had disengaged when selected. The operator's engineers found corrosion on the aircraft electrical connector to the audio warning unit and, after removing the corrosion, they reinstalled the original unit. Maintenance records indicated that the engineers believed that the corrosion was probably caused by moisture ingress through the DV window.

Examination of audio warning unit

As the audio irregularities on SE-MAJ were very similar to those on SE-LPS, the audio warning unit from SE-MAJ was returned to the AAIB for further investigation. Visual examination found the external condition to be good but when the external cover was removed the internal components were found to be wet and corrosion was seen on one of the PCBs (Figure 7). This examination was carried out seven days after the occurrence of 2 December 2021, so it is possible that the unit had partially dried out in the intervening time.

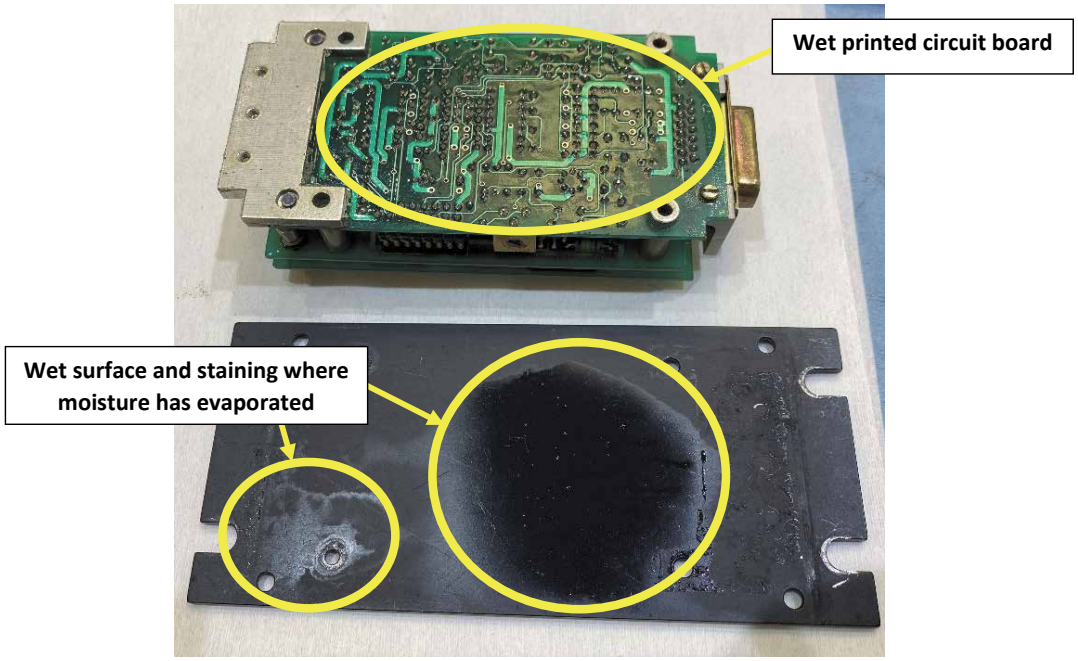

Figure 7

Visible moisture in the audio warning unit

Water ingress via the DV windows

On 16 April 1991 an optional SB (ATP-25-93-35176A) was issued after problems with electrical switches and intercom sockets caused by water ingress through the DV windows. The SB introduced extended side trim panels and drains. However, the operator's ATP fleet consisted of aircraft with and without the SB installed. SE-LPS did not have the SB embodied; SE-MAJ was equipped with the extended side trims, but they were found to be cracked and the joints with the adjacent structure had not been sealed.

Given the condition of the audio warning units that were removed from SE-LPS and SE-MAJ, the operator reported they would take the following safety actions:

- Install the extended side trim panels on all their ATP aircraft and repair any damaged panels.
- Waterproof the side-console switches on all their ATP aircraft.
- Check the rigging of every ATP DV window to make sure that they close correctly.
- Investigate the feasibility of remounting the audio warning unit and installing a drip shield to avoid moisture entering the unit from the top.

FDR recording quality

The FDR fitted to SE-LPS was a model PV1584 which records the data on a magnetic tape. These recorders can suffer from quality issues, resulting in parameter error rates that vary throughout the recording (Figure 8). Errors are expected to occur when recorders

stop and start between flights. Additional errors are likely to occur even on a good quality installation.

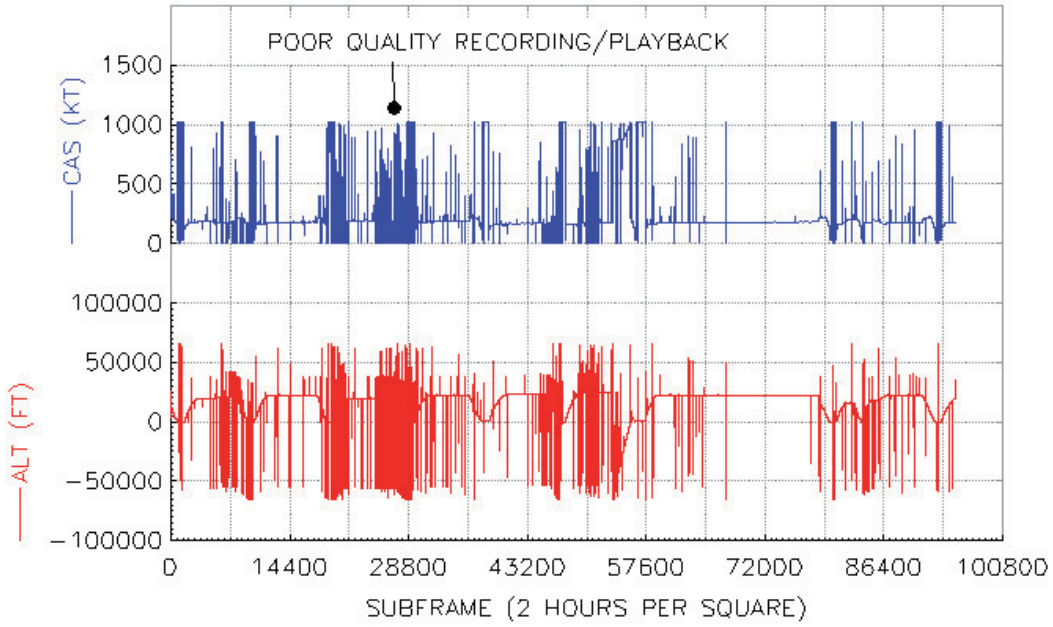

Figure 8

Example parameters illustrating quality issues of magnetic tape FDR recording from SE-LPS

The FDR system on SE-LPS was certified against '*CAA Specification No 10, Flight Data Recorder Systems, dated 1 May 1974'*. An extract from item 3.6.1 of the specification states:

> *'… the design objective for the digital data processing unit and the recorder shall be that not more than one word in 10^4 will be misread under the environmental and operating conditions to which the equipment may be subjected in service. …'*

For a parameter recorded at one sample per second, such as the CAS, a misread of one word in 10^4 equates to a parameter error every 2.8 hours. The CAS data from SE-LPS in Figure 8 indicates a much higher error rate.

When reviewing the quality of the recording, it was seen that some periods of the recording had significantly more errors than others. The recorder records the data in six parallel tracks along the tape using six write heads spaced across the tape. When recording and replaying, one read/write head is used for the full length of the tape and then the tape direction is changed and a different read/write head is used for the next pass. Non-uniformity of the quality of the recording is due to differences in the quality of the read/write heads and variations along the magnetic tape. FDR recorder quality checks do not require the whole recording to be checked.

SE-MAJ was also fitted with the same model of FDR as SE-LPS, and the recording from its occurrence flight also had significant quality issues (Figure 9).

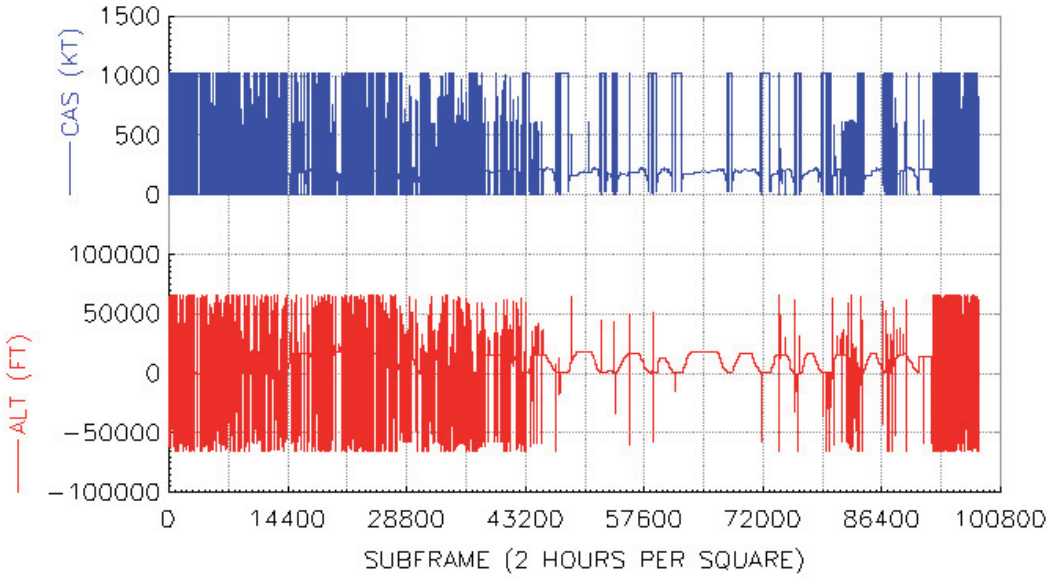

Figure 9

Example parameters illustrating quality issues of magnetic tape FDR recording, from SE-MAJ.

For the occurrences on SE-LPS and SE-MAJ, the better-quality recordings of the same data stored in the QAR solid state memories were used in the investigations. This may not be possible in the event of an energetic accident for which crash protected FDRs are designed to survive, whereas QARs are not crash protected. ICAO required magnetic tape FDRs and CVRs to be discontinued[7] by 1 January 2016. EASA reviewed this requirement under '*Notices of Proposed Amendment 2013-26*', which resulted in the prohibition on the use of magnetic tape CVRs but not FDRs: by extrapolation of the reduction in usage, EASA calculated that magnetic tape FDRs would no longer be in use by 2019.

Following an investigation into a serious incident involving an ATP (SE-MHF[8]), which was equipped with a PV1584 magnetic tape recorder, a Safety Recommendation (2019-002) was made by the AAIB to the EASA to bring the European standards into alignment with the ICAO standard that prohibits the use of magnetic tape recorders. The Safety Recommendation states:

> *'It is recommended that the European Union Aviation Safety Agency (EASA) set an end date to prohibit the use of flight data recorders that use magnetic tape as a recording medium, to ensure compliance with ICAO Annex 6 from that date'*

Footnote

7 ICAO Annex 6 parts I, ref 6.3.1.2 and 6.3.2.2 respectively.

8 Serious Incident on SE-MHF, AAIB Bulletin 12/2018, https://www.gov.uk/aaib-reports/aaib-investigation-to-bae-systems-operations-ltd-atp-se-mhf [accessed August 2022].

The EASA response was that there were too few installations of this type to pursue and that the issue was not perceived as a safety-of-flight issue. However, magnetic tape recorders are still being used on aircraft beyond the date that EASA believed they would no longer be in service and a number of them have been involved in AAIB investigations. The extent to which magnetic tape flight recorders are used by UK Air Operator Certificate holders is not known; therefore, the following Safety Recommendation is made to the CAA:

Safety Recommendation 2022-014

It is recommended that the Civil Aviation Authority review the use of magnetic tape flight data recorders used in aircraft operated by UK Air Operator Certificate holders and establish if there is a practical way to comply with the ICAO requirement to cease their use.

Given that the quality of magnetic tape recordings can vary significantly throughout the recording, and currently only a quality check of a sample of the recording is required, the following Safety Recommendation is made to the CAA:

Safety Recommendation 2022-015

It is recommended that the Civil Aviation Authority require that magnetic tape flight data recorders, used in aircraft operated by UK Air Operator Certificate holders, comply with the Civil Aviation Authority Specification No 10, regarding the error rate requirements, by checking the complete recording rather than by undertaking a sample check.

Analysis

The investigation could not identify any faults with the autopilot system that could explain the resistance to movement in the flying controls. However, the autopilot manufacturer identified a possible scenario involving an intermittent problem with either the autopilot disconnect switch or the associated debounce circuit in the autopilot controller. Corrosion was found in the audio warning unit which may have caused the extended duration of the altitude alert warnings.

Audio warnings

The crew reported anomalies with the altitude alert during the flight and the cavalry charge sounded repeatedly on SE-LPS after it landed; it also sounded repeatedly after the previous flight. The aircraft electrical connector to the audio warning unit was found to be corroded and corrosion was also found inside the warning unit.

Corrosion was also found within the warning unit fitted to SE-MAJ and the PCBs inside were wet. The combined effect of the corrosion and moisture cannot be readily assessed. However, given the similarities between the symptoms on both aircraft, it is likely that this contributed to, or caused, the extended duration of the altitude alerts and the repeated cavalry charge warnings on SE-LPS after it landed. The DV windows, which can be opened when the aircraft is on the ground, are known to be susceptible to water ingress. Previous SBs have been issued to reduce the likelihood of aircraft equipment being affected by

moisture ingress, but SE-LPS did not have these SBs embodied. The SBs embodied on SE-MAJ were found to be incomplete, and damaged, and would not have prevented water leaking through the DV window reaching the audio warning unit.

Autopilot

The autopilot manufacturer suggested that rapid electrical pulses might have occurred when the disconnect button was pressed, resulting in the autopilot computer disengaging whilst the servo solenoids remained energised. While the FDR and PFD would show that the autopilot was disengaged, the rapid pulses would cancel the cavalry charge before it had time to sound. The forces at the control column would be greater than normal, and the only way the crew could overcome these forces would be to either over-power the slipping clutch, press the SYN button, or remove electrical power from the autopilot by pulling the CB.

Whilst this scenario could explain the two similar occurrences on G-BUUR and SE-MHF, it could not fully explain the crew's account of the event on SE-LPS. In the case of SE-LPS, the commander reported that the excessive forces dissipated when he pressed his SYN button. The modification standard of the aircraft, however, meant that this should not have been possible.

The AAIB considered the possibility that the autopilot disengaged normally when the co-pilot pressed the disconnect button, but that the lack of the audible cavalry charge led the pilots to believe that it remained engaged. However, since both pilots felt resistance in the controls, and the commander reported that the resistance stopped when the SYN button was pressed, the possibility that the autopilot disengaging normally is considered unlikely.

The autopilot manufacturer identified additional testing to substantiate their theoretical failure scenario. If successful, this could result in changes to minimise the future arising rate. Safety action was taken by the CAA to include the proposed testing as part of the ongoing continued airworthiness of the ATP fleet.

The operator has removed SB 22-14 from all their aircraft, so that that both SYN buttons will override either autopilot.

Crew response to autopilot anomalies

The commander's significant experience on type as well as his knowledge of the previous AAIB report into a similar event meant that he was prepared to use the SYN button. The co-pilot's effective communication that he was experiencing difficulties with disengaging the autopilot also meant the commander understood rapidly what the issue was and was able to take appropriate action. As a result, the aircraft landed safely from the approach.

The crew tried both autopilot disconnect buttons and electric trims in accordance with the abnormal/emergency checklist without success. Whilst they did not try either the go around button, or the AP system selector button, it is considered unlikely that these actions would have released the servomotor solenoids. Whilst the design of the aircraft autopilot system allows the pilot to gain control of the aircraft through the use of the slipping clutches, this requires them to apply significant force on the flying controls. The

significant forces involved could have presented the pilots with a demanding manoeuvre as the aircraft was close to the ground.

Conclusion

The investigation concluded that the anomalies with the audio warnings were probably associated with corrosion and moisture caused by water ingress through the DV windows.

The AAIB was unable to replicate the reported anomalies in the autopilot system, but theoretical analysis by the autopilot manufacturer identified a scenario involving the autopilot disconnect button and the associated debounce circuit that could lead to a partial disengagement of the autopilot. This scenario could explain the previous occurrences on G-BUUR and SE-MHF but would only partially explain the occurrence to SE-LPS.

Although the aircraft abnormal and emergency checklist did contain a procedure for the failure of the autopilot to disengage, the commander reacted instinctively due to his awareness of a previous occurrence that he had read about in an AAIB report. While the slipping clutch is designed to allow the crew to overpower an autopilot that does not disengage, a substantial increase in the force required to operate the flying controls when late on the approach could present an increased safety risk to the aircraft. The commander used the SYN button which allowed him to operate the controls without hindrance and land the aircraft without further incident.

Safety actions

A s a result of this serious incident the following safety actions were taken:

- The aircraft operator took the following safety actions:
  - Restored the original SYN button logic on all their ATP aircraft.
  - Included the use of the SYN button to overcome the autopilot for all crew in a simulator session in early 2022.
  - Review the water ingress SBs on all their ATP aircraft. The SBs will be incorporated and repaired as necessary.
- The CAA will consider the investigation findings as part of their ongoing review of the ATP continued airworthiness.

Safety Recommendations

The following Safety Recommendations were made to the CAA:

Safety Recommendation 2022-014

It is recommended that the Civil Aviation Authority review the use of magnetic tape flight data recorders used in UK airspace and establish if there is a practical way to comply with the ICAO requirement to cease their use.

Safety Recommendation 2022-015

It is recommended that the Civil Aviation Authority ensure that magnetic tape flight data recorders, used in UK airspace, comply with the Civil Aviation Authority Specification No 10, regarding the error rate requirements, by checking the complete recording rather than by undertaking a sample check.

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