SERIOUS INCIDENT

Aircraft Type and Registration:	Saab 2000, G-LGNR
No & Type of Engines:	2 Allison AE 2100A turboprop engines
Year of Manufacture:	1995 (Serial no: 2000-004)
Date & Time (UTC):	6 November 2015 at 1700 hrs
Location:	On takeoff from Manchester Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 3 Passengers - 29
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	42 years
Commander's Flying Experience:	4,200 hours (of which 420 were on type) Last 90 days - 110 hours Last 28 days - 28 hours
Information Source:	AAIB Field Investigation

Synopsis

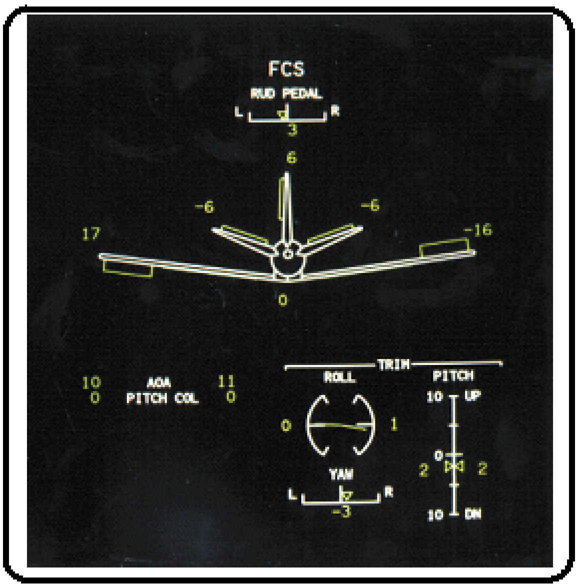
The pilots observed that the aircraft was flying in an unusual attitude. Shortly afterwards a roll mistrim indication illuminated to indicate that there were untrimmed forces in the aileron system. The pilots disconnected the autopilot and recovered the aircraft to straight and level flight. The roll mistrim indication ceased but the EICAS indicated that both ailerons were deflected up. The pilots decided to action a checklist which involved pulling a handle to separate the left and right ailerons. They found that having pulled this handle, aircraft controllability was reduced. The aircraft landed safely from its subsequent approach.

History of the flight

The aircraft was operating a commercial air transport flight from Manchester to Inverness. It departed at 1630 hrs, and the initial part of the flight was described by the crew as uneventful. The autopilot was engaged during the climb.

The aircraft levelled at FL090 and accelerated from 180 kt to 240 kt on a radar heading and in VMC. The pilot recalled that shortly afterwards the primary flight display (PFD) indicated that the aircraft had a nose-up attitude of 7° and 10° of roll to the left, an unusual attitude for straight and level flight. He also felt that the aircraft was not in balance. The PF alerted the pilot monitoring (PM) and together they cross-checked their instruments. A yellow 'R' MISTRIM indication then illuminated on the PFD, indicating there were untrimmed forces in the aileron system.

The PF decided to disconnect the autopilot, bracing the controls for the jolt he expected when doing so with an aileron mistrim. The jolt was more pronounced than usual and he had difficulty maintaining straight and level flight, finding that the aileron controls felt "sloppy" and unresponsive. He reduced airspeed to below 200 KIAS, and the PM viewed the Flight Control System (FCS) synoptic page on the Secondary EICAS Display (SED) (Figure 1). The pilots recalled that the FCS diagram indicated both of the aircraft's ailerons were deflected upwards, with the left aileron up 8° and the right aileron up 5°, and that whilst they were looking at the display both aileron depictions briefly deflected upwards to 17°.



SAAB

Figure 1

Example of FCS presentation on the SED Synoptic page

The pilots decided that there was a problem with the aircraft's aileron system, so the PM consulted the malfunction checklist kept in the cockpit. He read through the two aileron malfunction checklists it contained: *'Aileron system jammed'* and *'Aileron system open failure'*. Neither seemed to fit the symptoms, but the pilots remained under the impression that something was wrong with the ailerons, and as the controls were not jammed they decided to action the *'Aileron system open failure'* checklist (Figure 2). The pilots did not look outside the window to check the actual position of the ailerons, which can be seen from the cockpit if the ailerons are deflected up, and relied upon the SED synoptic page for indications of their deflection.

After pulling the ROLL handle (as directed by the checklist, to separate the left and right aileron control systems), both pilots flew the aircraft in turn to establish who had the most control. They determined that the left control wheel was more effective than the right, and so the commander remained as the PF. Initially a PAN call was transmitted to ATC but this was subsequently upgraded to a MAYDAY once it was clear that a landing would have to be made "with compromised flight controls."

SAAB 2000

MALFUNCTION CHECKLIST

AILERON SYSTEM OPEN FAILURE

*1. AUTOPILOT .... DISENGAGE
*2. Both pilots must act on the controls
*3. ROLL handle .... PULL
4. FLAPS .... UP
5. Target airspeed en route: 160 - 200 KIAS
6. DO NOT trim on failed side
7. Land at nearest suitable airport
8. LANDING TECHNIQUE .... REVIEW
   – Check controllability at safe altitude in the configuration and speed recommended below
   – Roll rate is reduced – use RUDDER to improve roll rate
   – Avoid turbulence and crosswind
   – GPWS FLAP .... OFF
9. For V_{REF} 0, see procedure ***M115***
10. End of procedure.

Land Flap	ICE ACC	M_i	M_i / W_i	LDF Flap 20
0	No	–	+W_i	1.3
	Yes	–	+W_i	1.3

Figure 2

Aileron System Open Failure Checklist

The pilots decided to return to Manchester and informed ATC that the aircraft had a reduced turning capability. The cabin crew were briefed and the PM set the navigation system for an ILS approach to Runway 23R at Manchester. Passing 4,000 ft, the PF requested the selection of Flap 15 in order to check controllability. When the flaps had extended to 7° the PF observed that the aircraft was more difficult to control, and when extended to 13° he requested they be reselected back up. The pilots then planned for a Flap 0 landing and reset the Vref of 152 kt accordingly. At approximately 200 ft agl on the approach the TAWS 'TOO LOW TERRAIN' and 'GLIDESLOPE' cautions sounded. The PF could see the runway and the PAPIs clearly, and the aircraft landed safely.

Recorded information

Incident flight

The operator provided Quick Access Recorder (QAR) flight data from the incident flight and the preceding sector. FDR data was not downloaded and by the time the event was notified to the AAIB the CVR recording had been overwritten.

The FDR and QAR record rudder pedal, trim actuator, rudder position, yaw damper and autotrim status. The position commanded by the flight control computer (FCC) is not recorded. Throughout the flight the yaw autotrim did not record any faults.

The takeoff was uneventful but, at 1,200 ft radio height as the aircraft accelerated through 150 kt, the recorded rudder trim position rapidly changed from approximately neutral to 22° right; rudder surface position remained unchanged at 2° right but both ailerons indicated a deflection of about 1.5° in a 'roll left' sense to maintain an essentially wings-level attitude. The autopilot was engaged at 1,600 ft radio height and, simultaneously, the data showed that the yaw damper disengaged. The aircraft manufacturer advised that the yaw damper is a condition for engagement of the autopilot and therefore it had remained engaged. It further advised that, in interpreting the recorded data, the yaw damper engagement status discrete parameter does not accurately reflect the actual engagement status under some circumstances. Twenty-two seconds later, the recorded rudder trim position value suddenly changed to 4° right. No changes of discrete status or warnings of autopilot roll mistrim, yaw autotrim, rudder or rudder control were recorded at this or any other point during the incident flight.

For the next four minutes, apart from during two heading changes, both ailerons showed 'roll left' deflections of about 2° from neutral and the rudder trim values constantly varied in the range 6° right to 22° right. The deflected ailerons, together with a relatively constant 0.05g lateral acceleration and a slight negative (left wing low) roll attitude, indicate that the aircraft was flying out of balance during this time. Pitch attitude varied between 4° and 6° nose-up.

The aircraft levelled at FL090 and accelerated to 245 kt; aileron deflection increased to 3° from neutral and lateral acceleration increased to 0.1g. As this change occurred, an aileron mistrim annunciation was recorded for ten seconds. At the end of this warning the autopilot disengaged and remained so for the rest of the flight[1]. The aircraft's roll attitude changed from -5° to wings level in just over a second but the aileron deflections and lateral acceleration imbalances remained; rudder trim position indicated 12° right at this point but very slowly trended towards being neutral.

Half a minute later, there was a marked 'jolt' observed in the lateral acceleration recording and, over the next 15 seconds, both ailerons progressively returned to neutral, lateral acceleration returned to zero and rudder trim position changed to a new steady value of 4° left. Rudder position also changed during this time from 2° right to about 4.5° left. Still at FL090, airspeed was reduced to between 190 kt and 200 kt.

Systems description

Flight Controls

General

The SAAB 2000 aircraft has conventional mechanical systems in roll, and fly-by-wire with hydraulic servos in pitch and yaw.

Footnote

[1] The autopilot may have been either manually or automatically disengaged, the data does not include a parameter to determine the method of disengagement.

Aileron control system

In manual control the ailerons are operated by the pilot through the control wheel, which uses a system of cables and pulleys that are directly connected to the ailerons and have a range of movement from +20˚ (±0.5˚) down to -24.2˚(±0.5˚) up. In the event of a control restriction, the pilot can manually operate the aileron disconnect (ROLL handle), which separates the left and right side of the aileron system. When the system is disconnected the left control wheel will control the left aileron and the right control wheel the right aileron. The aileron position is displayed on the SED.

The aileron trim system consists of a trim tab fitted to each aileron, each of which is operated by an electrical servomotor. The pilot can adjust the trim by using a trim switch located on the centre pedestal.

When the autopilot ROLL channel is engaged, movement of the ailerons is controlled by an electrical servomotor connected to the aileron control system. Manual trim can be used to reduce loads on the autopilot servomotor. High loads are annunciated by a yellow 'R' MISTRIM indication displayed on the PFD. If the high load remains for more than 10 seconds an AP ROLL AUTO MISTRIM caution will be displayed on the Primary EICAS Display (PED).

Rudder control system

The rudder control system consists of two independent systems. Each consists of a set of rudder pedals, a Linear Voltage Differential Transformer (LVDT), a Rudder Control Unit (RCU), and a rudder hydraulic servo actuator. The rudder control system also incorporates a yaw damper function, manual and auto trim, and a pedal feel unit.

In manual control the pilot operates the rudder pedals, which causes the mechanically connected LVDT to generate an analogue signal that is detected by the RCU. The RCU then commands the servo actuator to move the rudder to the position commanded by the pedals. The position of the rudder pedals, rudder, and rudder trim actuator are all displayed on the SED.

Yaw damper

The yaw damper should always be engaged during flight. With the yaw damper engaged, the RCU obtains accelerations from other systems on the aircraft and commands the servo actuator to move the rudder to a position to compensate for uncommanded yaw inputs. The yaw damper commands will automatically be set to zero by the FCC if the pedal force is greater than the breakout force[2] (16lb) of the trim and feel unit.

Rudder trim

The rudder trim system consists of a trim actuator and a pedal force cam unit, which is connected to both sets of rudder pedals. In manual flight the rudder trim is adjusted by

Footnote

[2] The pilot can overcome the automatic trim and yaw damper by applying a force of at least 16 lbs on the rudder pedals.

a manual trim switch, located on the centre pedestal, which operates the trim actuator that moves the rudder pedals through the pedal force cam unit. The FCC provides an autotrim function, which generates commands to eliminate steady state lateral accelerations. In autotrim, the FCC sends a signal, through RCU2, to the rudder servo and the trim actuator causing the rudder and rudder pedals to move to the commanded position. If the rudder pedals are constrained from moving, then the rudder will not move to the commanded position. Disengagement of the yaw autotrim will not generate any failure or fault warnings.

The rudder autotrim function is deactivated when rudder pedal deflection exceeds 5° from the trimmed position. Once deactivated, the deflection must be brought back to within 3° of the trimmed position before the autotrim function is reactivated. While a yaw trim failure will deactivate the autotrim function, the yaw damper will remain engaged and compensate for undemanded yaw inputs. Failure of the yaw autotrim generates an amber YAW AUTO TRIM INOP message on the EICAS.

Trim actuator position

The trim actuator position is obtained from two potentiometers. Potentiometer 1 sends an analogue signal to RCU1, which in turn provides data to Data Concentrator Unit 1(DCU). DCU1 provides the trim actuator position to the QAR. Potentiometer 2 provides the signal to DCU2, through RCU2, which is used by the FDR. DCU1 and DCU2 compare values and if there is invalid data, or a significant discrepancy in the values, it will display, when on the ground, a CONFIG TRIM red warning on the PED. If the signal from either, or both, potentiometers is lost in-flight, the FCC will command the yaw damper to disconnect.

Autopilot

The aircraft is equipped with an integrated two-channel autopilot and flight director consisting of two FCCs. The system provides dual flight directors, a 2-axis autopilot, automatic pitch trim control, independent yaw damping and yaw trim commands for the rudder control system. Continuous system monitoring is performed by the FCC for both the autopilot and yaw damper functions.

Aircraft Operations Manual

Flight Procedures Training

The flight procedures training section contains the following advice concerning aileron system faults:

> *'It is strongly recommended that these types of failures are trained during type rating in the simulator and repeated at regular intervals'*

And the warning:

> *'Do not trust the EFIS synoptic page indication!'*

Expanded Malfunction Checklist

This is a reference document normally held by the operator, as a part of its operations manual. This is not a part of the malfunctions checklist carried in the cockpit. The expanded checklist contained the warning:

> *'Before pulling the aileron disconnect in a suspected open failure case always verify an open failure by visually observing actual aileron movement'*

Malfunction checklist

The malfunction checklist is a document kept in the cockpit and used to assist pilots when dealing with a malfunction in flight. The advice that pilots should confirm the position of the aileron visually in these circumstances is not shown in this checklist.

Maintenance actions

Following the event the operator conducted a test of the RCU and rudder control system in accordance with the Aircraft Maintenance Manual[3]. It carried out a detailed inspection of all the connectors, connection beds, pins, and sockets on the RCU and trim actuator, and the control system was examined for evidence of an obstruction or control restriction. The only fault discovered was on the standby trim actuator which took 45 seconds to travel though its full range, instead of the required 16 to 20 seconds[4].

The operator replaced the RCU2, the rudder trim actuator and the left and right aileron position potentiometers. The operator stated that the RCU was referred to the OEM and no fault was found. As of 6 June 2016 the aircraft had flown 539 hours and 706 cycles since the event without a further incident involving the flying controls.

Manufacturer's flight trial

The manufacturer's test pilot conducted a flight trial to observe what would happen if the pedals were obstructed when the aircraft was climbing at 180 kt, then levelled at FL90 and accelerated to 240 kt. The test pilot obstructed the pedals by resting his feet on them. He observed that as the aircraft accelerated, the lateral acceleration increased and the bank angle increased to between 5° and 7°, then the 'R' MISTRIM indication illuminated, and ten seconds later the AP ROLL MISTRIM annunciator illuminated on the PED. The test pilot then removed his feet and the aircraft returned to normal flight. The test pilot commented that the force required to obstruct the pedals is low.

Analysis

The AAIB was unable to examine the aircraft prior to the flying control systems being disrupted and components changed, and the engineering analysis is based on QAR data and the examinations and system checks carried out by the operator.

Footnote

[3] Chapter 27-21-00-710-801.
[4] Chapter 27-12-00-720-001.

Throughout the event there had been no reported problems with either the flying control or autopilot/yaw damper systems. The QAR data also shows that the yaw autotrim remained engaged throughout the flight.

The QAR data from the previous flight shows that the output from the left aileron position transducer was on occasions erratic. At the start of the incident flight the output from the aileron position transducers appeared normal; however later in the flight the output from the left transducer was erratic and unreliable.

The autopilot and rudder control systems appeared to operate normally until the aircraft reached an altitude of 1,200 ft when the rudder trim position moved from -1.5 to -21.3º in six seconds. In manual mode the fastest the trim actuator can move through this range is 12 seconds, and in automatic mode the movement would be slower. While the rudder trim position recorded on the QAR was obtained from LVDT1 through DCU 1, the autotrim function is controlled by FCC 2, through RCU2, using positional data obtained from LVDT2 and DCU2 (the rudder trim position from LVDT2 is only recorded on the FDR). Following the replacement of RCU2 and the rudder trim actuator there were no further occurrences of erratic rudder trim positions recorded on the QAR or FDR. It is likely that as the autopilot, autotrim, and yaw damper all remained engaged, and no warnings or cautions were generated, that the signal from LVDT1 recorded on the QAR was erroneous. However, the evidence indicates that the signal from LVDT 2 which was used in the control of the trim actuator remained valid.

With the autopilot / yaw damper engaged, as aircraft speed increases, FCC2 will command RCU2 to move the rudder to maintain the aircraft in balance. RCU2 will also send a signal to the trim actuator to reposition the rudder pedals. The pilots' report that the aircraft became increasingly out of balance is consistent with the QAR data, which shows that lateral acceleration increased with aircraft speed. However, in comparing the QAR data with the previous flight, where the lateral acceleration remained around 0g, there is a noticeable difference in the position of the rudder pedals and rudder position between the two flights. On the previous flight as aircraft speed increased the rudder pedals and rudder moved close to the null position; whereas on the event flight the rudder pedals and rudder remained at 2° deflection to the right until the autopilot was disconnected, when they then moved to the null position over a 10 second period. After a further 25 seconds there was a rapid reduction in the lateral acceleration to the null position, both ailerons moved upwards by approximately 2° and the rudder pedals and rudder moved 3.7° to the left. This behaviour suggests that during the period that the autopilot was engaged there was a restriction that prevented movement of the rudder and rudder pedals.

Following the disengagement of the autopilot, and before the aileron disconnect (ROLL handle) was operated, the pilots reported that both ailerons moved upwards by several degrees. This was also seen on the QAR data. As the aircraft slowed for landing, both ailerons appeared to move upwards to approximately 17°, which discussion with the manufacturer indicates should have caused the aircraft to pitch nose-up. However, data from the QAR shows that there had been no impact on the flight path; moreover there was no corresponding change in the elevator position to counter the effect of the ailerons.

This suggests that at least one of the aileron position transducers was producing an erroneous signal.

The pilots were initially aware that the aircraft was flying "out of balance". This was probably caused by a restriction of the rudder pedals, perhaps inadvertently caused by one of the pilot's feet. On disconnecting the autopilot, the pilots were alerted by the jolt as the aircraft returned to balanced flight, and on checking the SED were presented with confusing information. They did not check the ailerons visually. The malfunction checklist in the aircraft did not highlight the importance of doing this.

The pilots, confused by the SED aileron indications and having made the decision to divert, omitted to complete the malfunction checklist. Subsequently they selected the flaps down, which was not appropriate in the circumstances, and were distracted late in the approach by TAWS warnings, which further added to their workload.

Conclusion

The investigation established that there had been two separate faults on the aircraft: one involved the rudder trim position recorded on the QAR and the second the output from the left aileron position transducer.

The first fault, with the rudder position, involved a restriction which prevented the rudder pedals from moving. The restriction ceased when the pilot disconnected the autopilot and flew the aircraft manually, and the investigation was unable to determine the cause of the restriction.

Safety actions

> The manufacturer stated that it intended to add the following to the *'Aileron system open failure'* section of the malfunction checklist at the next AOM revision: "NOTE: Verify an open failure by visually observing that one of the ailerons do not follow control wheel input."