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AAIB Bulletin S1/2023 *SPECIAL*

SERIOUS INCIDENT

Aircraft Type and Registration:	Bombardier CL-600-2B16 (604), D-AAAY
No & Type of Engines:	2 General Electric CF34-3B turbofan engines
Year of Manufacture:	2004 (Serial no: 5602)
Date & Time (UTC):	10 August 2022 at 1640 hrs
Location:	In the climb after departing Farnborough Airport, Hampshire
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 3 Passengers - 7
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damaged contact in number 1 system flap retract relay
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	13,091 hours (of which 5,655 were on type) Last 90 days - 102 hours Last 28 days - 41 hours
Information Source:	AAIB Field Investigation

Introduction

This Special Bulletin provides an update on the progress of the investigation into the uncommanded and unarrested flap extension above the maximum flaps extension speed that occurred on a Bombardier Challenger 604 aircraft, registration D-AAAY, on 10 August 2022. It follows publication of an earlier Special Bulletin[1], which provided preliminary information on the event and included a description of the flap operating system.

Footnote

[1] AAIB Special Bulletin S2/2022 published on 22 September 2022. Bombardier CL-600-2B16 (604 variant), D-AAAY - GOV.UK (www.gov.uk)

The investigation established that a failure in the System 1 retract relay prevented the system from arresting the uncommanded flaps extension. This failure also caused the flaps to retract at half speed during the previous 64 flights recorded on the FDR, without the pilots being aware. A failure of the retract or extend relays on either motor channel would have a similar effect on the flap speed.

Following this serious incident, the aircraft manufacturer issued an Advisory Wire[2] on 26 September 2022 to advise operators of this event, and on 29 December 2022 issued five Service Bulletins[3] (SB) for operators to check the flap system on the Challenger 600 series of aircraft. On 10 February 2023, Transport Canada issued an Airworthiness Directive[4] requiring the initial operational test detailed in the SB to be carried out within 100 flight hours or 15 months.

Summary

While actioning the SB, the operator of D-AAAY identified two further aircraft where the flaps had been operating at half speed over a number of flights. The investigation has established that the cause of the failure was damage to the D contacts in the flap extend relay, which resulted from an unsuppressed back-EMF generated when the flap Brake Detector Unit (BDU) was de-energised. The four flap extend and retract relays form part of the system to arrest an uncommanded flap movement.

Two Safety Recommendations have been made in this Special Bulletin to the Manufacturer to introduce a life policy for the relays, and a modification to protect the contacts from damage caused by the back-EMF. A third Safety Recommendation is made to the Regulator to reassess the safety case for the flap operating system. A Safety Recommendation had previously been made to the Manufacturer on 19 September 2022 to inform operators of the actions to take in the event of an uncommanded flap operation in flight.

Manufacturer's Service Bulletins

Requirement

The manufacturer's SBs recommended an operational test to verify the extension and retraction time of the flaps. They called for an initial action to be carried out within 100 flight hours with a repeat test every 100 flight hours for 600/601 series aircraft, and 400 hours for 604/605/650 series aircraft. This flight hour frequency aligns with existing scheduled maintenance tasks.

Early results from Manufacturer's Service Bulletins

On 9 January 2023 the AAIB was advised by an operator of two Challenger 604 aircraft who, while conducting the SB, found the flaps to be operating at half speed. The AAIB deployed a field team who, with representatives from the aircraft manufacturer, undertook

Footnote

[2] Bombardier Wire, AW600-27-2631. Basic issue: September 26,2022.
[3] Bombardier Service Bulletins: SB 600-0780, SB601-1112, SB 604-27-040, SB 605-27-011, SB 650-27-004 Basic Issue: Dec 29/2022.
[4] Transport Canada. Airworthiness Directive Number CF-2023-07, Effective date 2023, Issue date 10 February 2023.

an examination and test of the flap system. The operator also permitted the examination of a third Challenger 604 aircraft, where the flaps had run at the correct speed while actioning the SB. The aircraft are identified in this report as Aircraft 2, 3 and 4; D-AAAY, on which the failure was first identified, is referenced as Aircraft 1.

Aircraft 2

Aircraft 2 was manufactured in 2006 and had accumulated 10,300 hours and 4,687 flight cycles since new.

On 31 December 2022, the SB was carried out when the aircraft was on scheduled maintenance. The results of the test were as follows:

- The flaps extended at half speed and the retraction speed was normal.
- A ‘Break out box’ was connected between the aircraft and the Flap Control Unit (FCU) to allow a functional test[5] of the uncommanded movement arrest system to be conducted.
    - During step E3 of the procedure, the system performed as expected; flap movement stopped within the specified limits and a FLAP FAIL message was annunciated in the cockpit as expected.
    - During Step E8 of the procedure, the flaps stopped at 20° without the expected slight overtravel; the expected FLAP FAIL message was not annunciated.

Following extensive testing, the flaps started operating normally without any corrective action having been taken. The cause of the half speed flap operation was believed to be sticking contacts in the No 1 motor extend relay, K1CE.

All four extend / retract relays were replaced as a precaution and to allow further examination by this investigation.

Aircraft 3

Aircraft 3 was manufactured in 2000 and had accumulated 8,915 hours and 4,344 flight cycles since new.

As a result of the findings on Aircraft 2, the operator asked the operating crew of Aircraft 3 to time the flap movement when they returned to their operating base. The crew reported half speed operation on extension, and normal speed on retraction.

A ‘Break out box’ was connected between the aircraft and the Flap Control Unit to allow a functional test[5] of the uncommanded movement arrest system to be conducted.

Footnote

5 AMM Task 27-51-04-720-801, *‘Functional test of the Flap Control Unit (All drivers ON circuit)’*.

- During Step E3 of the procedure, the flaps stopped at 20° without the expected slight overtravel; the expected FLAP FAIL message was not annunciated.
- During Step E8 of the procedure, the flaps moved past 20° and stopped momentarily at 23° and a FLAP FAIL message was annunciated. This was as expected, but the flaps then retracted, uncommanded, until reaching the UP limit stops and the No 2 motor circuit breaker tripped after a few seconds.

Extensive testing of Aircraft 3 identified that the contacts on the No 2 motor extend relay, K2CE, were stuck in their energised positions. All four extend / retract relays were replaced by the operator as a precautionary measure and the system operated normally.

Aircraft 4

Aircraft 4 was manufactured in 2002 and had accumulated 6,487 hours and 4,241 flight cycles since new.

The SB was carried out and the flaps were found to operate normally. As a precaution, and to provide additional evidence to the safety investigation, the operator replaced the four extend / retract relays so that they could be examined in detail.

Recorded information

The FDR data for Aircraft 2, 3 and 4 were reviewed for evidence of non-normal flap movement speed during extension and retraction. This showed the following:

Aircraft 2: The FDR download contained 260 flights recorded between 22 May 2022 and 30 December 2022. During the most recent 53 flights, which occurred from the 6 October 2022, the flaps extended at half normal speed. During all the recorded flights, the flaps retracted at normal speed.

Aircraft 3: The FDR download contained 34 flights recorded between 22 November 2022 and 11 January 2023. During all the recorded flights, the flaps extended at half normal speed and retracted at normal speed.

Aircraft 4: The FDR download contained 25 flights recorded between 22 December 2022 and 17 January 2023. During all the recorded flights, the flaps extended and retracted at normal speed.

Flap extend and retract relays

Four relays are used to switch electrical power to the two flap drive motors and to release a solenoid operated brake in the BDU fitted in each wing, to allow flap movement. The flap operating system is divided into a No 1 and No 2 System to provide redundancy, and each system has an extend and a retract relay controlling the operation of a motor. Should one system fail, the other system is still capable of operating the flaps, but the operation will be at half speed as only one of the two motors will be operating.

The extend and retract relays are a 4-channel double-pole relay. The component manufacturer's datasheet states that for an inductive[6] load, the relay contacts are specified for 8 amps and a maximum operating cycle life of 20,000 operations.

The schematic layout of the relay pins is shown in Figure 1. When the relay is de-energised:

- Contacts A1, B1, C1 and D1 are OPEN.
- Contacts A2, B2, C2 and D2 are the input to be switched.
- Contacts A3, B3, C3 and D3 are CLOSED.
- Contacts +X1 and -X2 provided electrical power to the operating coil, when energised.

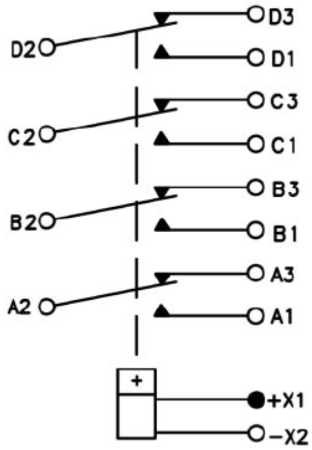

Figure 1

Schematic of relay pin arrangement in the de-energised condition

The D contacts are used to switch the 28 V DC to the BDU brake solenoid coils, the other three sets of contacts (A, B and C) are used to switch each of the three 115 V AC phases to the flap drive motor.

Examination of the relays removed from D-AAAY

Identity of relays

The relays are identified as:

Relay	Description
K1CE	No 1 system extend
K2CE	No 2 system extend
K3CE	No 1 system retract
K4CE	No 2 system retract

Footnote

[6] An inductive load is a part of an electrical circuit that uses magnetic energy to produce work.

Continuity check

An electrical continuity check of all four extend and retract relays removed from D-AAAY was carried out in both the energised and de-energised condition. These checks indicated that the results were as expected in the de-energised condition, but for the K3CE relay in the energised condition, for No 1 system retract, the results were abnormal, Figure 2. O/C refers to open circuit and the measurement values are Ohms (Ω).

Contacts	Relays			
	K1CE	**K2CE**	**K3CE**	**K4CE**
A2 to A3	O/C	O/C	0.2 Ω	O/C
B2 to B3	O/C	O/C	O/C	O/C
C2 to C3	O/C	O/C	0.2 Ω	O/C
D2 to D3	O/C	O/C	O/C	O/C
A2 to A1	0.1 Ω	0.2 Ω	O/C	0.1 Ω
B2 to B1	0.2 Ω	0.2 Ω	O/C	0.1 Ω
C2 to C1	0.1 Ω	0.1 Ω	O/C	0.1 Ω
D2 to D1	0.2 Ω	0.2 Ω	0.1 Ω	0.1 Ω

Figure 2

Results of continuity check in energised condition. Anomalies are highlighted in red

Computerised tomography scanning of the relays

All four of the flap extend and retract relays from D-AAAY were scanned using a computerised tomography (CT) scanner.

The scans identified anomalies with the D contacts of relays K1CE, K2CE and K3CE. The contacts in relay K4CE appeared normal. An example of an image from the K3CE scan is shown in Figure 3.

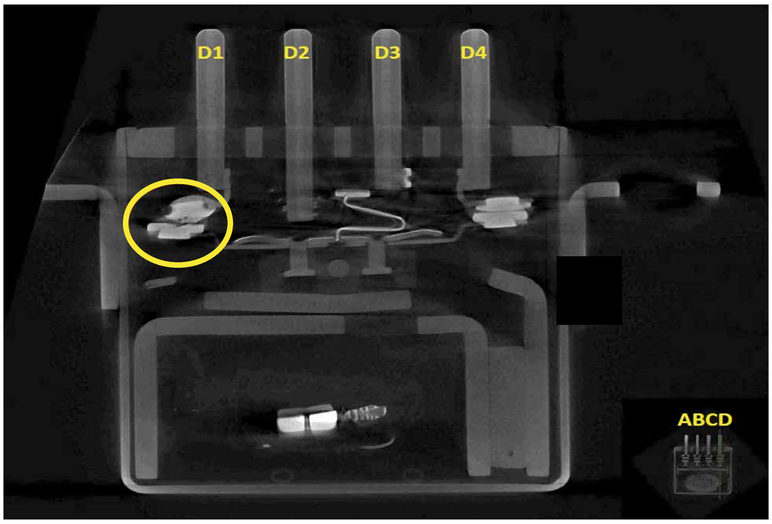

Figure 3

Relay K3CE showing D1 contact damage, circled in yellow

Forensic examination of relays

The relays and the BDU from D-AAAY were taken to a laboratory specialising in forensic examination of electrical components. Before being dismantled for internal inspection, the relays were electrically checked again and the results for relay K3CE in the energised condition was found to differ from the previous test; the other relays conformed to the datasheet specification. The significant differences between the tests are highlighted in red in Figure 4.

Contacts	Relays			
	K1CE	K2CE	K3CE	K4CE
A2 to A3	O/C	O/C	O/C	O/C
B2 to B3	O/C	O/C	O/C	O/C
C2 to C3	O/C	O/C	O/C	O/C
D2 to D3	O/C	O/C	O/C	O/C
A2 to A1	0.1 Ω	0.2 Ω	O/C	0.1 Ω
B2 to B1	0.2 Ω	0.2 Ω	O/C	0.1 Ω
C2 to C1	0.1 Ω	0.1 Ω	O/C	0.1 Ω
D2 to D1	0.2 Ω	0.2 Ω	0.1 Ω	0.1 Ω

Figure 4

Significant differences from previous test in energised condition are highlighted in red

Internal condition of relays

The relays from D-AAAY were dismantled to allow examination of the contacts. All four relays had the same part number; Figure 5 shows the disassembled contacts of relay K3CE.

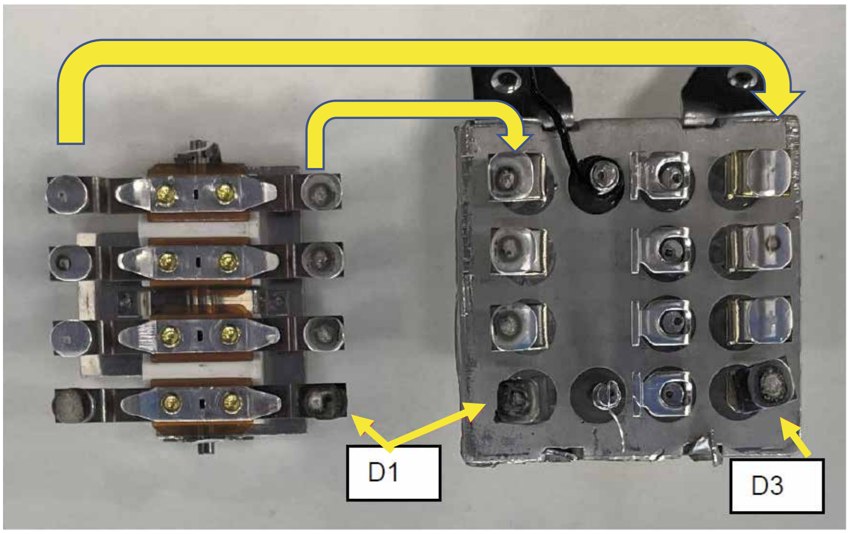

Figure 5

General arrangement of relay contacts, disassembled.
Arrows show how the part on the left connects to the part on the right

Prior to full disassembly, the contacts were examined using an optical microscope and significant damage was found on the D contacts on relays K1CE, K2CE and K3CE. The damage to the D1 contact on relay K3CE is shown in Figure 6.

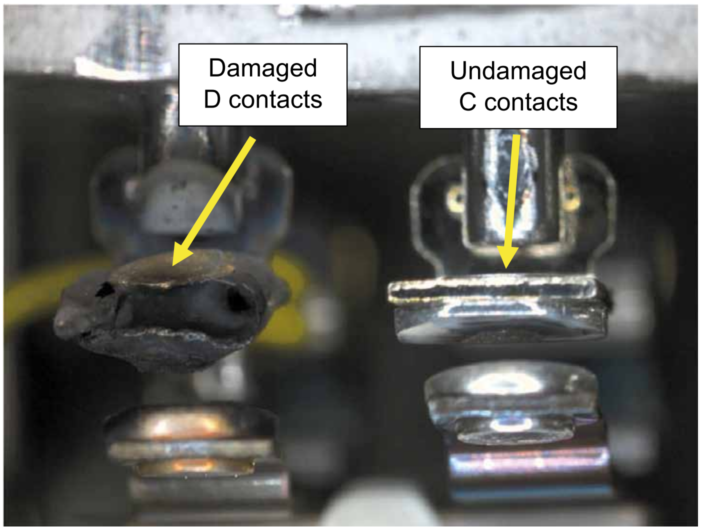

Figure 6

K3CE relay showing contact damage

Scanning Electron Microscopy inspection and Energy Dispersive X-ray analysis was conducted on a selection of contact pads which showed evidence of welding and pulling apart.

Preliminary examination of the relays removed from Aircraft 2, 3 and 4

External condition of relays

The extend and retract relays removed from Aircraft 2, 3 and 4 were visually inspected, and appeared to be in good condition. No anomalies were noted with their connecting pins.

Aircraft 2

Apart from the K2CE relay, the manufacturing date on the relays was consistent with them having been fitted at the time of aircraft manufacture.

The maintenance records for Aircraft 2 showed that the K2CE extend relay had been replaced in April 2018, at 7,596 flight hours and 3,316 flight cycles, after trouble shooting of a defect that caused a FLAP FAIL EICAS message. The trouble shooting found that the BDU brake solenoids were permanently energised. Further investigation found that the K2CE extend relay was not operating normally. Once this relay was replaced, the flap system operated normally.

The K2CE relay, which had not failed, and was replaced in 2018, was CT scanned and the D1 and D2 contacts were found to show signs of erosion and material transfer (Figure 7). This relay had been in-service for approximately 2,700 flight hours and 1,371 flight cycles.

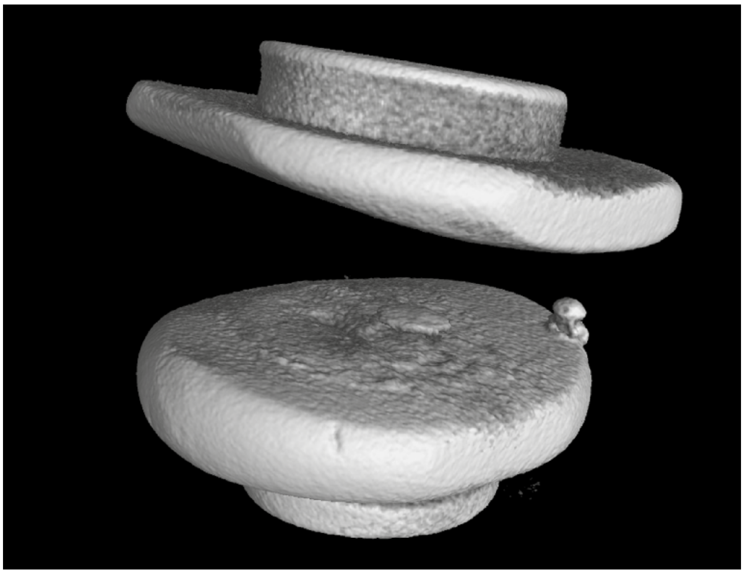

Figure 7

Aircraft 2, relay K2CE, contacts D1 and D2 showing surface degradation and material transfer

Aircraft 3

The K2CE relay from Aircraft 3 was found to have the D1 and D2 contacts welded together. When in the de-energised condition; the contacts should have been open. The D2 and D3 contacts were also closed; this would be their normal position with the relay de-energised (Figure 8). In this condition, if the uncommanded flap movement arrest system was activated, rather than the flap movement being arrested, the flaps would retract.

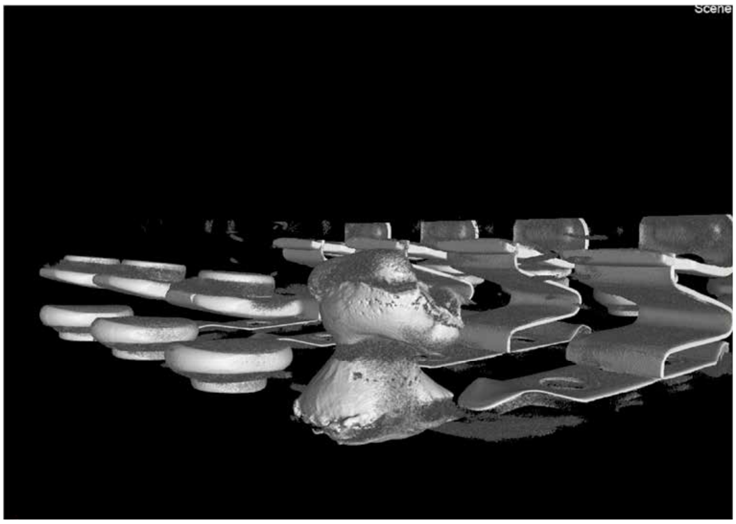

Figure 8

Aircraft 3, relay K2CE, showing welded D1 and D2 contacts

Aircraft 4

Aircraft 4, which had passed the SB flap movement timing test, also had degraded D1 and D2 contacts on relay K3CE. Figure 9 shows erosion and metal transfer between the contacts.

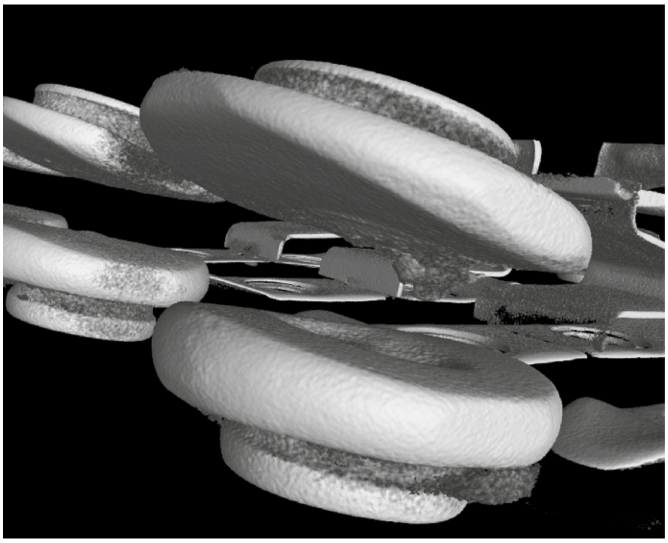

Figure 9

Aircraft 4, relay K3CE, showing erosion and metal transfer on contacts D1 and D2

Summary of damage found on examined relays

In most of the relays examined, metal erosion and metal transfer were visible on the D contacts to varying degrees. Figure 10 shows damage to the D1 and D2 contacts on relay K1CE from Aircraft 2, where the flaps initially extended at half speed before the fault cleared.

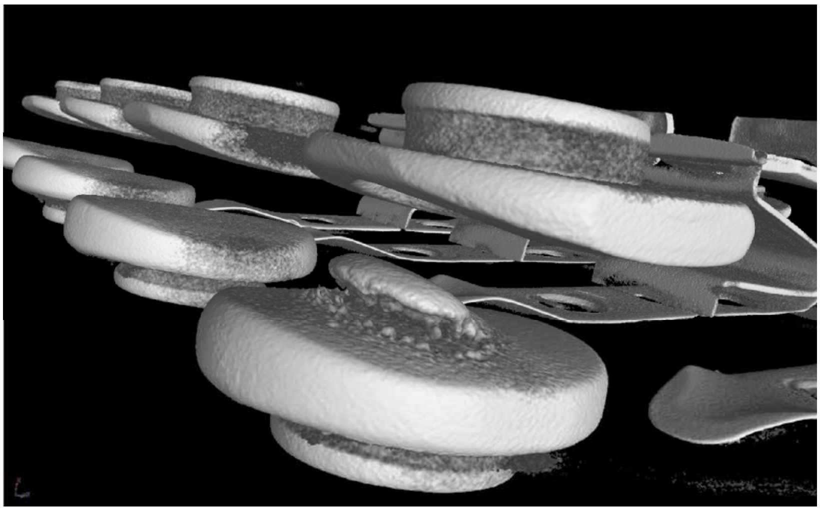

Figure 10

Aircraft 2, relay K1CE, showing erosion and metal transfer on contacts D1 and D2

Examination of the Brake Detector Unit

The aircraft was fitted with two BDU's, one on each wing. Each consists of a 28 V DC solenoid operated brake and a speed sensor detector unit (Figure 11). The investigation considered the effect of the solenoid operated brake on the relay, as their electrical power is switched by the D contacts in each of the four extend and retract relays. To provide redundancy each brake solenoid has two operating coils, one powered by each operating system, and each system powers an operating solenoid in each of the two BDU's; these are connected in parallel. The brake solenoids are energised to release the brake and are de-energised to apply the brake.

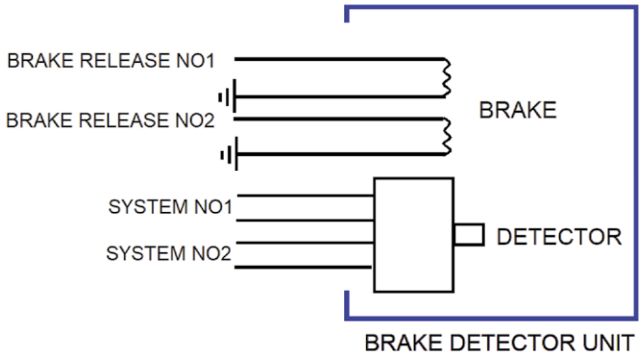

Figure 11

Schematic of BDU Brake Solenoid arrangement

Laboratory testing of the BDU coil resistance indicated they were within specification. The current and voltage during solenoid switching was measured using an oscilloscope (Figure 12). When the solenoid was de-energised a transient voltage spike of up to approximately 300 V was seen, and this spike regularly exceeded 150 V during repeated switching. The voltage spike is likely to be the back electro motive force (EMF) which is a known feature of inductive loads and is caused by the current to the solenoid coil decaying and inducing the EMF after the electrical supply has been switched off. There was no protection or suppression provided within the flap operating system to prevent or reduce this back-EMF.

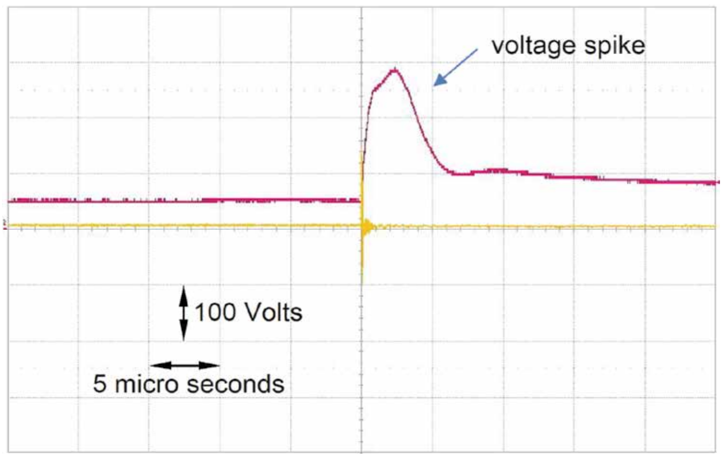

Figure 12

Oscilloscope output showing typical voltage spike after de-energising the BDU coil

Operator's response to the initial findings

Following the uncommanded and unarrested flap extension on D-AAAY, and the finding of damage to the D contacts on the other three Challenger 604 aircraft in their fleet, the operator replaced and introduced their own precautionary life policy for the extend and retract relays.

Certification standard

The Type Certificate[7] for the Challenger 604 aircraft was issued by Transport Canada and, with a number of listed exemptions, is compliant with Title 14 of the Code of Federal Regulations Part 25 (FAR 25).

FAR 25.1309 covers equipment, system and installations and the following sections are applicable to the arrest of an uncommanded flap movement:

'(b) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that -

(1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and

(2) The occurrence of any other failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.'

Analysis

The arrest of an uncommanded flap movement relies on the four extend / retract relays operating correctly to remove electrical power to the flap motors. Evidence from three aircraft inspected by the AAIB shows that these relays can fail and prevent correct operation of the uncommanded flap movement arrest system.

The failure of the relays on these three aircraft was caused by damage to the D contacts which switch electrical power to the BDUs. The damage was consistent with arcing between the contacts, which caused metal transfer and the welding of the contacts. As all the contacts in the relay are mounted on a common shaft, the welding of the D contacts would stop the other three sets of contacts from working properly. Examination of relays provided to the investigation, which had not failed in-service, also had damage to the D contacts showing that the damage had accumulated over a period of time.

During laboratory testing, when the BDU solenoids were de-energised, a transient voltage spike was seen to peak at up to 300 V and regularly exceeded 150 V. This spike is caused by a back-EMF, which could cause arcing across the D contacts. There is no protection within the electrical system to suppress this back-EMF.

Footnote

7 Transport Canada, Type Certificate Data Sheet, Number A-131, Issue 62, Issue Date September 14, 2022.

The relays have an inductive load life of 20,000 operating cycles. During a normal flight there will be four flap extensions and two flap retractions, with each movement energising and deenergising the BDU brake solenoids. This would mean the relays would reach their life after 5,000 flight cycles for the extend relays and 10,000 flight cycles for the retract relays. The three aircraft on which the relays had failed had flown 3,900 (retract), 4,687 (extend) and 4,344 (extend) flight cycles. The only damage seen on the relay contacts was due to arcing, indicating that the lower-than-expected time to failure was probably due to the unsuppressed back-EMF. Therefore, the following Safety Recommendation is made to Bombardier Aviation:

Safety Recommendation 2023-004

It is recommended that Bombardier Aviation introduce a modification on the Challenger 600 series of aircraft to protect the D contacts within the extend and retract relays of the flap operating system from unsuppressed back-EMF electrical arcing.

Airworthiness Directive AD CF-2023-07 requires a timing check on flap movement to be conducted within 100 flight hours or 15 months and, dependent on aircraft variant, repeated every 100 or 400 flight hours. This check will determine if a relay has failed, but it does not assess the condition of the contacts and will not identify a degraded relay that is close to failure.

The rate of accumulating damage on the D contacts is not known. Furthermore, the aircraft maintenance programme does not consider the component manufacturer's life of the relay of 20,000 operating cycles. The maintenance policy is for the relays to remain fitted to the aircraft until a failure is detected; however, detection can be many flight hours after a failure has occurred. The correct function of these relays is required for the operation of the safety critical, uncommanded flap movement arrest system; therefore, the following Safety Recommendation is made to Bombardier Aviation:

Safety Recommendation 2023-005

It is recommended that Bombardier Aviation introduce a life policy for the flap operating system relays on the Challenger 600 series of aircraft, which takes account of the component's specified life and is sufficient to ensure that any in-service damage on the D contacts on the extend and retract relays remains acceptable for continued operation.

The uncommanded, unarrested movement of the flaps is potentially catastrophic and requires two concurrent failures. The original safety case considered this to be extremely improbable. However, this investigation has identified that on at least three different aircraft a relay was in a failed condition for a significant number of flights, and the failure was not detected even though the flaps moved in one direction at half speed. The failure of any one of these relays is a latent failure because it is not annunciated to the operating crew or maintenance staff. The undetected latent failure of these relays suggests that the original safety case for the uncommanded, unarrested flap movement may no longer be valid. This is because the protection offered by the flap brake system is no longer available and a single failure of another part of the system could be sufficient to cause a catastrophic outcome. This possibility is unlikely to satisfy the 'extremely improbable' requirement. At the time of certification, FAR 25.1309 required that the occurrence of any failure condition which would prevent the continued safe flight of the airplane is 'extremely improbable'. To ensure that the Challenger 600 series of aircraft meets this requirement, the following Safety Recommendation is made to Transport Canada:

Safety Recommendation 2023-006

It is recommended that Transport Canada reassess the safety case for the flap operating system on the Challenger 600 series of aircraft to ensure it meets the requirements of Title 14 of the Code of Federal Regulations Part 25.1309.

Further investigation

The investigation continues to examine all pertinent factors associated with this serious incident and a final report will be issued in due course.

Published 2 March 2023.