BRAKE PROBLEMS DURING LANDING

The purpose of the Dutch Safety Board's work is to prevent incidents or to limit their after-effects. It is no part of the Board's remit to try to establish the blame, responsibility or liability attaching to any party. Information gathered during the course of an investigation – including statements given to the Board, information that the Board has compiled, results of technical research and analyses and drafted documents (including the published report) – cannot be used as evidence in criminal, disciplinary or civil law proceedings.

GENERAL INFORMATION

Incident number:	2010005
Classification:	Accident
Date, time[1] of incident:	20 January 2010, 14.05 hours
Place of the incident:	Amsterdam Schiphol Airport
Registration:	CS-DXR
Aircraft type:	Cessna Aircraft Cooperation Citation 560 XLS
Aircraft category:	Twinjet
Flight type:	Ferry flight
Flight phase:	Landing
Aircraft damage:	Major
Number of crew:	Two
Number of passengers:	None
Personal injury:	None
Other damage:	Damage to airport infrastructure
Light conditions	Daylight

SUMMARY

While landing on Runway 06 at Amsterdam Schiphol Airport the crew attempted to stop the aircraft at the end of the runway. When the first officer commenced braking this however had little effect. The first officer subsequently activated the emergency brake system, at which point the aircraft exited the runway to the right. The aircraft finally came to a halt on Runway 18L-36R, which is located at the end of Runway 06. The two occupants sustained no injuries however the aircraft was severely damaged.

[1] All times in this report are local times unless stated otherwise.

This report is based on an investigation conducted by the Dutch Safety Board and inspection of the wheels performed by the aircraft manufacturer and the airline operating the CS-DXR.

Note: This report has been published in the English and Dutch language. If there are differences in interpretation the Dutch text prevails.

FACTUAL INFORMATION

Occurrence description

The incident involved a flight from Rotterdam Airport (EHRD) to Amsterdam Schiphol Airport (EHAM). No anomalies on the aircraft were noted by the crew prior to the flight. Near Amsterdam Schiphol Airport, air traffic control gave the crew permission to land on Runway 06. Permission was also given to exit the runway after the aircraft had landed via the end of Runway 06. The flight destination was a parking stand at Schiphol-East.

After landing the first officer wanted to commence with braking by pressing down on the foot pedals but this had no effect. The 'LO BRK PRESS' and 'ANTISKID INOP' warning lights illuminated in the cockpit. Next the first officer activated the emergency brake system whereupon the aircraft turned to the right. Steering the aircraft using the foot pedals did not affect the aircraft turning, whereupon the aircraft ultimately came via the grass alongside the runway to a halt on Runway 18L-36R (figures 1 and 2). The right wheel of the main landing gear collapsed to the aft, damaging the flaps and other wing surfaces. The aircraft was severely damaged as a result.

Figure 1: CS-DXR after landing on Runway 06. The aircraft came to a halt on Runway 18L-36R.

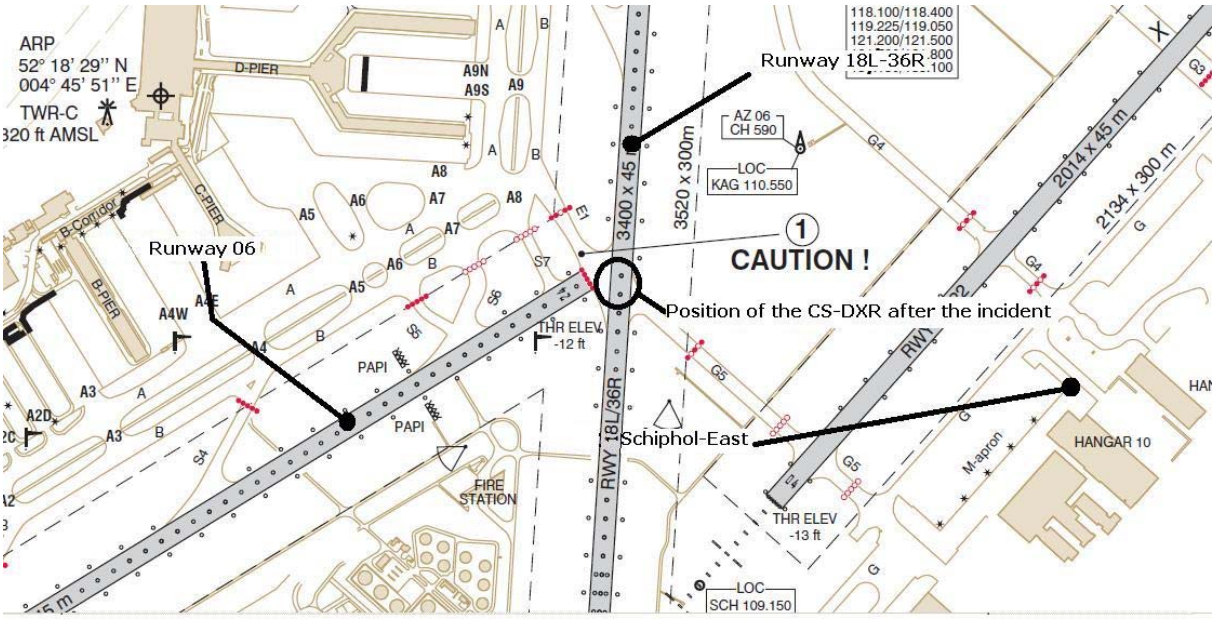


Figure 2: Position of the CS-DXR following the event.

The weather

The Royal Netherlands Meteorological Institute (KNMI) observed and communicated the following weather information around the time of the incident at Amsterdam Schiphol Airport via a METAR[2] weather report. The temperature and dew point were 4 °C and 2 °C respectively with light clouds at 1000 feet. The wind of 10 knots was coming from an easterly direction (80 degrees).

Main landing gear and brake system

The main landing gear of the Cessna Citation comprises a left and a right wheel strut. One wheel is attached to each wheel strut. Each wheel consists of different disc brakes (i.e. a 'brake unit'), which are pressed together by means of five cylinders to enable braking.

In principle braking is achieved by hydraulic pressure controlled by the crew using foot pedals. In case of a failure of the primary system a back-up system is incorporated (figure 3). This secondary system consist of a pressure cylinder containing nitrogen, which is operated by a control lever located in the cockpit.

If the landing gear is extended and the hydraulic reservoir in the primary system drops below 900 PSI, the 'LO BRK PRESS' and the 'ANTI-SKID INOP' warning lights illuminate in the cockpit.

The primary system is equipped with an electronic anti-skid system. This system prevents wheel lock during braking and generates the best possible performance. This system also ensures that the braking power is adjusted to each wheel strut in the event of asymmetrical wheel speed. This ensures the aircraft does not turn to the left or right while braking.

When the secondary (emergency) system is used the anti-skid system is unavailable. Furthermore when the secondary system is used the brake power is not adjusted if a difference in wheel speed between the left and right main landing gear is present.

[2] Standard weather report used in aviation (with an aviation meteorological code).

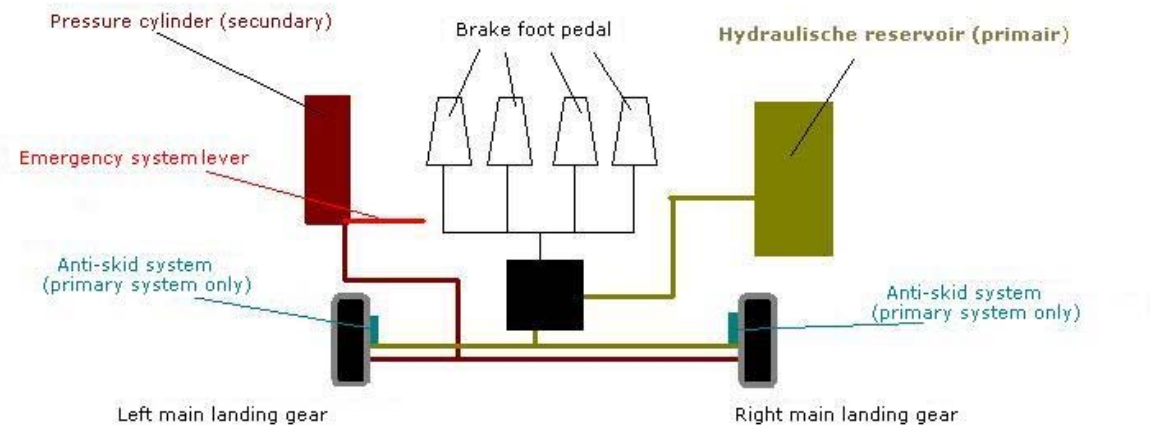


Figure 3: Diagram showing the brake system of the main landing gear.

Pre-flight maintenance of the main landing gear
During the pre-flight check of the preceding flight, the crew noted that there was just enough pressure in the 'oleo struts' (shock absorbers) of the main landing gear. Therefore the crew submitted a maintenance request to the head office, requesting that the pressure level be increased at Rotterdam Airport. Maintenance was subsequently carried out on the main landing gear at Rotterdam Airport. The left and right wheel struts were filled with gas to the level prescribed by the maintenance manual.

INVESTIGATION AND ANALYSIS

Dutch Safety Board investigators were dispatched to the scene following the incident. The aircraft was found on Runway 18L-36R. The start of one skid mark was found on Runway 06, 765 metres from the aircraft. This skid mark ran across a manhole cover located in the grass alongside the runway. Impact marks were also found on the manhole cover. The marks ultimately lead to the strut of the right wheel that had collapsed backwards.

Furthermore a trail of (hydraulic) fluid was found on Runway 06 left of the centreline. This trail must have come from the left side of the aircraft because the aircraft had landed on the centre of the runway. No other evidence was found on the runway.

From information from the on duty air traffic controller it emerged that while the aircraft was taxiing after landing, a cloud of mist was visible at the rear of the aircraft.

Investigation of recorded digital information
The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR). Both recorders were read out and the information was used to analyse the accident flight. The aircraft was also equipped with a quick access recorder (QAR). The information recorded by the QAR was also used for the investigation. This information was equal to the information on the FDR. A total of 11 flights had been recorded; the analysis of the data focused on the landing of the last flight.

Figure 4: The CS-DXR after the event with the skid mark of the right main landing gear in the foreground.

According to the QAR information, the aircraft approached the runway at Amsterdam Schiphol Airport on a magnetic course of approximately 60 degrees (see Appendix A for the graph of the QAR data). Two peaks of vertical acceleration were recorded at a height of zero feet this is considered to be the landing of the aircraft. The speed at that time was 106 knots and the longitudinal acceleration (linear acceleration of the aircraft) was no more than -0.07 g. After having taxied on the runway for 51 seconds, the crew radioed air traffic control. Approximately 18 seconds later a change in magnetic heading to the right was recorded. Approximately 12 seconds later, the crew reported to air traffic control that the aircraft had braking problems. Thereupon the air traffic controller promptly took action by instructing the aircraft behind the CS-DXR to perform a touch-and-go landing, and by sending the emergency services to the location of the CS-DXR. Approximately four seconds later the aircraft came to a halt on a magnetic course of approximately 160 degrees.

No data was available on the QAR about the status of the brake system. In addition, no warnings were recorded. The analysis of the QAR data shows that after the landing, the speed brakes (system which uses air brakes) and reverse thrust (engine thrust is directed in the opposite flight direction in order to slow down) had not been used. Since the aircraft was due to exit the end of Runway 06, the crew decided not to use speed brakes or reverse thrust and to defer braking until reaching the end of the runway.

Technical investigation

Analysis of the skid marks showed that the brakes on the right side were in working order. No skid marks were found left of the runway centre line. The technical inspection therefore focused on the primary and secondary brake systems and the left main landing gear.

During the inspection the hydraulic fluid reservoir which is part of the primary brake system was found to be empty. The pressure in the cylinder of the secondary (back-up) system was 600 PSI whereas it normally is 2000 PSI.

When the wheel was disassembled from the left wheel strut, a partly damaged insert was found to be loose in the wheel (see Appendix B). The insert ensures that the discs rotate in conjunction with the wheel. The insert is kept in place by two lugs, an inboard lug and an outboard lug (see figure 5).

During the inspection the tip of the screw, positioned between the outboard lug and the insert, was found in the outboard lug. Furthermore, impact marks were found on three of the five hydraulic brake cylinders of the left main landing gear. The marks that were found demonstrate that the insert had come into contact with the brake cylinders, which were subsequently damaged.

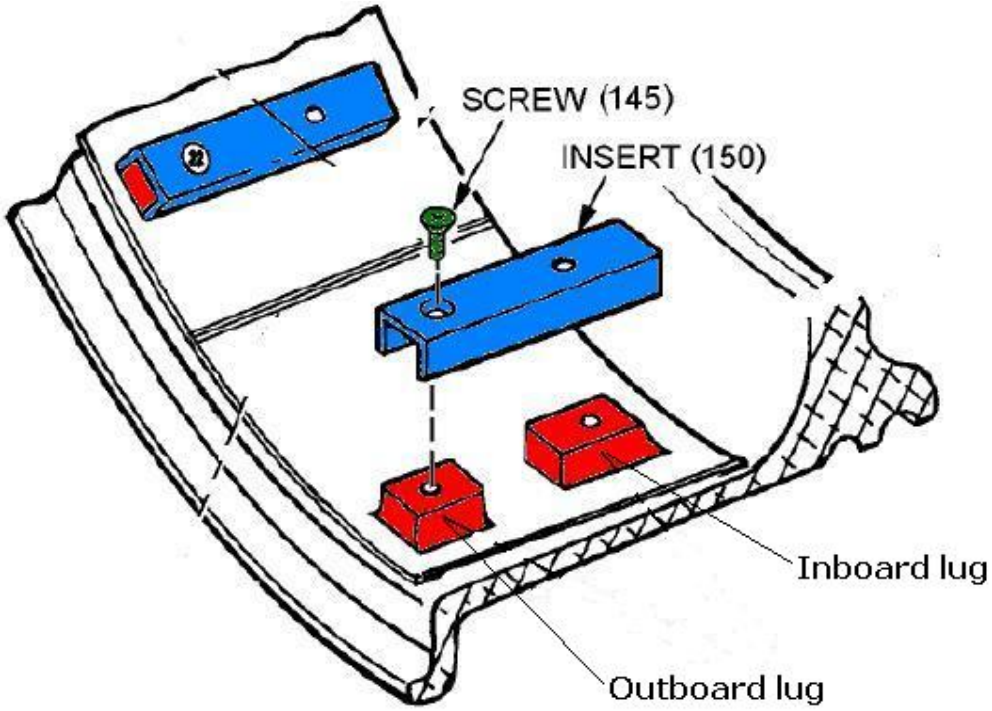


Figure 5: Detailed view of the insert (blue), the inboard and outboard lugs (red) and the screw (green).

Part of the investigation was to test the brake system for leaks. To that end the hydraulic system was connected to a hand pump containing hydraulic fluid. The pressure test revealed that when pressure of hydraulic fluid was applied on the brake system the fluid leaked out two of the five brake cylinders in the left main landing gear. Closer examination of the leaking brake cylinders revealed that these were partly unscrewed, as a result the system was not completely closed. The investigation revealed that while the wheel rotated the loose insert came into contact with the brake cylinders. Repetitive impacts of the insert resulted in the turning of two brake cylinders which were subsequently partially unscrewed.

The pressure test furthermore showed that it was not possible to build up pressure in the brake cylinders on left hand side. It was concluded that when the crew activated the brakes, the available brake fluid in the primary system had leaked out as a result of the leakage in the two brake cylinders. This was most likely was the ‘cloud of mist’ the air traffic controller had witnessed at the rear of the aircraft.

When braking was initiated using the primary system the brake pressure dropped below the level of 900 PSI as a result of the leakage. As a consequence the two warning lights 'LO BRK PRESS' and 'ANTISKID INOP' illuminated. This corresponds to the statement made by the crew who noticed the two warning lights. In accordance with the emergency braking procedure, the captain subsequently activated the secondary brake system.

Both the primary and secondary brake systems utilize the same brake cylinders. The leak on the left hand side resulted in loss of brake pressure even when the secondary system was activated. The leaking brake cylinders on the left side made it impossible to generate brake power on the left hand side using the secondary system. Since the anti-skid system is unavailable in the secondary system, braking did occur on the right-hand side. This explains the skid marks of the right landing gear and the absence of marks left of the centre line of Runway 06.

After the incident the captain stated that the aircraft could not be kept on the runway with full rudder deflection. It is likely that counter steering with the rudder at low speed would not have been effective enough and as a result the aircraft could not be aligned with the direction of the runway.

Wheel inspection of the aircraft fleet performed by the airline operating the CS-DXR
Following this incident, the airline performed wheels inspections of their Citation fleet aircraft in Europe and the spare wheels available in stock. Of the 92 wheels in total, two wheels were found to have insert screws which were torqued insufficiently. One aircraft was found to have similar brake unit damage to that of the CS-DXR. In the USA, four loose inserts were found during wheel inspections of Cessna Citation types XLS and 560 operated by this airline. This finding was the result of 70 inspected wheels.

Wheel investigation at the aircraft manufacturer
The left and right wheels of the CS-DXR were sent to the aircraft manufacturer for closer examination. The tip (end) of the screw which remained in the outboard lug of the CS-DXR wheel was examined. The examination focused on the failure mechanism of the fractured surface of the screw. The investigation of the fractured surface shows that the fracture in the screw occurred as a result of cyclic load. The investigation furthermore shows that the screw, which goes through the insert and the outboard lug, does not function as a connecting element. The screw's sole purpose is to keep the insert in place. The connection method between the insert and the inboard and outboard lugs is interference fit. This connection method is based on the principle of mutual friction surface of two objects. This means that the dimensions of both components play an important role for the applied connection method.

During the examination of the wheel with the loose insert, it was established that both the inboard and outboard lug on which the insert was mounted, were below the dimension (thickness) specified by the manufacturer (see Appendix C for more details). Only three of the ten lugs met the specifications. The five inboard lugs and five outboard lugs on the right wheel, however, did meet the specifications set by the manufacturer. In addition to the two wheels of the CS-DXR, an another examination was performed on a damaged wheel from the same airline where a detached insert was discovered. During the examination of this particular wheel, it emerged that 9 of the 10 lugs did not meet the manufacturer's specifications.

If either a lug or an insert does not meet the specifications this can cause the connection to be frictionless which in turn will subject the screw to cyclic loading. This was established during the investigation. When the screw ultimately fails as a result of cyclic loading the connection to keep

the insert in place is lost. The insert can be pushed outside in a lateral direction, and damages the brake cylinders when the wheel rotates. The combined direction of rotation of the left wheel and the screw thread on the brake cylinder causes the insert to loosen the brake cylinder, ultimately resulting in leakage. It should be noted that a loose insert on the right-hand main landing gear can in fact damage the brake cylinder but cannot loosen the brake cylinder.

Corrective actions taken during the investigation
In April 2010 the aircraft manufacturer and BF Goodrich, the wheel and brake manufacturer, published a Service Bulletin aimed at improving wheel inspections.[3] The manufacturers recommend that the inboard and outboard lugs and the insert be inspected each time wheels are changed. The relevant components should be replaced when dimensions are found to be below specifications.

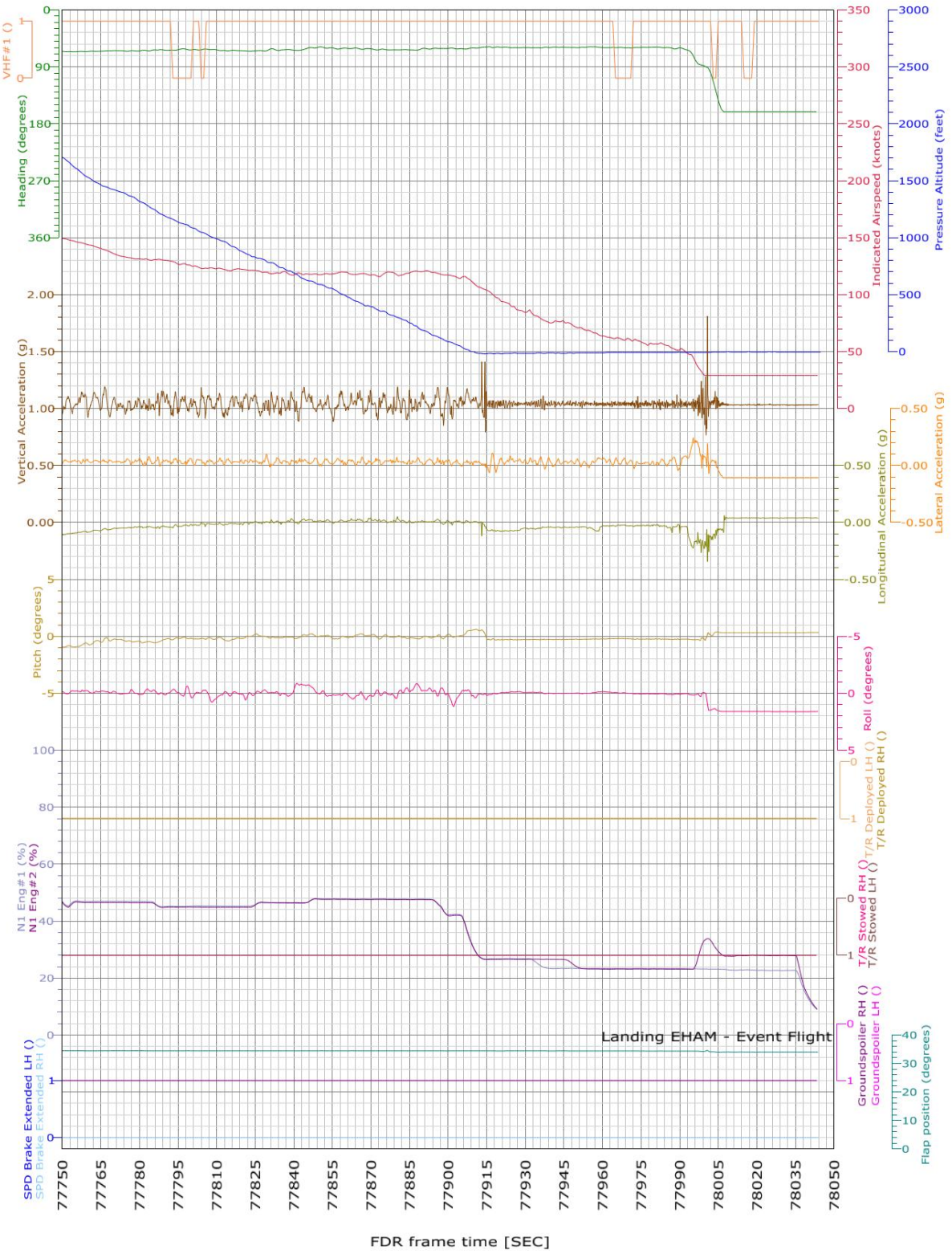
CONCLUSION

The investigation can be summarised with the following conclusions:

- The technical investigation of the left wheel of the CS-DXR has shown that both the inboard lug and the outboard lug, where the loose insert was located did not meet the specifications set by the manufacturer.
- The method chosen to fix the lugs and the insert was interference fit, this connection method fails when dimensions deviate as was established by the investigation.
- As a result of an inadequate fit between the two lugs and the insert, the screw was subjected to stress forces until it failed causing the insert to detach and allow lateral movement.
- As a result of the loose insert, a number of brake cylinders on the left wheel strut were damaged.
- As a result of the loose insert and wheel rotation at least two brake cylinders were damaged (unscrewed).
- As a result of the damaged (unscrewed) brake cylinders no brake pressure could be build up on the left-hand side.
- Asymmetrical braking occurred when the emergency system was used as a result of the damaged (unscrewed) brake cylinders.
- Directional control could not be maintained using the available control surfaces due to the low speed, and the aircraft exited the runway to the right.

[3] Goodrich Service Bulletin 3-1571-32-6 16 April 2010.

APPENDIX A: DATA FROM THE QUICK ACCES RECORDER (QAR)



APPENDIX B: TECHNICAL INVESTIGATION OF THE CS-DXR's LEFT WHEEL STRUT

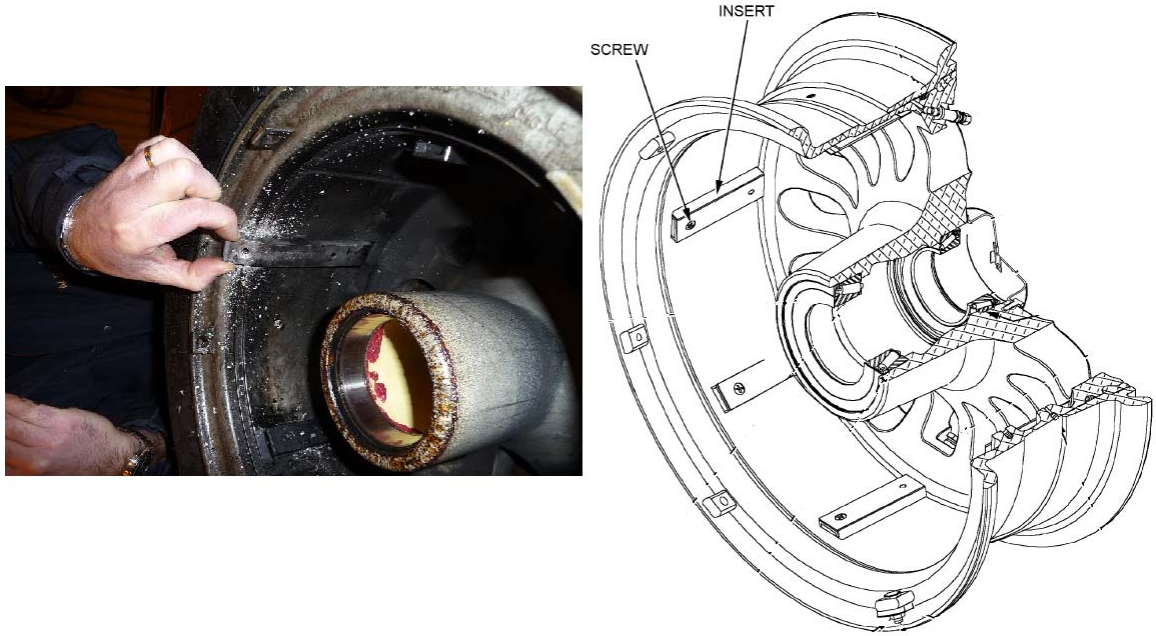


Figure 6: The loose and damaged insert of the CS-DXR's left wheel as found during the technical investigation [left]. A wheel diagram, with a detailed view of the screw and the insert [right].

Figure 7: Brake cylinder damage on the left wheel strut with the brake discs on the left. On the right, the brown bar shows the position of the insert on the brake discs. The photograph shows that if the insert is able to move in a lateral direction, it can come into contact with the brake cylinders.

Figure 8: Detailed photograph showing the hydraulic fluid leaking from the two brake cylinders in the left wheel strut.

APPENDIX C: TECHNICAL INVESTIGATION SCREW, THE INBOARD AND OUTBOARD LUGS OF THE WHEELS

Examination *of the screw on the CS-DXR's left wheel*
During the examination of the left wheel it was established that part of the screw connecting the insert to the inboard and outboard lugs, was still located in the outboard lug. The end of the screw was removed and the fractured surface of the screw investigated. Metallurgical investigation of the screw's fractured surface revealed that the fracture had occurred as a result of high cyclical fatigue with a low load.

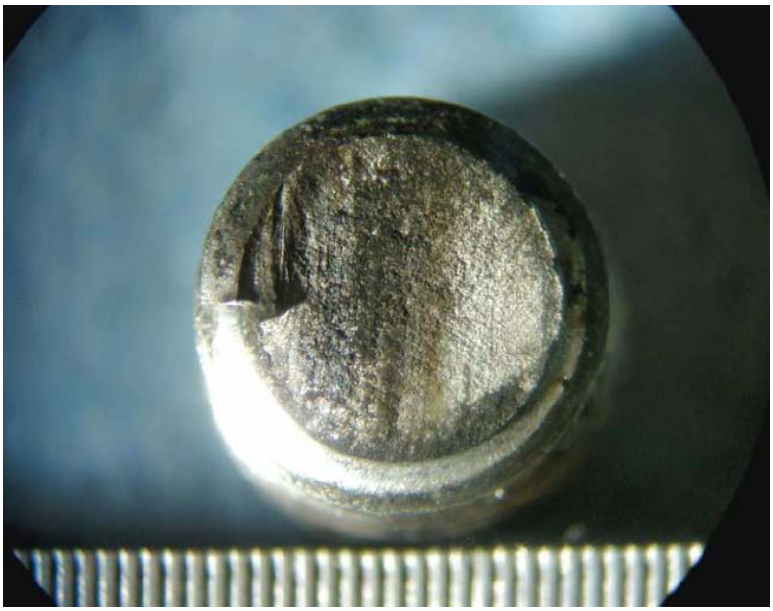


Figure 9: Enlarged fractured surface of the screw found in the lug of the left wheel [Source: Cessna].

Examination of the lug
For this examination three wheels were examined in detail: the CS-DXR's left and right wheels and a wheel which was found to have similar damage to that of the CS-DXR. This investigation focused on the dimensions of the lug. Each wheel contains five inboard and five outboard lugs. An insert is kept in place by an inboard and an outboard lug.

An analysis of the dimensions of the various lugs which were determined during the examination for this investigation are depicted in a graph (figure 10). The green area shows that the inboard and outboard lugs both meet the manufacturer's specifications. This means that the interference fit is adequate and fulfils the design specifications.

The orange area shows that either the inboard or outboard lug does not meet the specifications. The red area marks the area where both the inboard and outboard lugs do not meet the manufacturer's specifications. This is the area where the interference fit is not guaranteed. Analysing figure 10 it shows that the two lugs, were damage on the wheel was found, are both located in the red area. Therefore it is concluded that both the inboard and outboard lugs do not meet the specifications set by the manufacturer which entails a risk the insert can detach.

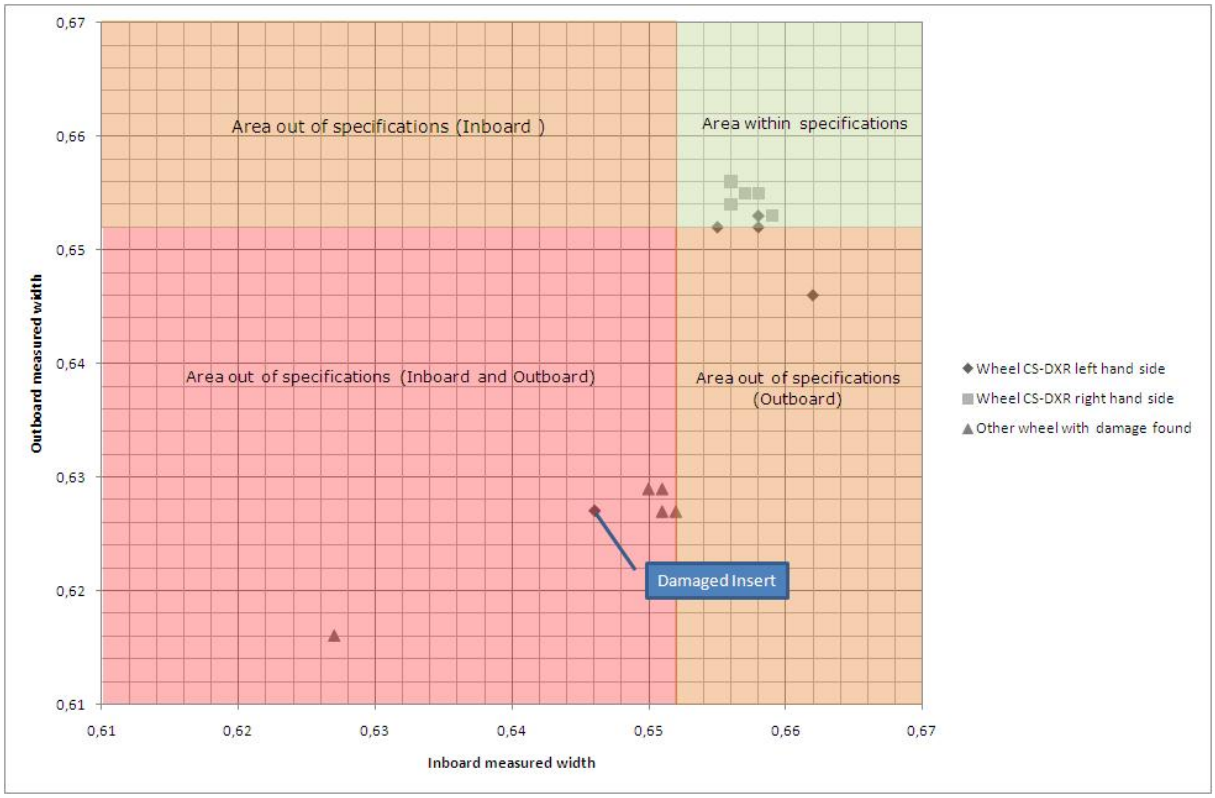


Figure 10: Graph showing the dimensions measured during the investigation of the inboard and outboard lugs of the three wheels which were inspected.