ACCIDENT

Aircraft Type and Registration:	Bombardier CL-600-2B16 Challenger 604, N999PX
No & Type of Engines:	2 GE CF34 turbofan engines
Year of Manufacture:	1998 (Serial no: 5387)
Date & Time (UTC):	31 January 2022 at 0018 hrs
Location:	London Stansted Airport
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - 2
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damaged beyond economical repair
Commander's Licence:	Airline Transport Pilots Licence
Commander's Age:	48 years
Commander's Flying Experience:	4,235 hours (of which 1,320 were on type) Last 90 days - 48 hours Last 28 days - 36 hours
Information Source:	AAIB Field Investigation

Synopsis

Control was lost during an attempted landing in a strong crosswind, following an ILS approach. The left wingtip struck the runway several times and remained in contact with the ground as the aircraft departed the paved surface into the grass area at the side of the runway. The aircraft's stick pusher also activated, resulting in a hard landing that damaged the aircraft's nose landing gear assembly. The investigation determined that the approach was flown at an airspeed slower than appropriate for the conditions, and the aircraft floated during the landing, leading to an excessive angle of attack prior to the excursion.

The aircraft manufacturer stated that it intends to enhance the guidance it provides regarding crosswind landing technique.

History of the flight

The flight on the privately operated aircraft originated in El Gouna Airport, near Hurghada, Egypt, flying to London Stansted Airport via Cairo International Airport. The crew were notified of the flight two days beforehand but were not given a departure time. The day before the flight they were told the aircraft would depart at 1000 hrs, with the crew reporting for duty at 0900 hrs.

The operator telephoned the crew at 0835 hrs on the day of departure to advise that they required the flight to depart at 1130 hrs. The crew thus reported for duty at 1030 hrs on

30 January 2022, and departed for Cairo at 1130 hrs with three passengers, landing at 1230 hrs. Before departure the commander noted that the crew's duty was likely to be about 14 hours due to a long flight to Stansted caused by strong headwinds.

The departure from Cairo with two passengers, planned for about 1400 hrs, was delayed until 1853 hrs. The estimated flight time was 5 hours 15 mins, giving an ETA of 0008 hrs on 31 January 2022.

The departure from Cairo and the cruise to Stansted were uneventful. As the crew prepared for the approach, they noted from Stansted's 2350 hrs ATIS that the wind was from 290° at 13 kt. Based on estimated landing weight, they calculated a V_{REF} of 119 kt and a V_{REF} +X[1] of 125 kt[2].

The aircraft received radar vectors to establish on the ILS to Runway 22. During the approach the commander, who was PF, noted on the integrated electronic flight instrument system that wind at 1,500 ft aal was 54 kt and was primarily a crosswind. Once the aircraft had established on the glideslope it was configured for landing with FLAPS 45. Soon after, the crew contacted the Stansted Tower, which reported a surface wind from 300° at 13 kt gusting 25 kt. The co-pilot, who was PM, stated that after they received the surface wind he asked the commander if he was "OK" with the wind to which the commander replied he was comfortable with it. The co-pilot then said to the commander that if he was uncomfortable at any time they would perform a go-around (GA), which the commander acknowledged. ATC cleared the aircraft to land and passed the same surface wind, which the co-pilot acknowledged. This was about 90 seconds before the aircraft touched down.

After the commander disconnected the autopilot at approximately 150 ft aal the co-pilot made several calls of "excessive bank". The co-pilot considered the commander was "doing his best" in the gusty conditions.

The aircraft had no autothrottle. The commander recalled that he closed the thrust levers at about 50 ft aal and made a small nose-up elevator input. The aircraft did not have automated height callouts, so the co-pilot called 50 [ft], 40, 30, 20, 10 with reference to the radio altimeter display at the bottom of his attitude indicator. The aircraft began to float in the landing attitude about 10 ft above the runway. The commander recalled there was some windshear which led to the IAS suddenly reducing, and the left wing "snap rolled/dropped" followed by a temporary loss of directional control as the aircraft turned left by about 30°. The aircraft then landed on its nosewheel, followed by its left and then right landing gear, before departing the paved surface onto the grass. The commander believes the stick pusher activated at some stage.

The commander initiated a GA but he did not recall if either of the crew verbalised it. The co-pilot stated that after the bounce he called "go around" two or three times. The commander did not remember calling for FLAPS 20 according to the GA procedure, but believes the co-pilot made that selection when he realised a GA was initiated. As the commander

[1] The aircraft manufacturer stated that it uses the term V_{REF} +X. Others use V_{APP}

[2] See *CL-604 operating manual* below regarding V_{REF} +X calculation.

advanced the throttles, he felt the co-pilot's hand assisting. Once the aircraft had started to accelerate through V_{REF} the commander pitched the aircraft up and the landing gear was selected UP. During the GA a NOSE DOOR OPEN warning[3] and a WOW INPUT caution[4] message illuminated. The co-pilot commented that during the GA the commander pitched the aircraft up "excessively" to about 20 to 25° and the airspeed started decreasing towards about 180 kt. As a result, he pushed on the flying controls, instructed the commander to "fly the aircraft" and to fly level at 4,000 ft amsl and 200 kt.

About 30 seconds after the GA had been executed, having seen "A LOT OF SPARKS COMING OUT OF THE AIRCRAFT AND ON THE RUNWAY", ATC asked the crew twice if everything was "OK", before they received a reply. The co-pilot responded that they were OK, advised ATC that they would be levelling off at 4,000 ft amsl, and requested vectors for another ILS approach. The aircraft was then instructed to call the ATC radar controller.

Being aware that the aircraft had bounced onto its nosewheel, and with the associated warning and caution, the crew discussed the implications of possible damage. As they had plenty of fuel, they decided to lower the landing gear and obtained down and locked indications. The NOSE DOOR OPEN warning then extinguished.

On initial contact with the ATC radar controller the co-pilot stated that once they had completed some checklists they would state their intentions, probably to land at Stansted. ATC reported surface wind from 290° at 16 kt, gusting 26 kt. The co-pilot asked the ATCO if she could find an airport nearby with "NORMAL WIND CONDITIONS", stating when asked that their crosswind limit was 15 kt. Soon afterwards the ATCO reported surface wind at London Gatwick Airport from 280° at 14 kt, gusting 18 kt, and advised the runway orientation of 260°/080°. The crew decided to divert to Gatwick, and received radar vectors to the ILS for Runway 26.

The aircraft landed at Gatwick without further incident. However, there was a grinding noise from the nosewheel as the aircraft slowed. Consequently, they elected to stop on the Rapid Exit Taxiway and, after an inspection by airport marshallers revealed damage to the nosewheel, they shut down the aircraft. After vacating the aircraft to inspect the nosewheel they discovered damage to the aircraft's left wingtip.

Pilots' comments

Commander

The commander stated that he had been working for the operator since 2019.

Due to the limited amount of flying he was required to do he observed a personal crosswind limit of 20 kt, as he was cautious about operating the Challenger 604 (CL-604) in strong crosswinds. He believed he had told the copilot this during the approach brief for the ILS into Stansted. He had completed recurrent training in a simulator every six months, despite the requirement being every 12 months. He completed his most recent Licence Proficiency

3 Indicated that the aircraft's nose gear door had failed open.
4 'Weight-on-wheel input' indicated that the aircraft was unable to determine if it was airborne or on the ground.

Check two weeks before the accident. During this simulator detail he completed a crosswind landing, a rejected landing and had a demonstration of the aircraft's stall and stick pusher.

He commented that when they reviewed the TAF for Stansted, before departing El Gouna, he noticed the wind was from 260° at about 10 to 15 kt – less than his personal crosswind limit. When they reviewed the TAF again in Cairo the crosswind was still less than 20 kt. Due to the unexpected delay in Cairo, he updated his Flight Risk Assessment Tool[5] score for this sector and considered delaying the flight to the next day. His assessment of the fatigue risk was that "it was within the line but at the line" and decided to proceed with the flight.

The commander added that his workload was very high during the final approach but did not recall the co-pilot's monitoring calls of "excessive bank" at about 150 ft aal.

The commander considered that impairment due to fatigue was not a cause of the accident but that the length of the working day and the time of arrival, in combination with commercial pressure, was likely to have induced plan continuation bias[6].

He reflected later that he should have initiated a GA when the aircraft floated after the flare. He added that having elected to continue with the landing he should have added some power in the float to stop the speed reducing excessively, while holding an appropriate attitude as he waited for the aircraft to touch down.

Co-pilot

The co-pilot stated that he completed his type rating on the CL-604 in October 2021 and had about 150 hours on type. He was qualified to fly the CL-604 as the commander and copilot. He had previously operated scheduled flights for a major commercial air transport (CAT) operator.

The co-pilot said he was not aware of the commander's personal crosswind limit. He did not recognise the idea of a personal limit and commented that the aircraft limits should be observed.

The co-pilot stated that after the bounce and his GA call he noticed that the aircraft had left the paved surface and was on the grass verge of the runway. He added that after the aircraft had levelled at 4,000 ft, both pilots were "shaken". While the commander suggested that they should go back to Stansted, the copilot recommended that they look for a more favourable airport with a small crosswind component.

The co-pilot believed that the commander wanted to make a smooth landing as he knew this was "important for the owner". He considered there were no landing performance issues at Stansted given its long runway.

---

5 A Flight Risk Assessment Tool enables proactive hazard identification and can visually depict risk. It can be an invaluable tool in helping pilots make better go/no-go decisions.
6 An unconscious cognitive bias to continue with the original plan despite changing circumstances.

The co-pilot commented that while he had done crew resource management training with his previous CAT operators, he had not done any during his CL-604 type rating or with the operator of N999PX.

Personnel

Three pilots worked for the operator. There was no formal management or training structure for them, and each had a different agreed working pattern. The commander was informally considered to be the chief pilot and a line trainer but did not have any instructional qualifications. The co-pilot had completed type training for the CL-604, and the commander and other pilot, who worked for the operator, were providing informal line training to him.

The accident pilots reported that the relationship between them was strained. Difficulty arose from differences in their working patterns that were considered unfair, and from differences in their preferred style of giving and receiving instruction. They also differed in their reported approach to flying: the co-pilot favouring a highly standardised and procedural approach expected in a CAT operation and the commander favouring a more flexible approach found in general aviation operations. The co-pilot reported that he managed the relationship, while flying, by maximising his professionalism in the cockpit and strictly adhering to standard procedures and callouts.

When the accident occurred both pilots had been awake for 17 hours or longer and were in their window of circadian low. They had experienced delays during the previous flight, and delays at Cairo. They had also experienced higher than normal workload during the accident flight due to turbulence and a nervous passenger. The commander had a caffeine drink before the approach. There were no other reported fatigue risk factors for either pilot. The pilots were responsible for managing their own fatigue risk and no guidance or rules were provided by the operator.

Meteorology

An aftercast produced by the Met Office stated that during the period of the aircraft's approach and landing a cold front passed over the south-east of England moving in a southeasterly direction, producing scattered rainfall and low cloud across the area. The surface winds at Stansted between 2220 hrs and 0100 hrs were forecast as initially southwesterly, with mean speeds of 15 kt, gusting 25 kt, becoming north-westerly after midnight with mean speeds of 12 kt and no gusts. Observed winds through the period were initially south-westerly, later becoming north-westerly, in a range of 12 to 16 kt mean speed with one gust reported at 24 kt.

The forecasts at Heathrow and Gatwick Airports were similar, with forecasts of southwesterly winds becoming northwesterly at 12 to 15 kt and gusting 25 kt.

Stansted TAFs

In the briefing pack for the flight from Cairo to Stansted the TAF for Stansted, issued at 0502 hrs stated that the surface wind would become between 1200 hrs and 1500 hrs on 30 January, from 230° at 10 kt, before becoming, between 1900 hrs and 2100 hrs on 30 January, from 230° at 15 kt gusting 25 kt. The effective crosswind was 3 kt gusting 4 kt. It would then become, between 2100 hrs and 2400 hrs on 30 January, from 290° at 18 kt, gusting 30 kt. This equated to a crosswind component of about 16 kt, gusting 26 kt.

Stansted METARs

The METAR/ATIS published at 2350 hrs on 30 January stated that the surface wind was from 290° at 13 kt.

The METAR/ATIS published just after the accident at 0020 hrs on 31 January stated that the surface wind was from 300° at 13 kt gusting 24 kt, giving a crosswind component of 12 kt gusting 23 kt.

Anemometry data

London Stansted Airport provided the investigation with anemometry data that recorded the wind every second. The maximum wind speed recorded around the time of the accident was 20 kt from 300°. This was consistent with that forecasted and disseminated to the crew, either via METARs prior to the aircraft's arrival, or via the wind check given to the crew on short final of 300° at 13 kt gusting 25 kt. This equated to a crosswind component of 12 kt gusting 24 kt.

London Stansted Airport

The approach chart for the ILS approach to Runway 22 is at Figure 1. The missed approach procedure is '*Climb straight ahead not above 3000* [ft amsl].'

The Runway 22 LDA is 3,049 m.

The *Landing Performance* section of the CL-604's *Airplane Flight Manual* (AFM) indicates that in the prevailing conditions the actual landing distance would be approximately 760 m and the landing field length (landing distance required) approximately 1,290 m.

Weight and balance

The aircraft contained 16,000 lb of fuel on takeoff from Cairo, 2,000 lb more than required. The flight log and the pilots' accounts indicate the aircraft landed at Stansted with a total weight of between 32,243 lb and 32,803 lb. The takeoff and landing weights and CG were within the aircraft's flight envelope throughout.

Perf-06-01-25 of the AFM indicates that with FLAPS 45 and the landing gear down, the reference stall speed (V_{SR}) at 33,000 lb would be 99 KCAS.

Page 06-01-1 of the AFM states that V_{REF} is a minimum of 1.23 V_{SR}. Section Perf-06-1 of the CL-604's quick reference handbook indicates that at a landing weight of 33,000 lb a V_{REF} of 123 KIAS would be appropriate.

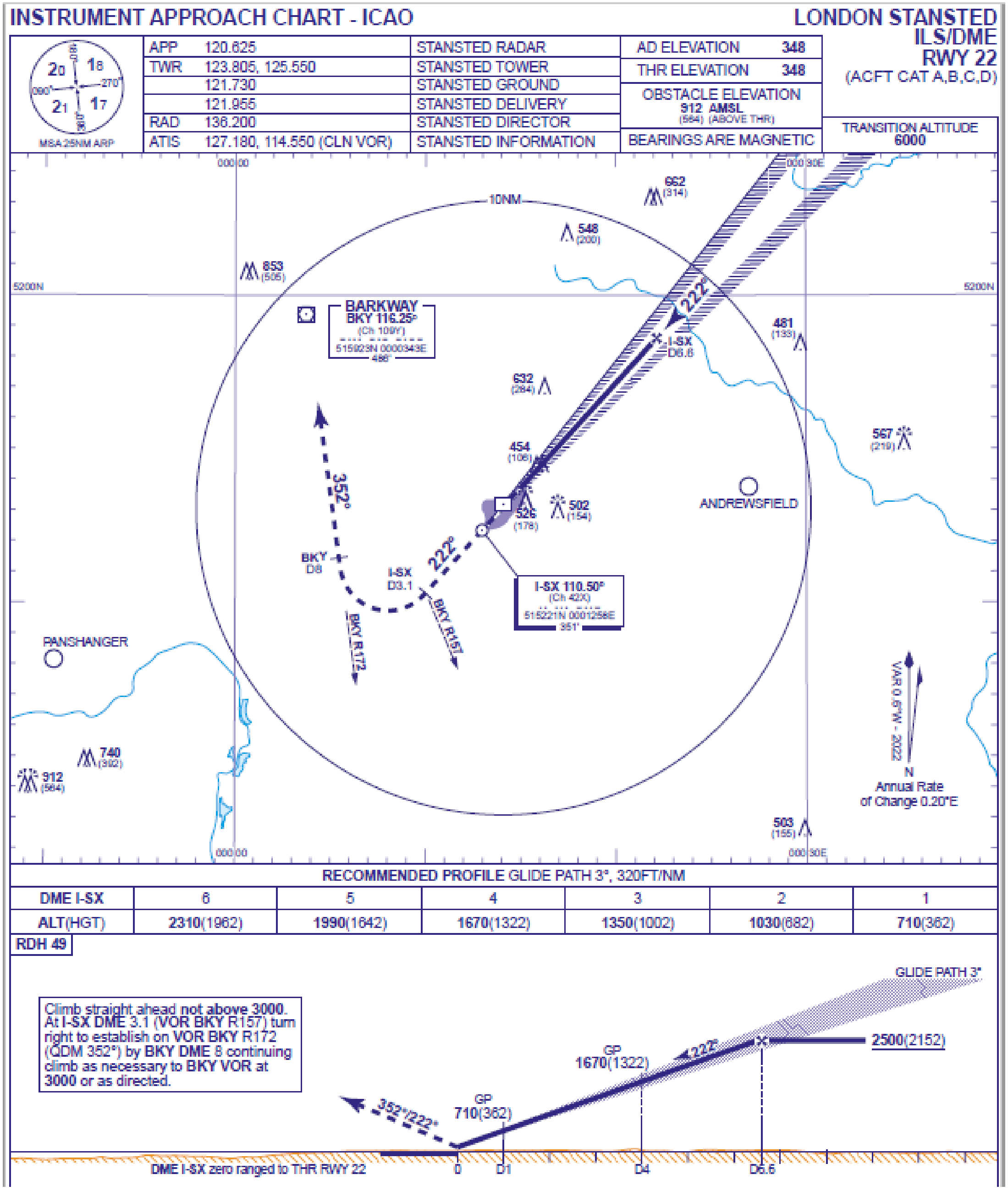

Figure 1

ILS approach chart for Runway 22
(UK AIP)

The AAIB calculated for a weight of 33,000 lb, using the charts on page 06-03-27 of the CL604’s AFM, V_2 + 10 KIAS would have been 144 KIAS.

Manufacturer's documents

Airplane Flight Manual

The CL-604's AFM stated the following:–

> *'CHAPTER 6 – PERFORMANCE*
>
> *5. PERFORMANCE CONDITIONS AND CONFIGURATIONS*
>
> *…*
>
> *D. Demonstrated Crosswind (Take-Off and Landing)*
>
> *The maximum demonstrated crosswind component for take-off and landing [at 33 feet (10 meters) tower height] is 24 knots and is not considered limiting for take-off and landing. When using reverse thrust, this speed is limiting.'*

The crew planned to use reverse thrust on the landing.

CL-604 Operating Manual

The manufacturer's Operating Manual (OM) stated in '*NORMAL PROCEDURES, Approach and Landing*' that V_{REF}+X is calculated by adding a wind correction of '*half steady state crosswind plus all gust (regardless of direction). Maximum correction is + 20 KIAS*' to the V_{REF}. For the reported wind of from 300° at 13 kt gusting 25 kt, and a V_{REF} of 123 kt, this equates to a V_{REF} +X of 142 kt.

It also stated the following:

> '***1. APPROACH AND LANDING***
>
> *The following procedures are recommended in the event of a missed approach or any other situation which would necessitate making a go-around maneuver, with the airplane in the landing configuration…*
>
> *An all engine go-around maneuver after touchdown during a normal landing is entirely the prerogative of the pilot to employ if conditions are not conducive for a full-stop landing.*
>
> *…*
>
> *Go-Around Procedure*
>
> *(1) Thrust levers…................................Advance to the pre-determined go-around N1 setting, while simultaneously pressing the Take-Off/Go-Around (TOGA) switch.*
>
> *(2) FLIGHT SPOILER lever (if extended) ....Select to RETRACT.*

(3) Airplane .... Rotate smoothly, at a speed of not less than V_{REF}

(4) Pitch attitude..Adjust to achieve a speed of not less than V2 + 10 KIAS as the flaps are retracted to 20°.

(5) FLAPS ....Select to 20°.

When a positive rate of climb is achieved:

(6) LDG GEAR lever ....Select to UP.

…

At a safe altitude (not below 400 feet AGL):

(7) FLAPS ....Select to 0°

…

L. Bounced Landing

If the pilot believes that thrust must be added and maintained until touchdown to salvage a landing, then a rejected landing should be executed.

Should the aircraft bounce on landing, a rejected landing should be executed. Go-around thrust should be set and the normal landing attitude or slightly higher should be maintained. Aircraft configuration should not be changed at this time. Once the aircraft is accelerating above VREF and climbing through a safe height, the go-around maneuver should be continued.

Improper landing technique (thrust levers not at IDLE) may result in a shallow bounce. Should the pilot decide not to execute a rejected landing, then the normal landing attitude should be maintained and the thrust levers reduced to IDLE. Be aware that following the bounce, the ground spoilers may deploy as soon as the thrust levers are set to IDLE, even if the aircraft is still in the air.'

Crosswind guidance

The manufacturer provides guidance on crosswind landings for some of its aircraft, including the Challenger 300 series, in the respective *Recommended Operational Procedures and Techniques* (ROPT). However, the only guidance for the CL-604 is in the OM Supplementary Procedures, 06-13, '*Operation on Contaminated Runways*', '*Crosswind Landings*', where it states, '*In crosswind conditions, the crosswind crab should be maintained for as long as possible, until prior to touchdown…*' There is no guidance on crosswind landings in Normal Procedures, 04-08, '*Approach and Landing*' or its ROPT.

The manufacturer commented that its pilots' preferred technique for crosswind landings on the CL-604 was to fly wings level and de-crab in the flare, which is less likely to result in a wingtip strike than flying wing-down into wind.

Accident site

Examination of Runway 22 at London Stansted Airport showed three separate wing strike marks on the paved surface between the intersections of Taxiways Papa, Romeo and Uniform, each approximately 20 m long (Figure 2). Paint transfer from N999PX's wing was evident in the strike marks on the runway (Figure 3), becoming a furrow in the grass. As it continued to travel through the grass, the wingtip struck a concrete pad. Several pieces of debris were found in this area, including fragments of wingtip skin panel and wingtip light transparency.

Tracks corresponding to all three landing gear wheels were also evident in the grass.

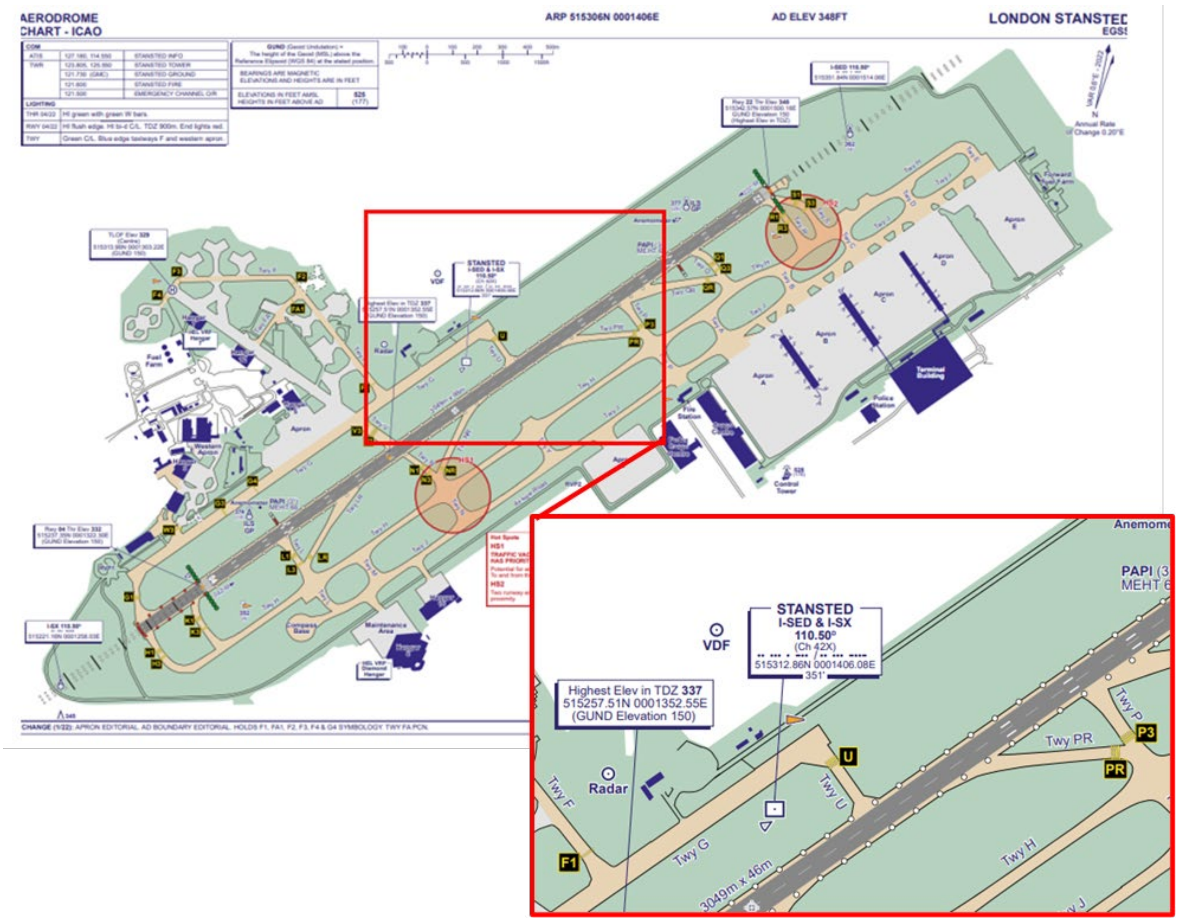

Figure 2

London Stansted Aerodrome Chart, inset showing area where N999PX left wing struck the ground

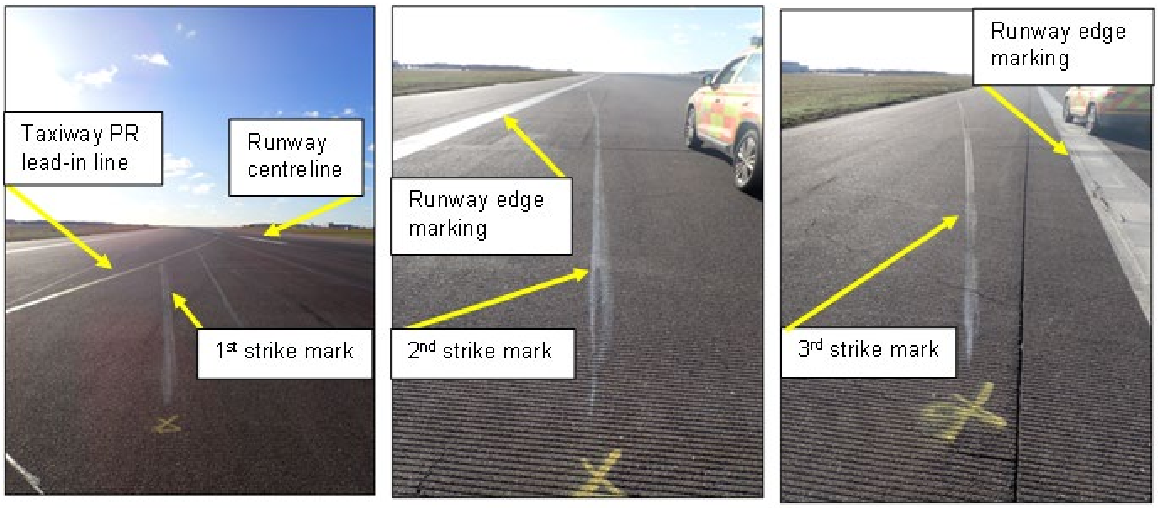

Figure 3
N999PX wing strike marks on Runway 22, viewed in direction of travel

Recorded information

Flight recorders

The aircraft was fitted with a CVR and FDR. The CVR, which was a solid-state device, had a nominal recording duration of 30 minutes but the aircraft remained powered for some time after landing at Gatwick and the recording of the event was overwritten.

CVR quality and operational test

The CVR's Cockpit Area Microphone channel, which records ambient sound in the cockpit, was unintelligible due to a high level of electrical noise on the recording. The balance of recording levels across the other channels was poor. The unit fitted to N999PX was last tested for correct operation in November 2011. The aircraft manufacturer recommends this check is carried out every 1,200 flight hours, having recently changed this interval from every 800 flight hours. N999PX was not operated commercially and, although these intervals were not mandated by regulation, N999PX's operator chose to use them for its maintenance programme. This change assumed that 500 flight hours would be flown each year but, as the annual utilisation of N999PX was much lower, this meant that the CVR on N999PX had not been tested for correct operation for over 10 years. In November 2022, following this event, the aircraft manufacturer introduced alternative calendar-based recommendations[7], for maintenance tasks on aircraft with low annual utilisation.

[7] The Low Utilization Maintenance Program was added to the CL-604 Maintenance Planning Document, Section 8.1.

FDR data for the approach and GA

Data from the FDR is shown in Figure 4, each square on the x-axis representing five seconds. This shows that N999PX's autopilot was disconnected at 150 ft agl at an IAS of 136 kt, the landing gear was down and FLAPS 45 selected. Both engines were set at approximately 50% N_1 (Point A on Figure 4). Before this there are mostly only minor modulations in control surface deflections, with slightly larger rudder deflections. The autopilot maintained the aircraft's flightpath without the application of large surface deflections. The angle of attack (AOA) vanes agreed and remained below +5°.

After the autopilot was disconnected, an increasing amount of left rudder was applied, the demand becoming more oscillatory over time, while the ailerons were positioned to give a right wing-down rolling moment. The power setting of the engines was increased to about 60% N_1 and the values recorded by the left and right AOA vanes diverged, indicating that N999PX was then in a sideslip.

Passing 50 ft agl and 130 kt, thrust was gradually reduced to idle over a period of eight seconds (from Point B). The aircraft, still in a sideslip, was then progressively flared for landing but did not touch down, instead remaining airborne for a further six seconds; and the AOA recorded by both vanes increased, reaching 18° for the left vane.

N999PX then suddenly rolled left and pitched sharply down (Point C)[8]. N999PX's pitch attitude changed from +8° to -2° and the roll attitude changed from 10° right wing-down to 13° left wing-down in under 2 seconds. Shortly afterwards, despite a substantial nose-up elevator input, and movement of the ailerons and rudder to recover the bank of the aircraft, the aircraft touched down on the nose and left landing gear, and then the right landing gear (Point D).

Engine N1 began to increase as a minimum airspeed of 101 kt was recorded but, because the elevators were still positioned to demand a nose-up attitude, the AOA and pitch attitude rose rapidly again and reached +24° and +14° respectively. The aircraft again rolled to the left, reaching 30° of bank and pitched down, this time making ground contact with the left and nose landing gear despite the further application of nose-up elevator (Point E). The FDR recorded a normal acceleration of nearly 2.5g at this point.

The aircraft went around and the flightpath stabilised in the climb, but the position of the individual landing gear disagreed and, subsequently, a master warning was triggered (Point F). At about 550 ft agl during the GA the aircraft's pitch reached a maximum of 21.6° nose-up.

8 Aircraft manufactured from serial number 5463 onwards are equipped with an FDR that records at a higher data rate and record parameters for activation of the stick shaker and pusher. However, N999PX (serial number 5387) predated this change, and the FDR did not record parameters for either the stick shaker or pusher.

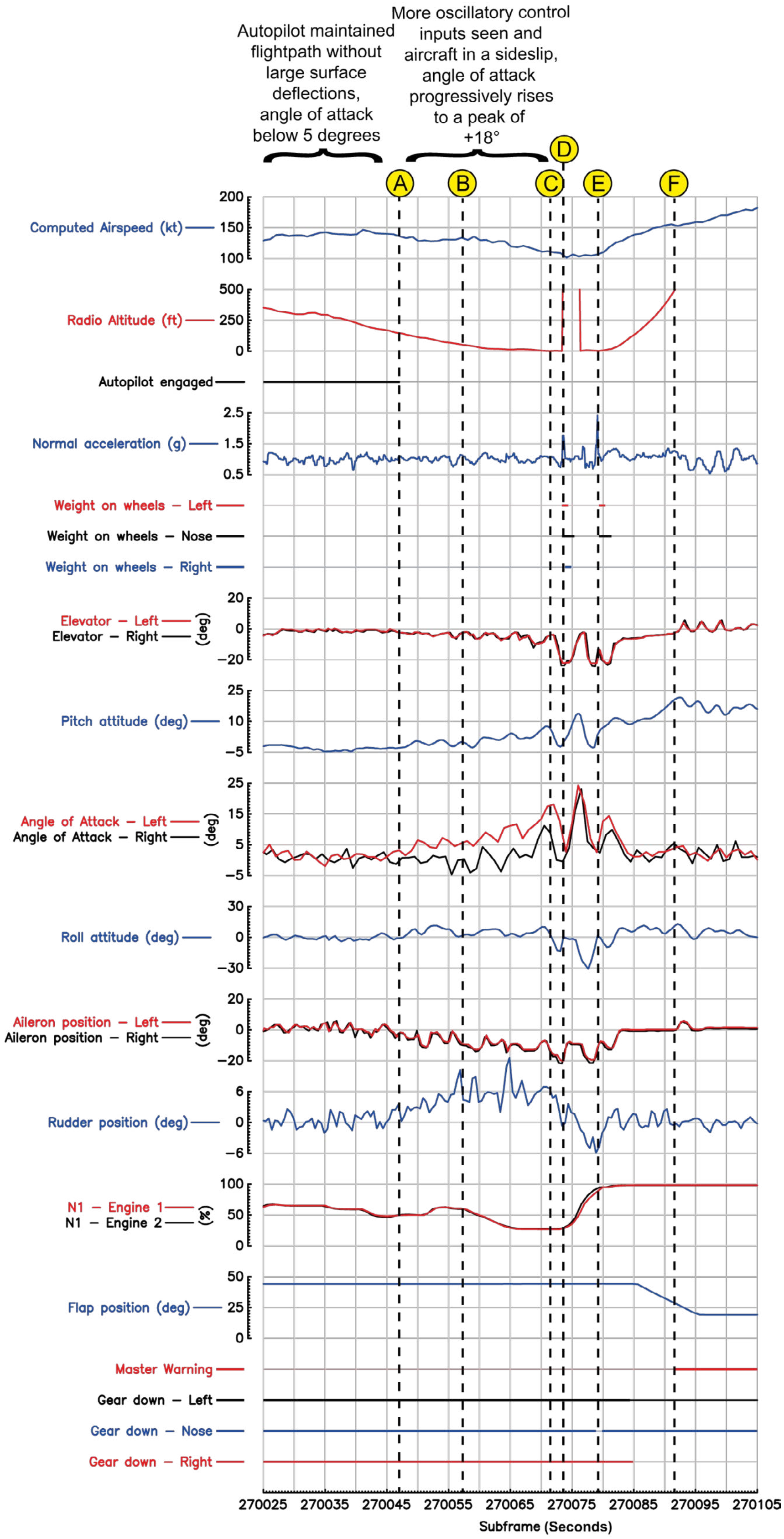

Figure 4

Data from the FDR showing N999PX's approach and GA at London Stansted

Closed-circuit television

Closed-circuit television (CCTV) recordings from London Stansted captured the aircraft's approach and GA, showing that N999PX struck the ground at least twice. An image from one of these recordings is shown below (Figure 5).

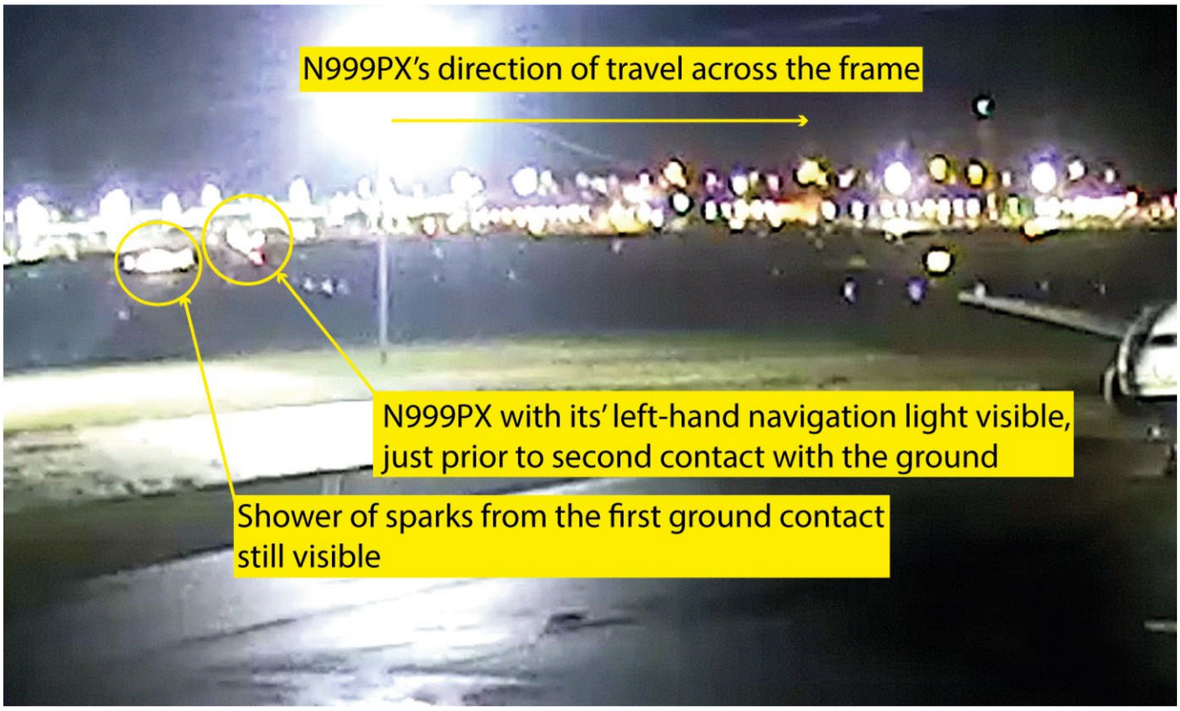

Figure 5

CCTV from London Stansted showing N999PX striking the ground

Aircraft information

General

The Bombardier CL-604, a variant in the Challenger 600 series of aircraft, is a low wing business jet powered by two fuselage-mounted GE CF34 turbofan engines. The wings of aircraft in the Challenger 600 series are thin high-speed aerofoils.

Stall protection system

The natural stall characteristics of the Challenger 600 series are a stall with no pre-stall warning (such as buffet), an abrupt load factor reduction at the instant of stall, and an uncontrolled and uncontrollable rolling motion. Any recovery action other than reducing the AOA is ineffective. In order to meet certification requirements, Challenger 600 series aircraft are equipped with an artificial stall protection system, incorporating stick shaker alert and stick pusher recovery functions.

The stall protection system (SPS) on the CL-604 provides the flight crew with aural, visual and tactile indications of an impending stall. It comprises a dual channel analogue stall protection computer (SPC), two AOA vanes, two dedicated lateral accelerometers for sideslip compensation, a stick shaker motor on each control column and a stick pusher motor connected to the right elevator control system.

The SPC includes algorithms which define the AOA thresholds[9] for engine auto-ignition, stick shaker and stick pusher activation. The stick pusher thresholds are set to lower AOAs than the AOA for natural aerodynamic stall, so that the stick pusher functions as prestall intervention. For each flap setting, the nominal engine auto-ignition, stick shaker and stick pusher thresholds are constant between the ground and 2,000 ft, reduce linearly between 2,000 ft and 15,000 ft and are constant above 15,000 ft.

The SPC monitors the AOA angle, lateral acceleration, flap position and pressure altitude from the air data computers and uses these inputs continuously in flight to calculate the AOA thresholds. If the signal from one AOA vane exceeds the calculated auto-ignition threshold, both engine's auto-ignition systems will activate. If the AOA continues to increase and the signal from one of the AOA vanes exceeds the programmed stick shaker threshold, the stick shaker motor on that side will activate and if the autopilot is selected it will be automatically disengaged. Both control sticks will shake as they are mechanically connected giving a tactile and aural alert. If both AOA vanes exceed the shaker threshold, both stick shaker motors will activate.

At even higher AOA, if the signal from one AOA vane exceeds the programmed pusher threshold, it will trigger the STALL aural warning and the red flashing STALL WARNING lights on the glareshield. If the signal from both AOA vanes exceeds the programmed pusher threshold, the stick pusher motor will be activated and will apply approximately 80 lb force to the control columns.

Other aircraft types incorporate logic to reduce the stick pusher input close to the ground. On the CL-604 there is no reduction or modulation in stick pusher force if an activation occurs close to the ground. The aircraft manufacturer advised that the stalling characteristics of the aircraft are such that a stall close to the ground could result in an unrecoverable loss of control. The SPS is therefore active throughout the entire flight. While the manufacturer acknowledges that a stick pusher activation close to the ground could result in the aircraft nose being driven into the ground, it stated that this is considered less hazardous than a stall.

The motor will cease to be active and the force on the control column removed once the AOA reduces below a calculated value below the pusher threshold. This hysteresis is to ensure that the push is of sufficient duration.

If the rate of increase of AOA is greater than one degree per second, the SPC lowers the AOA threshold to activate the aural, visual and tactile indicators at a lower AOA. This is to prevent the aircraft's pitching momentum from carrying it through the stall warning/stick pusher sequence into the stall.

In the case of a rapid increase in AOA, it is possible for the stick shaker and stick pusher to

[9] Bombardier publications also use the terms 'firing angle' and 'trip point'.

activate with little delay or even simultaneously, but this information is not included in the OM.

The stick pusher is armed when both STALL PROT PUSHER switches, located on the pilot and co-pilot side panels, are ON.

Operation of the stick pusher and associated warnings will cease in the following circumstances:

- The compensated AOA signal decreases from the pusher threshold by a predetermined degree
- G-switch activation at 0.5G
- Pilot or co-pilot AUTOPILOT/STICK PUSHER disconnect button is pushed and held
- Either STALL PROT PUSHER switch is selected off (although the stick shaker will remain armed in the case)

Stall protection system modifications, maintenance requirements and normal procedures

Two modifications are available on the CL-604 SPS: Service Bulletin (SB) 604-27-005 *'Dormant failures in the stall protection computer*' Revision 2[10], dated 30 September 2005 and SB 604-27-031 *'Introduction of a new angle of attack sensor'* Revision 2[11] dated 24 May 2011. Following embodiment of both SBs in 2011 at 4,109 flight hours, N999PX was equipped with the most up to date configuration of the SPS. SB 604-27-031 replaced the original contact-type AOA transducer, which was prone to mechanical wear, that could cause the transducer output to behave in a non-linear manner. It introduced a new design of non-contact transducer which was not susceptible to wear. Completion of SB 604-27-031 therefore eliminated the need for frequent repetitive functional checks on the AOA vanes. Completion of SB 604-27-005 substantially increased the interval for the functional checks of the SPC flap input and sideslip compensation from every 100 hours and 400 hours respectively, to every 4,800 hours. N999PX had not reached this interval at the time of the accident, having only completed 761 flight hours since installation of the new SPC.

Two separate operational tests of the SPC are required to be performed every 800 hours. One checks that each channel individually triggers the required warnings (single channel operational test) when it is supposed to and the other checks that STALL FAIL condition is correctly indicated if the difference between the left and right AOA values exceeds a predetermined amount (dual channel operational test). Both operational tests were most recently performed on N999PX in September 2021 as described below.

The CL-604 AFM Normal Procedures Consolidated Checklists describe a SPS daily check which tests the operation and sequencing of the stall protection system, including the engine

10 Initial issue dated 30 June 2003.
11 Initial issue dated 27 Jan 2010, Revision 1 dated 22 March 2010.

auto-ignition and the stick shaker and pusher activation. This must be completed by the crew prior to the first flight of the day. The crew could not recall completing the SPS daily check but had no reason to believe it was not completed.

N999PX recent maintenance history

N999PX was manufactured in 1998 and had been operated by the operator since 2007. It had a valid Airworthiness Certificate. The aircraft was maintained at a maintenance facility in the UK. A 12-month inspection was carried out in August 2021. The most recent maintenance check was carried out between 16 and 28 September 2021 at 8,402 flying hours and 4,842 cycles, when various items of line maintenance were performed. In accordance with the operator's normal practice, several defects had been recorded in the aircraft's technical log on the inbound flight to the maintenance facility. Due to this practice, it was not known how long each defect had been present for.

One of the documented defects related to a pilot report that the right AOA vane did not move or was intermittently inoperative. The maintenance engineers were unable to recreate the problem on the ground. The right AOA vane was replaced. Operational tests of the SPC (single and dual channel) were performed after replacement of the AOA vane and no anomalies were noted. No subsequent reports relating to the AOA vane were noted in the technical log.

At the time of the accident N999PX had accrued 8,451 flying hours and 4,870 flight cycles.

Manufacturer's stick shaker and pusher calculations

As stick shaker or pusher activation was not recorded on the FDR (N999PX predated the change to a higher rate recorder) the aircraft manufacturer performed retrospective calculations to determine the likely shaker/pusher status during the accident sequence. The calculations used the AOA values recorded on the FDR (corrected for recorded sideslip) to determine if the shaker or pusher thresholds were exceeded[12].

The calculations showed that the left AOA value exceeded the stick shaker threshold for approximately two seconds just prior to the first touchdown. Approximately four seconds later, both the left and right AOA values exceeded the stick shaker and pusher thresholds just prior to the second touchdown. The calculations showed that there would have been, at most, one second between the second stick shaker activation and the stick pusher activation.

Aircraft examination

Preliminary aircraft examination

The aircraft was examined on Taxiway Juliet at London Gatwick the morning after the accident. The outboard portion of the left wing and winglet had suffered considerable damage (Figure 6). There was a dent on the lower surface of the outboard leading edge.

12 The parameters for the AOA vanes and sideslip are recorded asynchronously, at differing rates, and therefore are at best an approximation of the behaviour of the stall protection system, especially when the approach to stall is highly dynamic.

The landing light glazing at the wingtip and several fairings and skin panels were missing. The wingtip lower skin was abraded, in some locations through its entire thickness, and there was damage to the sub-structure. Grass and earth were lodged in the landing light housing and in the exposed structure at the base of the winglet. The winglet and wingtip trailing edge skin showed evidence of ground contact, including the mounting plate for the wingtip static discharge wick which was abraded flat. There was also evidence of ground contact on the outboard rear corner of the left aileron, a small section of which was missing, and on the aileron's outboard static discharge wick. The aileron upper skin was buckled. The trailing edge of the outboard flap fairing also showed evidence of ground contact.

Figure 6

Damage to N999PX left wing

Light scuffing was noted on the fuselage skin at the left wing root, which may have indicated relative movement between the wing and fuselage.

The nose landing gear left wheel axle had failed such that the top of the left wheel was angled towards the landing gear leg (Figure 7). Severe scoring and abrasion on the inboard sidewall of the left tyre had been caused by the tyre rotating against a grease nipple at the bottom of the oleo. Some localised buckling was evident on the lower fuselage skin immediately aft of the nosewheel bay.

Figure 7
Damage to N999PX nose landing gear (view looking aft)

The left tyre was deflated and the aircraft was towed to a remote stand at the airport and was parked for several weeks.

Detailed aircraft examination and damage assessment

The aircraft was subsequently moved to a hangar where a full hard landing inspection was performed by the maintenance organisation, under the direction of the aircraft manufacturer. This included general and detailed visual inspections of the aircraft structure and control surfaces, and operational tests of various systems. In addition to the visible external damage, the inspections identified some bulging and buckling of skin on the right side wall of the nose landing gear wheel bay in the vicinity of the nose landing gear trunnion fitting.

The main and nose landing gears were removed and sent to the landing gear manufacturer for stress testing; the results were unknown at the time of publication of this report.

An operational test of the aileron control system revealed several anomalies with the hydraulic actuation aspects of the system and identified that the ailerons did not return to neutral without moderate force being applied.

A wing symmetry/alignment check identified that the degree of twist to the left wing was out of allowable limits. The aircraft manufacturer considered that this indicated permanent plastic deformation of the wing attachment point, meaning that ultimate strength of the materials had been exceeded. In order to return to service, the aircraft would have required a complete wing set replacement. The aircraft insurers considered that the damage to the aircraft was beyond economical repair.

Neither the SPC nor the AOA vanes were removed from the aircraft for functional testing.

Other events

The AAIB is aware of two other events, occurring within five weeks of this accident, where the stick pusher on a CL-604 activated close to the ground. One event occurred on 27 January 2022 involving 2-SLOW, which experienced a left wingtip strike, stick pusher activation and nose landing gear collapse during landing at Heraklion Airport in Greece. The other event occurred on 28 December 2021 to G-XONE, on approach to Bern, Switzerland. In that case, the crew was able to recover the flightpath of the aircraft after the stick pusher had activated, but the aircraft had descended to 4 ft aal.

These events are under investigation by the Hellenic Air and Railway Safety Investigation Authority and Swiss Transportation Safety Investigation Board respectively, and Accredited Representatives from the AAIB are appointed to each investigation.

Analysis

Aircraft and site examination

Examination of the aircraft and ground marks revealed that the left wingtip and winglet, and the trailing edge of the aileron and outboard flap fairing, struck the runway during the landing sequence. This was consistent with the aircraft being in a left wing low and nose-high attitude. Wingtip contact with the ground continued as the aircraft departed the runway into the grass area to the left.

The damage to the nose landing gear axle probably occurred during the second touchdown on the nose and left landing gears, when the normal acceleration reached the maximum recorded value of almost 2.5g. It is likely that activation of the stick pusher contributed to the landing attitude and therefore the damage sustained by the nose landing gear axle.

Pre-flight decision making

The aircraft started the approach into Stansted nearly five hours later than planned and the forecast crosswind was stronger than forecast for the original arrival time. Having been delayed, had the crew considered the weather nearer the revised ETA they may have noted that a gusting 30 kt crosswind was forecast and given more consideration to alternate plans should the wind be out of limits on arrival.

Calculation of approach speeds

The AAIB calculated a V_{REF} 4 kt greater than that obtained by the crew, and a V_{REF} +X for the reported wind 17 kt greater. The lower speed used by the crew provided less margin for the effects of a gusting wind, with the potential for an excessive AOA to develop. Wind information was passed to the crew and commented on by the co-pilot, with sufficient notice to increase V_{REF} +X or discontinue the approach. However, the nature of the relationship between the two pilots may have influenced their communication. The co-pilot adhered to standard monitoring and callouts such as he used in CAT operations and no further discussion took place.

It would not have been necessary to recalculate an increased V_{REF} +X accurately, assuming it was not so great as to prevent the aircraft landing or stopping: any increase in airspeed in the given conditions would have reduced the AOA, and therefore the onset of any wing drop or stick shaker and pusher activation.

Handling during the approach

London Stansted Airport provided the investigation with anemometry data that recorded the wind every one second. This was consistent with information forecasted and disseminated to the crew. There was no evidence of any crosswind in excess of the aircraft's limit of 24 kt, the maximum recorded crosswind component occurring just before the landing was that reported by ATC. However, the effective crosswind component of the wind reported by ATC (13 gusting 25 kt) exceeded the commander's personal limit of 20 kt. When the relevant wind information was transmitted by ATC the commander's workload was high and he may not have heard it or, if he heard it, he may not have been able to analyse it promptly. The co-pilot reported that he was not aware of the commander's personal limit, so did not prompt the commander to observe it.

V_{REF} +X should be maintained until the aircraft crosses the threshold. The aircraft's IAS reduced below the crew's calculated V_{REF} +X of 125 kt about 5 seconds before idle was selected, with no recorded increase in engine thrust to compensate. As there was no autothrottle, this may indicate the commander's attention was focused on the aircraft's flight path. The co-pilot's callouts of excessive bank angle indicate he was monitoring the flightpath.

The premature deceleration below V_{REF} +X, without a correcting thrust increase, resulted in reduced energy as the aircraft entered the flare and subsequent float, and indicated the crew were not closely monitoring airspeed.

The AFM suggested that with FLAPS 45 and the landing gear down, the 1g stall speed at 33,000 lb would be 99 kt. The lowest speed recorded was 101 kt as the aircraft floated above the runway for several seconds.

The aircraft floated along the runway after the flare at about 10 ft for six seconds, probably because the commander wanted to make a smooth landing for the comfort of the passengers. Had the aircraft touched down soon after the flare was initiated it is less likely the stick pusher would have activated, and the aircraft may have stayed on the runway.

The commander commented that he should have added some power in the float to stop the speed reducing excessively. However, in the CL-604's OM it stated that '*If the pilot believes* *that thrust must be added and maintained until touchdown to salvage a landing, then a rejected landing should be executed.'* Had the commander recalled the OM guidance he might have discontinued the landing earlier. He had practised a crosswind landing and a rejected landing two weeks before the accident, and could probably have performed them competently.

Recorded elevator inputs during the final approach, after the autopilot was disconnected, appeared normal for the conditions until the flare. Aileron inputs were of greater magnitude, the aircraft flying the rest of the approach with the right wing down (into wind) and with significant left rudder deflection (flying with crossed controls). While there was no specific guidance in the CL-604's OM on how to handle a crosswind landing, the de-crab technique was recommended in the CL-604's Supplementary Procedures for contaminated runways. The co-pilot stated that he used this technique when flying, and it was appropriate for an aircraft with a relatively short landing gear and low wing.

The investigation did not determine the precise cause of the runway excursion.

Fatigue, decision making and communication

The pilots experienced a long working day that included delays, higher than normal workload and a tense relationship between them. The accident occurred during their window of circadian low. As there were no other fatigue risk factors, it is unlikely that reduced manual flying performance due to fatigue was severe enough to cause the accident. However, it is possible that the relationship issues and fatigue factors affected the pilots' decision making and communication prior to the flight and during the approach.

The go-around

During ATC exchanges after the GA the co-pilot did not respond promptly and his voice showed some indications of stress. This, and the crew's action to level off at 4,000 ft amsl (the published procedure being not above 3,000 ft amsl) indicate that the crew may have experienced startle, surprise or heightened stress. Their subsequent request to divert to an airport with a crosswind of no more than 15 kt, significantly less than the aircraft or commander's limits, indicates a desire to operate cautiously for the remainder of the flight.

Stall warning

The AAIB is aware of two other events involving low airspeed in CL-604 aircraft that occurred between December 2021 and January 2022.

Retrospective calculations by the aircraft manufacturer following the accident involving N999PX suggest that the stick shaker activated immediately prior to the first touchdown and that both the stick shaker and stick pusher activated prior to the second touchdown. Based on the FDR data, the conditions for activation of the stick pusher were achieved only briefly. Therefore, stick pusher activation was probably brief. However, the stick pusher activated with little delay after the stick shaker, giving the pilots little time to recognise and take the appropriate action after the shaker activated before the pusher applied a significant forward force on the control column.

The aircraft was equipped with the latest configuration of SPS, and operational checks of the SPC had been carried out four months before the accident. The manufacturer's calculations suggest that the SPS operated as intended and that the stick shaker and pusher activations were valid.

The lowest indicated speed achieved by the aircraft was 101 kt, 2 kt above the reference stall speed for the aircraft configuration. Stick pusher activation may have prevented a wing stall and more consequential outcome.

Crosswind landing guidance

Soon after the autopilot was disconnected the aircraft was in a sideslip until the flare before touchdown. However, a wings level attitude, followed by a de-crab in the flare, was the manufacturer's pilots preferred crosswind landing technique and that quoted for contaminated runways in the CL-604's OM.

The manufacturer provides guidance on crosswind landings for some of its aircraft, including the Challenger 300 series, in the respective ROPT. However, the only guidance for the CL-604 is in the OM Supplementary Procedures, 06-13, '*Operation on Contaminated Runways*', '*Crosswind Landings*', where it states, '*In crosswind conditions, the crosswind crab should be maintained for as long as possible, until prior to touchdown…*' There is no guidance on crosswind landings in Normal Procedures, 04-08, '*Approach and Landing*' or its ROPT.

The aircraft manufacturer indicated that it intended to update CL-604 manuals to include a similar level of information regarding crosswind landing technique as the other aircraft it manufactures but did not say when it would complete this action.

Conclusion

The aircraft yawed and rolled rapidly following a long float with insufficient airspeed in strong gusting wind conditions. Stick shaker activation was followed almost immediately by stick pusher activation, resulting in the aircraft landing on its nosewheel.

A crosswind exceeding the commander's personal limit was forecast before departure. It would have been possible to delay departure or select an alternative arrival aerodrome with more favourable conditions.

The commander reflected that although there was an opportunity to discontinue the approach earlier, he had felt compelled to continue with the landing by a degree of plan continuation bias. Fatigue, commercial pressure and the nature of their interactions may have made the pilots more susceptible to this bias.

Safety actions

The aircraft manufacturer stated it intends to update CL-604 manuals to include a similar level of information regarding crosswind landing technique as the other aircraft it manufactures.

Published: 30 November 2023.