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Swiss Transportation Safety Investigation Board STSB

Final Report No. 2359 by the Swiss Transportation Safety Investigation Board STSB

concerning the accident involving the Bombardier Global 6000 aircraft 9H-AMZ

on 6th April 2016

at Geneva Airport (LSGG)

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General information on this report

This report contains the Swiss Transportation Safety Investigation Board's (STSB) conclusions on the circumstances around and causes of the aircraft accident under investigation.

In accordance with article 3.1 of the 10th edition of annex 13, effective from 18th November 2010, to the Convention on International Civil Aviation of 7th December 1944 and article 24 of the Federal Aviation Act (LFG, SR 748.0, 21. December 1948, as of 1 January 2019), the sole purpose of an investigation into an aircraft accident or serious incident is to prevent further accidents or serious incidents from occurring. Legal assessment of the circumstances and causes of aircraft accidents and serious incidents is expressly excluded from the safety investigation. It is therefore not the purpose of this report to establish blame or to determine liability.

Should this report be used for purposes other than those of accident prevention, this statement should be given due consideration.

The German version of this report constitutes the original and is therefore definitive.

All information, unless otherwise indicated, relates to the time of the accident.

All of the times mentioned in this report, unless otherwise indicated, are given in coordinated universal time (UTC). For the region of Switzerland, Central European Summer Time (CEST) was the local time (LT) at the time of the accident. The relationship between LT, CEST and UTC is:
LT = CEST = UTC + 2 h

Contents

Final Report

Summary

Owner	Chandler 6000 Aviation LLC, 160 Greentree Drive, Suite 101, Dover, Delaware 19904, USA
Operator	Comlux Malta Ltd, Villa Margherita, Ta’ Xbiex Terrace, Ta’ Xbiex XBX 1035, Malta
Manufacturer	Bombardier Business Aircraft, 200 Côte-Vertu Ouest, Dorval, Québec, Canada H4S 2A3
Aircraft type	BD-700-1A10 (Global 6000)
Country of registration	Malta
Registration	9H-AMZ
Location	Runway 05 at Geneva Airport (LSGG)
Date and time	6th April 2016, 13:59 UTC

Investigation

The accident occurred on 6th April 2016 at approx. 13:59 UTC. It was reported at 14:10 UTC. The investigation was opened at 15:00 UTC by the Swiss Transportation Safety Investigation Board. The STSB informed the relevant authorities in the following countries about the accident: Malta, Canada. Canada appointed an authorised representative who took part in the investigation.

The investigation was based on the following information:

- Evidence collected at the location
- Statements from the flight crew
- Statements from people who saw the accident
- Data recording from the cockpit voice recorder (CVR) and flight data recorder (FDR)
- Radio communication recordings
- Radar data
- Recordings of meteorological conditions

This final report is published by the STSB.

Synopsis

Following an uneventful flight from Bodensee-Airport Friedrichshafen (EDNY), the crew of the Bombardier BD-700-1A10 Global 6000 long-haul business aircraft, registered as 9H-AMZ, made an approach using the instrument landing system to runway 05[1] at Geneva Airport (LSGG), where there were light winds at the time. Approximately two minutes before 9H-AMZ landed, with the aircraft flying a stabilised final approach about 4 NM from the runway threshold, a commercial aircraft Airbus A319 commenced its take-off run from the start of runway 05 and took off around 40 seconds later. The crew of 9H-AMZ flew over the displaced threshold of runway 05 with the correct approach profile and at the correct reference speed, and commenced the flare at a radio altitude of 10 ft. Moments later, the aircraft was caught by a positive

[1] At the time of the accident the runway directions were still marked 05 and 23.

wind shear of around 13 kt and rolled into a slight right bank, which the crew countered with an aileron deflection to the left. Immediately afterwards, the aircraft suddenly and severely rolled on its longitudinal axis to a left bank angle of 12.1°. The crew immediately countered this with a vigorous aileron deflection to the right. Nevertheless, 9H-AMZ struck the runway with its left wingtip and subsequently touched down with the main landing gear whilst at an almost horizontal bank attitude. The process of slowing down and taxiing from the runway was uneventful.

The occupants of 9H-AMZ were not injured. The aircraft was damaged on the left outer leading-edge slat.

There was no third-party damage.

Causes

The accident, in which a business aircraft touched the runway with one wingtip (wingtip strike), can be attributed to a high bank angle during the landing flare. The most probable cause for this high bank angle was found to be wake turbulence from a commercial aircraft that had previously taken off on the runway, which caused the business aircraft to roll around its longitudinal axis.

The accident was caused by the combination of the following factors:

- Light wind weather conditions, which delayed the decay of wingtip vortices;
- A prolonged landing flare near the ground, which led to a touchdown at the end of the landing zone at low airspeed;
- Insufficient distance between the displaced runway threshold and the point of rotation[2] of an aircraft, which had previously taken off.

Safety recommendations

Three safety recommendations are made in this final report.

[2] Point at which the lift-off is initiated and the aircraft nose is raised.

1 Factual information

1.1 Background and history of the flight

1.1.1 General

The flight was carried out under Instrument Flight Rules (IFR). It was a commercial flight.

Throughout the entire flight, the Pilot in Command (PIC) acted as the Pilot Flying (PF) and the First Officer (FO) acted as the Pilot Monitoring (PM).

1.1.2 Background

The long-haul business aircraft type BD-700-1A10 (Global 6000), registered as 9H-AMZ, had been flown from Saint Louis Downtown Airport (KCPS) to Malta (LMML) two days before the accident. On the morning of 6th April 2016, the first officer had already carried out three flights in 9H-AMZ. During the first flight, which had taken off from Malta (LMML) for Friedrichshafen (EDNY) at 06:15 UTC, and on the onward flight to Stuttgart (EDDS), he had performed the role of FO in the right-hand seat. He had then acted as PIC in the left-hand seat on the flight back from Stuttgart to Friedrichshafen.

The pilot in command met with the FO in Friedrichshafen and together they completed the flight plan necessary for the onward flight to Geneva. One cabin crew member and two passengers were on board. 9H-AMZ was still filled with 13,250 lb of Jet A-1 fuel. As the minimum block fuel for this flight was 5,159 lb, there was no need to fill up. The V-speed for take-off and Reference Landing Speed (V_{REF}) for a possible return to Friedrichshafen and for the approach to Geneva later on were calculated, along with the corresponding take-off and landing distances.

1.1.3 History of the flight

With 9H-AMZ having taken off from Friedrichshafen at 13:15 UTC and following an uneventful flight, the PM contacted the aerodrome control tower (TWR) in Geneva at 13:54:35 UTC. At that time, 9H-AMZ was already making its approach using the instrument landing system (ILS) to runway 05, around 12 nautical miles (NM) before the runway threshold at a flying altitude of 5,200 ft Above Mean Sea Level (AMSL). The Air Traffic Controller (ATC) instructed 9H-AMZ to maintain an Indicated Airspeed (IAS) of 160 kt until it was 6 NM from the runway threshold and then reduce its speed to the final approach speed.

At 13:56:27 UTC, a commercial aircraft Airbus A319 with radio call sign EZY32PZ was given clearance to proceed via Taxiway (TWY) G and take-off from the start of runway 05 (see illustration 1).

At 13:57:15 UTC, the PF switched off 9H-AMZ's autopilot and subsequently flew the aircraft manually until landing. 9H-AMZ was already configured for landing with a landing flap position of 30° and its landing gear deployed. At roughly the same time, EZY32PZ began its take-off run from the start of runway 05.

At 13:57:41 UTC, EZY32PZ took off from runway 05 just before TWY D. At that time, 9H-AMZ was 2.5 NM before the runway threshold in a stabilised final approach and was flying at a Ground Speed (GS) of 122 kt.

At 13:57:53 UTC, the ATC gave 9H-AMZ clearance to land on runway 05 and informed the crew at the same time that the current ground wind in the landing zone was 4 kt from 210°.

At 13:58:52 UTC, 9H-AMZ flew over the start of runway 05 at a Radio Altitude (RA[3]) of 100 ft and an IAS of 112 kt. The aircraft had the correct approach profile for touchdown after the displaced threshold for runway 05. At an RA of 50 ft, the PF switched the thrust levers to idle. 3 seconds later, at 13:59:01 UTC and an RA of around 10 ft, an elevator control input was recorded, which initiated the flare.

The crew observed that the aircraft was caught by a light updraft shortly after commencing the flare. A few seconds later, 9H-AMZ rolled on its longitudinal axis into a slight right bank angle, which the PF countered with an aileron deflection to the left. Immediately afterwards, surprisingly for the flight crew, the aircraft suddenly and severely rolled on its longitudinal axis to a left bank angle of 12.1° and the aircraft yawed slightly to the right on its vertical axis by 10°. The PF immediately countered these rolling movements with a vigorous aileron deflection to the right. Nevertheless, 9H-AMZ struck the runway with its left wingtip, which was not noticed by the crew. The aircraft then touched down on the runway with zero bank angle (wings level).

The ATC observed from the control tower that, at 13:59:11 UTC, level with TWY E and a few metres above the ground, 9H-AMZ suddenly made a severe bank to the left and in doing so might have touched the ground with its left wing. Simultaneously, the ATC noticed white smoke develop underneath the aircraft, which usually occurs when the main landing gear touches down.

At the same time, the flight crew of an aircraft with flight number EZS56PN, which was at parking position 34 on the apron south of the runway, observed that the left wing of 9H-AMZ touched the ground, when the aircraft was level with TWY E.

At that time, the A319 which had previously taken off was climbing approximately 3 NM beyond the end of runway 05.

The ATC ordered an inspection of the runway immediately after 9H-AMZ had landed, during which no foreign objects or scratch marks were found.

After landing, 9H-AMZ taxied across the apron “South” to its intended parking position. During the subsequent visual inspection, severe scratch and rubbing marks were found on the underside of the left outer leading-edge slat.

Throughout the entire approach, the crew correctly completed all of the necessary checklists in accordance with the Flight Crew Operating Manual (FCOM). During the flight, the crew worked together in the cockpit in a calm, relaxed and professional manner.

[3]The radio altitude is shown by the radio altimeter, which uses radar to measure the aircraft’s exact flying altitude above the ground. The radio altimeter in the Global 6000 is designed to display a radio altitude of 0 ft with a tolerance of +/- 2 ft upon touchdown with the main landing gear.

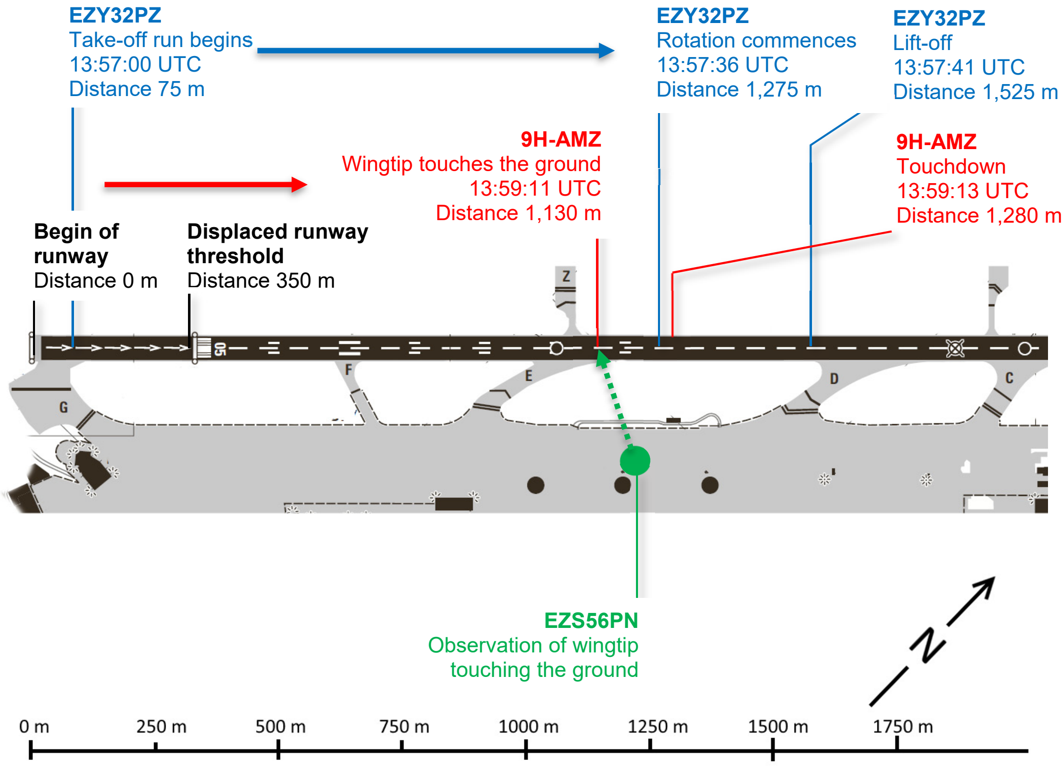

Illustration 1: View of the south-west section of runway 05. Positions of the departing Airbus A319 (EZY32PZ) and of the landing Global 6000 (9H-AMZ). On the south apron, the position of the aircraft (EZS56PN) is shown, from which the contact with the ground was observed.

1.1.4 Time and location of the accident

Accident location	Runway 05 at Geneva Airport (LSGG)
Date and time	6th April 2016, 13:59 UTC
Light conditions	Daytime
Altitude	1,407 ft AMSL (429 m AMSL)

1.2 Injuries to persons

1.2.1 Injured persons

Injuries	Crew members	Passengers	Total no. of occupants	Third parties
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	0	0	0	0
None	3	2	5	n/a
Total	3	2	5	0

1.3 Damage to aircraft

The aircraft sustained damage to the left outer leading-edge slat in the form of scratch and rubbing marks due to the contact made with the ground (see illustration 2).

Illustration 2: Left outer leading-edge slat shown in its extended position with scratch and rubbing marks on the underside

1.4 Third-party damage

There was no third-party damage.

1.5 Information on people concerned

1.5.1 Flight crew

1.5.1.1 Pilot

1.5.1.1.1 General

Person	German citizen, born 1956
Licence	European Union Aviation Safety Agency (EASA) Airline Transport Pilot Licence Aeroplane (ATPL (A)), issued by the German Federal Aviation Office (LBA)

All of the information available indicates that the pilot reported for duty well-rested and healthy. There is no indication that fatigue was a factor at the time of the accident.

1.5.1.1.2 Flying experience

Total	10,467 h / 4,027 landings
On the accident type	2,341 h / 656 landings
During the last 90 days	77 h / 10 landings
On the accident type	77 h / 10 landings
During the last 24 h	0:55 h / 1 landing
On the accident type	0:55 h / 1 landing

The PIC had completed a total of 2,341 flight hours and 656 landings in Global Express and Global 5000 aircraft. In November 2015, he completed difference training for the Global 6000 variant in a simulator, which was stipulated due to its new avionics, the Global Vision Flight Deck (GVFD). The flight on 6th April 2016 from Friedrichshafen Airport (EDNY) to Geneva (LSGG) was his first flight in a Global 6000.

1.5.1.2 First officer

1.5.1.2.1 General

Person	Austrian citizen, born 1973
Licence	EASA ATPL(A), issued by Austro Control GmbH in Austria

All of the information available indicates that the first officer reported for duty well-rested and healthy. There is no indication that fatigue was a factor at the time of the accident.

1.5.1.2.2 Flying experience

Total	4,961 h / 3,538 landings
On the accident type	330 h / 102 landings
During the last 90 days	38 h / 14 landings
On the accident type	38 h / 14 landings
During the last 24 h	4:05 h / 4 landings
On the accident type	4:05 h / 4 landings

The first officer already had practical experience in the Global 6000 aircraft type, including as pilot in command.

1.6 Information on the aircraft

1.6.1 General information

Registration	9H-AMZ
Aircraft type	BD-700-1A10 (Global 6000)
Characteristics	Twin-jet business aircraft with turbofan engines, wings with 34° sweep and conventional flight control system
Manufacturer	Bombardier Aerospace Inc.
Year of manufacture	2016
Serial number	9656
Owner	Chandler 6000 Aviation LLC, 160 Greentree Drive, Suite 101, Dover, Delaware 19904, USA
Operator	Comlux Malta Ltd, Villa Margherita, Ta' Xbiex Terrace, Ta' Xbiex XBX 1035, Malta
Engines	Two Rolls-Royce BR700-710A2-20

Airframe operating hours	45:36 h TSN[4]
Number of landings	17
Mass and centre of gravity	Both mass and centre of gravity were within the permissible limits of the Aircraft Flight Manual (AFM)

1.7 Meteorological information

1.7.1 General weather conditions

Behind a cold front, a narrow ridge of high pressure extended from the Bay of Biscay to the northern side of the Alps. The clouds subsequently dispersed along the southern foot of the Jura mountains.

1.7.2 Weather at the time and location of the accident

The weather conditions in Geneva were dry and quite sunny with good visibility. The boundary layer was well mixed and therefore stratification was neutral. Above approximately 3,000 ft AMSL, the wind blew from south-west to west. At an altitude of 10 m above ground, there was variable, weak wind.

Weather/clouds	1/8-2/8 at 4,300 ft AMSL 3/8-4/8 at 5,300 ft AMSL
Visibility	10 km or more
Wind	2-4 kt, variable (see chapter 1.7.4)
Temperature / dew point	16°C / 3°C
Atmospheric pressure QNH	1,014 hPa, pressure reduced to sea level, calculated with the values of the ICAO[5] standard atmosphere
Hazards	None

1.7.3 Astronomical information

Light conditions	Daytime	
Position of the sun	Azimuth 230 degrees	Elevation 39 degrees

1.7.4 Wind measurements

At Geneva Airport, the local wind is continuously measured at three positions along the runway (see illustration 3). However, the measurement at the ‘centre’ position does not meet the criteria of ICAO Annex 3[6] for the mid-value of tarmac runway 05/23, but is primarily used for the grass runway. The wind measurements which were saved in the SAMAX[7] equate to the average wind measured in the last two minutes.

[4] TSN: Time Since New

[5] ICAO: International Civil Aviation Organization

[6] ICAO Annex 3: Meteorological Service for International Air Navigation

[7] SAMAX: Swiss airport movement area control system (surveillance radar system for runways, taxiways and apron)

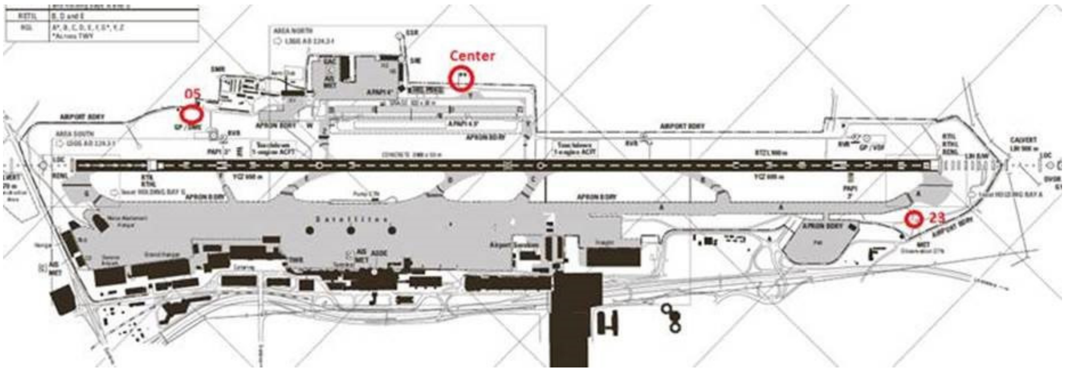

Illustration 3: Positions (red circles) of the three anemometers 05, centre, and 23 for measuring wind at Geneva Airport (LSGG)

At the time when 9H-AMZ was landing, the following ground wind was measured at the three anemometers (see illustration 4):

Time	Runway threshold 05	Middle of the runway ‘Centre’	Runway threshold 23
13:57:43 UTC	4 kt from 210°	4 kt from 040°	4 kt from 110°
13:59:11 UTC	2 kt from 250°	4 kt from 020°	4 kt from 100°

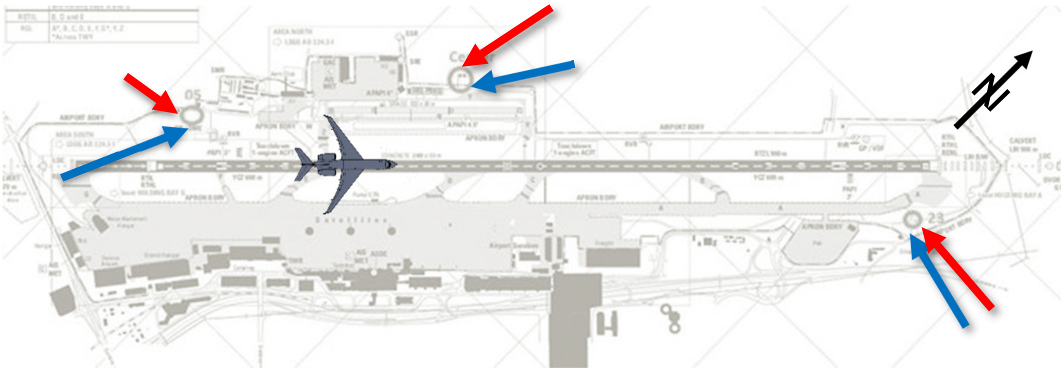

Illustration 4: Wind measurements in Geneva (LSGG) as recorded by ground radar along runway 05 at the time of the departing lead A319’s take-off (in blue) and at the time of 9H-AMZ’s wingtip strike (in red); the aircraft symbol shows the position at which the aircraft touched the ground with the tip of its left wing.

1.8 Navigational aids

Not applicable

1.9 Communication

The appropriate radio communication between the crew and the air traffic control tower took place in English and without difficulties.

1.10 Airport information

1.10.1 General

Geneva Airport is in the south-west of Switzerland. In 2015, it saw a traffic volume of 189,000 movements.

The airport reference altitude is 1,411 ft AMSL.

1.10.2 Runway equipment

The runways at Geneva Airport have the following dimensions:

Runway designation	Dimensions	Altitude of runway threshold
05/23	3,900 x 50 m	1,411 / 1,365 ft AMSL
05 grass / 23 grass	823 x 30 m	NIL

At the time of the accident, the Landing Distance Available (LDA) on runway 05 with a displaced threshold was 3,570 m.

1.11 Flight recorders

1.11.1 Flight data recorder

Model	FA2100
Manufacturer	L-3 Aviation Recorders

The Digital Flight Data Recorder (DFDR) was removed from 9H-AMZ immediately after the accident and read out in the STSB laboratory. The recordings had been saved for the entire flight until after the engines were switched off on the apron in Geneva.

Analysis of the DFDR data showed the following (see annex 1):

- 9H-AMZ was making a stabilised ILS final approach to runway 05 with normal approach configuration, i.e. with extended slats and flaps in the maximum position of 30° for a standard landing.
- The Magnetic Heading (MH) varied between 44.5° and 46.6° during the approach on the ILS 05. The bank angle ranged between 2.1° Left Wing Down (LWD) and 4.4° Right Wing Down (RWD).
- The IAS displayed prior to flying over the runway threshold during the short final approach was 115 kt, the ground speed was 120 kt.
- At 13:58:52 UTC during its descent, 9H-AMZ passed a Radio Altitude (RA) of 100 ft, the IAS was 113 kt.
- At 13:58:55 UTC and an RA of 50 ft, the thrust levers were pulled back to the idle position within 1 second. At around the same time, the aircraft turned slightly to the left on its vertical axis to an MH of 41.2° and its IAS increased slightly to 117 kt.
- At 13:58:59 UTC and an RA of 10 ft, the pitch attitude of 5.1° increased to an Attitude Nose Up (ANU) of approximately 7.3° with the commencement of the flare. Subsequently, 9H-AMZ remained at a constant RA of around 10 ft for approximately 4 seconds, before beginning to descend slightly once more with an almost constant ANU of maximum 7.5°. The IAS displayed reduced continuously to 106 kt, the bank angle fluctuated between 2.6° LWD and 0.2° RWD.
- At 13:59:06 UTC, at an RA of 1 ft, 9H-AMZ rolled into a bank of 4.9° RWD within 3 seconds. The PIC countered this rolling movement on the longitudinal axis by moving the aileron control stick to the left by 25°. At the same time, the IAS displayed increased from 106 kt to 117 kt in 0.8 seconds, whilst the GS decreased slightly from 113 kt to 111 kt, which indicates a positive wind shear of approx. 13 kt.
- At 13:59:09 UTC, the aircraft rotated around its longitudinal axis with a high roll rate, reaching a maximum bank angle of 12.1° LWD within 2 seconds

which the PIC countered by moving the control stick sharply to the right by 59°. At the same time, 9H-AMZ yawed to the right by 4.8° to an MH of 46.5°.

- At 13:59:13 UTC, 9H-AMZ touched down with both the left- and right-hand side main landing gear wheels simultaneously and wings level. The nose landing gear touched down 6 seconds later.
- Immediately after the main landing gear had touched down, a lateral acceleration of 0.17 g to the right was measured, which indicates that the aircraft touched down in a slight sideslip to the left.

1.11.2 Cockpit voice recorder

Model	FA2100
Manufacturer	L-3 Aviation Recorders

The cockpit voice recorder (CVR) was removed from the aircraft along with the DFDR and was read in the STSB laboratory. Voice recordings were available for the entire flight until after the engines were switched off.

1.12 Information on the wreckage, the impact and the accident site

Not applicable

1.13 Medical and pathological findings

There is no evidence of health problems or fatigue in relation to the crew.

1.14 Fire

Fire did not break out.

1.15 Survival aspects

Not applicable

1.16 Tests and research results

1.16.1 Simulation of the flight dynamics

In collaboration with the aircraft manufacturer, a simulation model of the Global 6000’s flight dynamics was created which had already been used for the certification of the full flight simulator for the Global 5000 and Global 6000 aircraft models. Using this simulation model, conclusions could be drawn about the dynamic behaviour of 9H-AMZ during landing depending on the aileron deflections effected, the engine power set and the current environmental conditions.

The simulations were run with different wind profiles in both horizontal and vertical directions and an overlying, external rolling moment, thereby reproducing the flight dynamics of 9H-AMZ according to the data from the DFDR as accurately as possible. The results of the simulations showed that an additional, external rolling moment that could be attributed to either a local loss of lift or a vortex must have acted upon the aircraft.

Using a simplified calculation, the local loss of lift and the resulting rolling moment were quantitatively estimated based on the local angles of attack along the wings that occurred in the simulation. The results indicated that a loss of lift could be ruled out as a possible and sole cause for the high roll rate. Therefore, the aircraft must have been seized by a vortex during landing.

1.17 Information on various organisations and their management

1.17.1 General

The aviation company has outlined the operating procedures for the crew in various operational handbooks. These include the Operations Manuals (OM) OM A and OM B. Whilst OM A contains general operating procedures, the specific procedures for the aircraft type BD-700 are stated in OM B. The aircraft manufacturer's AFM and FCOM are referenced in OM B. As a supplement and for training purposes, the aircraft manufacturer has also made an online e-learning module available with the operating procedures for take-off, approach and landing in crosswinds.

1.17.2 Operating procedures

1.17.2.1 Approach speed

According to information from the manufacturer, the Reference Landing Speed (V_{REF}) for the Global Express aircraft type, from which the Global 6000 was developed, is based on the conservative V_{SMIN} method where $V_{REF} = 1.326 \times V_{SMIN}$[8]. A large proportion of the certification for the Global Express had originally been carried out using the V_{SR} method, where $V_{REF} = 1.23 \times V_{SR}$[9], thus permitting a lower approach speed. On test flights with a reduced approach speed of V_{REF} -5 kt, however, this resulted in a restricted view from the cockpit to the runway due to the high angle of attack, and the problem that the engine power could only to be reduced immediately before touchdown in order to sufficiently break the sink rate for landing. Subsequently, in consultation with the Canadian aviation authority Transport Canada, the reference landing speed for the Global 6000 was defined following the V_{SMIN} method, thus the V_{REF} is approximately 6 to 8 kt higher than with the V_{SR} method.

The approach speed can be calculated according to the tables in the FCOM and the AFM. For the landing in Geneva on the day of the accident, the V_{REF} was 116 kt, which conformed with the information on the load sheet that was available to the flight crew.

For the Global 6000 aircraft type, the V_{REF} is defined in such a way that no further increase in speed is required apart from the surcharges noted in FCOM and AFM. According to the FCOM, wind corrections have to be made for gusts, whereby half of the gust speed and a maximum of 10 kt is added to the V_{REF}.

The manufacturer also stated that the speed of the aircraft drops by about 4% until touchdown when initiating a normal flare. For a V_{REF} of 116 kt this equates to a touchdown IAS of 111 kt. In test flights during the certification phase, a good level of aircraft controllability on both the longitudinal and vertical axes was also ascertained at an IAS of 100 kt and with a higher aircraft weight than in the present case; this was also the case for a state of thrust with full rudder side-slip.

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[8] V_{SMIN}: The non g-corrected stick pusher activation speed at 1g vertical acceleration where the control column is pushed forwards by a mechanism so that the aircraft does not stall. V_{SMIN} is 2% higher than V_{SR}.

[9] V_{SR}: the reference stall speed at 1g vertical acceleration

1.17.2.2 Landing technique

The normal landing technique is described as follows in the FCOM:

"At or below 50 ft AGL[10]:

1. *Thrust levers .... IDLE*
2. *Airplane attitude .... Maintain until close to the runway Perform partial flare and touchdown without holding off."*

This means that at a flying altitude of 50 ft AGL or lower, the thrust levers are moved to the idle position whilst at the same time maintaining the pitch attitude of the aircraft until immediately above the runway. Subsequently, a partial flare is initiated without delaying the landing gear's touchdown on the runway.

In addition, the FCOM states regarding crosswind landings: The tips of the wings can make contact with the runway when landing with an increased bank angle. To prevent this from happening, the bank angle should be limited to 3° or less and the aircraft should touch down immediately after coming into alignment with the runway. During a prolonged flare, the pilot continually increases the pitch attitude, meaning that the wingtips move closer to ground due to the pronounced sweep of the wing (see illustration 5).

In the manufacturer's e-learning module, the landing technique for landing in crosswind conditions is described in detail and with special focus on the problem of a wingtip strike occurring when landing with a higher pitch attitude due to the pronounced sweep of the wing's geometry.

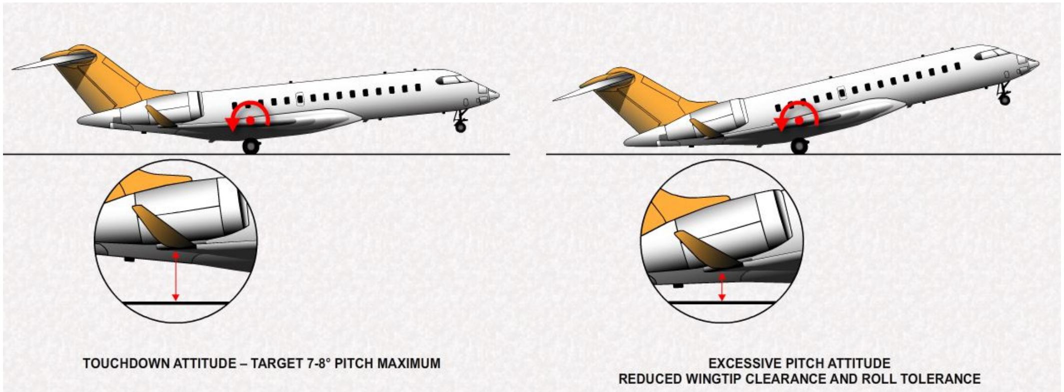

Illustration 5: The image on the left shows the pitch attitude, which is a maximum of 7-8° during a normal landing, and the corresponding distance between the tip of the wing and the ground. Increasing the pitch attitude reduces this distance and the maximum acceptable bank angle as displayed in the image on the right (source: Bombardier e-learning module).

The bank angle at which a wingtip touches the ground decreases as the pitch attitude increases and is dependent on whether the landing gear is in the static or flight position (see illustration 6). As the lift on the wing rapidly decreases during landing and the landing gear is thereby compressed, the limiting static value is to be taken into consideration. In this accident, the pitch attitude at which the wingtip strike occurred was approximately 4.7°, which gives a bank angle of 9.0° (static) and 11.7° (flight) respectively.

In the e-learning module, a warning clearly states that a bank angle of more than 10.3° during touchdown is highly likely to lead to a wingtip strike.

[10] AGL: above ground level

WING-STRIKE ROLL ANGLE (STATIC VERSUS FLIGHT)		
Pitch Attitude	**Roll Angle (Static)** (Gear strut compressed)	**Roll Angle (Flight)** (Gear strut extended)
0°	10.6°	13.5°
3°	9.6°	12.3°
6°	8.5°	11.2°
9°	7.4°	10.1°

Illustration 6: The wing-strike roll angle (bank angle) in relation to the pitch attitude and whether the landing gear is in the static (gear strut compressed) or flight (gear strut extended) position (source: Bombardier e-learning module).

1.18 Additional information

1.18.1 Temporal degradation of wake turbulence

Wake turbulence refers to turbulence that occurs behind an aircraft for various reasons whilst it is flying. The two main causes of wake turbulence are wingtip vortices and jet wash from the engines. Jet wash generates very powerful and turbulent airflow, however, due to the rapid loss of energy seen in strong turbulence, jet wash dissipates within a very short period of time. In contrast, wingtip vortices are more stable and remain present for several minutes.

The temporal degradation of wingtip vortices is a complex aerodynamic process that is heavily influenced by atmospheric environmental conditions. In a turbulent wind field, for example, the wingtip vortices are quickly weakened. In less turbulent, low-wind situations, however, it is possible that wingtip vortices may remain present for several minutes.

In a study, the American Institute of Aeronautics and Astronautics (AIAA) has described the chronological course of wingtip vortices using Large Eddy Simulations (LES)[11] and compared them with readings from various airports that were carried out using LIDAR[12]. From this and other studies it is clear that the decay of the wingtip vortices is very slow, especially in the first phase, which can last up to two minutes, and the energy bound in the wingtip vortices can still be around 75% of the original maximum value after this period.

1.18.2 Separation minima

To combat the danger posed by the occurrence of wingtip vortices between departing and arriving aircraft, the ICAO has issued corresponding guidelines[13] that govern the separation minima between aircraft depending on their wake turbulence category. The EASA regulations are based on these guidelines and must be applied by the Air Traffic Service (ATS). If the ATS follows by means of a surveillance

[11] Using Large Eddy Simulation (LES), large eddies can be directly calculated numerically.

[12] LIDAR: Light Detection and Ranging, a method of detecting and measuring movements in an air mass using a laser beam

[13] ICAO Doc 4444 Chapter 8.7.3 "*Separation minima based on ATS surveillance systems*"

system, e.g. radar or ADS-B[14] data, the minimum separation is based on a distance. If no such surveillance system exists, the minimum separation is defined over a time. In the case of a displaced threshold, such as on runway 05 in Geneva, specific, time-based intervals are defined. For example, if a wake turbulence category MEDIUM aircraft lands behind a previously launched HEAVY, a 2-minute interval must be maintained.

Between aircraft of the same wake turbulence category there are no minimum separation requirements defined concerning wake turbulence. In this case only the minimum radar separation of 3 NM[15] in final approach and the minimum runway separation minima must be observed. According to the latter, an approaching aircraft may only fly over the threshold of the runway after the preceding aircraft has flown over the end of the runway or rolled off the runway.

In deviation from this, the Air Traffic Management Manual (ATMM) of Geneva Airport (LSGG) regulates this runway separation minimum as follows: A preceding Category 3 aircraft[16] must have taken off and overflown a point at least 2,400 meters behind the runway threshold for landing aircraft. Such a reduction of the runway separation minima is possible based on the EASA regulations after a corresponding risk assessment. However, the distance- or time-based minimum separation minima regarding wake turbulence between two aircraft remain unchanged.

In the present case, both the starting aircraft type A319 and the landing aircraft type Global 6000 belonged to the same wake turbulence category MEDIUM, in which aircraft of the weight class between 40 t and 136 t are classified.

For situations with one departing and one landing aircraft behind it, there exist general recommendations. For example, The US Federal Aviation Authority (FAA) recommends a planned touchdown point on the runway that is before the rotation point of the departing lead aircraft (see illustration 7).

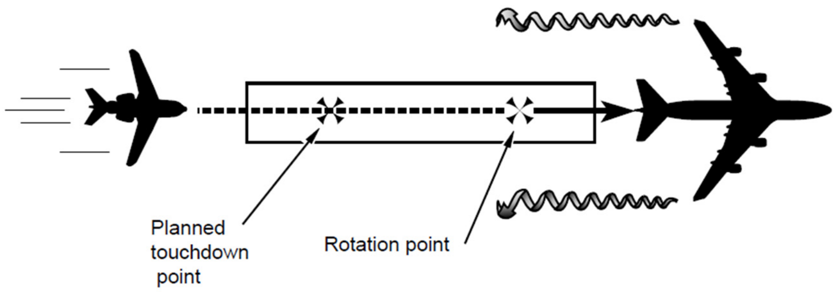

Illustration 7: Landing behind a departing larger aircraft (source: "*Pilot and Air Traffic Controller Guide to Wake Turbulence"*, FAA)

1.18.3 Other incidents

In 2014, the UK's Air Accidents Investigation Branch (AAIB) investigated two incidents involving the Global 6000 aircraft type where a wingtip strike occurred during landings in a light crosswind with crosswind components of 11 and 9 kt respectively.

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[14] ADS-B: Automatic Dependent Surveillance: an air traffic control system for displaying flight movements in the airspace

[15] According to ICAO, a reduced radar separation of 2.5 NM is permitted on final approach within 10 NM of the runway threshold; however, this is not applied in Switzerland.

[16] According to ICAO Doc 4444 Chapter 7.11 or ATMM in Geneva, aircraft with a maximum take-off weight of 7,000 kg or more belong to Category 3.

In both cases, the PF prematurely aligned the aircraft with the runway (de-crab) at an RA of approximately 85 ft. Subsequently during the flare, which was already initiated at an RA of approximately 50 ft, continual additional movements of the rudder pedal to and fro were observed and at the same time the ANU was increased to 11.7° and just under 10° respectively (prolonged flare). With an IAS of 106 kt and 103 kt respectively, the aircraft suddenly and severely rolled on its longitudinal axis, which could not be stopped even by an immediate countering aileron deflection, with the result being that the wing tip came into contact with the runway with a bank angle of 11.8° RWD and 8.8° LWD respectively. In both cases, the flight crew could only attribute the rapid movement on the aircraft's longitudinal axis to a furious gust of wind which must have seized the aircraft just above the ground. They regarded the bank angle as not being excessively high and did not notice the wingtip strike that followed.

Over the course of the investigation carried out by the AAIB, the aircraft manufacturer supplemented the FCOM and the e-learning modules for the Global 6000 with guidance on how to conduct landings in crosswind conditions. In particular, this guidance emphasises that the de-crab manoeuvre is initiated only shortly before touchdown using the rudder pedal and that the landing should subsequently take place straight away with zero bank angle.

1.19 Useful or effective investigation techniques

Not applicable

2 Analysis

2.1 Technical aspects

There is no evidence of pre-existing technical faults that could have affected the accident.

2.2 Human and operational aspects

2.2.1 History of the flight

On approach to runway 05 in Geneva, 9H-AMZ's landing mass of 29.0 tonnes was well below the maximum permissible landing mass and the centre of gravity was in a central position. Due to the low landing mass, the reference landing speed (V_{REF}) was relatively low at 116 kt. The configuration for the approach was prepared early and the aircraft was in a stable final approach until initiation of the flare.

At a Radio Altitude (RA) of approximately 100 ft, the Indicated Airspeed (IAS) was 116 kt, which corresponded to the correctly calculated reference landing speed. The PF moved the thrust levers back into the idle position at an RA of approximately 50 ft, which complies with the guidelines in the FCOM and, at an RA of approximately 10 ft, raised the ANU from 5.1° to 7.3° to initiate the landing flare.

Subsequently, 9H-AMZ continued to fly at roughly the same altitude for approximately 4 seconds whilst the PF maintained the pitch attitude at a constant, and then slowly descended further. The IAS continually decreased during this phase to 105 kt, which is considerably below the speed of 111 kt, at which, according to the manufacturer, the aircraft would touch down on the runway if a standard flare had been initiated.

The brief level flight and the resulting low speed indicate that the initiation of the flare was too pronounced, resulting in a prolonged flare. This does not comply with the procedure for a standard landing as described in the FCOM, which states that the pitch attitude should be maintained until in the immediate vicinity of the runway and that subsequently the aircraft should immediately touch down after a partial flare (see chapter 0).

The flight crew had observed that the aircraft was caught by a light updraft shortly after initiating the flare. The increase in pitch attitude during the flare to a maximum of 7.5°, effected by the PF using the elevator, corresponded to a usual figure for a standard landing. In the present case, where the aircraft was also caught by a light updraft after initiating the flare, the increase in pitch attitude was too pronounced, which would subsequently explain the prolonged flare.

In test flights during the certification phase of the Global 6000, the manufacturer had proven that, even at an IAS of 100 kt and with a higher aircraft mass than in the present case, the aircraft retained a good level of controllability on both its longitudinal and vertical axes. The relatively low speed shortly before touchdown can therefore be ruled out as a triggering factor for the further course of the accident.

Immediately above the runway at an RA of 1 ft, 9H-AMZ was suddenly seized by a strong, positive wind shear with a speed of 13 kt. At the same time, the aircraft rolled on its longitudinal axis into a slight right bank angle, which the PF countered with an immediate, appropriate aileron deflection to the left. The crew subsequently noticed that the aircraft was lifted to an RA of approximately 3 ft and that, with a high roll rate, it rolled into a left bank angle whilst yawing slightly to the right at the same time. The PF countered the rolling movement on the aircraft's longitudinal axis with an appropriate vigorous aileron deflection to the right, he was however not able to prevent the tip of the left wing from striking the runway. During the entire flare, there was no indication that the aircraft would be exposed to these sudden, violent rolling movements just before touchdown. It is therefore plausible that the crew was surprised by the sudden increase of the bank angle.

A powerful wind shear such as this cannot be explained by the prevailing wind conditions, with wind speeds measured at a maximum of 4 kt, and therefore caught the flight crew off guard.

The hypothesis that the severe rolling movement on the aircraft's longitudinal axis could be attributed to a local loss of lift on the wings has been discussed using technical analysis. A simulation model of the Global 6000's flight dynamics was used to show that a local loss of lift on the wings could, at most, have only made a small contribution to the severe rolling movement on the aircraft's longitudinal axis. The results of the simulations showed that an additional moment of force caused by external environmental conditions must have affected the aircraft. The calm weather conditions at the time of the accident cannot explain a turbulent and rotating air mass of this kind.

At 13:57:00 UTC, approximately 130 seconds before 9H-AMZ touched down, an Airbus A319 with the flight number EZY32PZ commenced its take-off run from the start of runway 05. The distance from the start of the runway to the point at which rotation was initiated was approximately 1,275 m and approximately 945 m from the displaced runway threshold for landing aircraft (see illustration 1, chapter 1.1.3). The A319 took off at 13:57:41 UTC at a distance of 1,575 m from the start of the runway. With the increase in the angle of attack during rotation, the wingtip vortices at both wingtips increased significantly and reached their maximum at take-off.

About 90 seconds after the A319 had taken off, 9H-AMZ made contact with the runway with the tip of its left wing approximately 800 m after the displaced runway threshold and approximately 145 m before the location at which the A319 had initiated rotation. On runway 05 in Geneva, with a displaced runway threshold of 330 m, the touchdown zone extends to approximately 1,250 m beyond the beginning of the runway. During a landing with a prolonged flare, it is therefore possible that the aircraft only touches down at the end of the touchdown zone, i.e. in that area of the runway in which a departing lead aircraft initiated rotation or even lifted off.

The wind readings along the runway showed conditions with low wind speeds from various directions (see chapter 1.7.4). A thermal release would not explain a sudden wind shear of 13 kt. Therefore, there is strong reason to believe that because of the weak wind, the wingtip vortices from the departing A319 remained present for a prolonged period of time, were able to stay above the runway and shift towards 9H-AMZ's touchdown point. The theoretical and experimental findings of the investigation show that wingtip vortices, particularly in less turbulent conditions, can remain present for several minutes and dissipate only very slowly.

Based on the present findings, the most likely explanation for the accident is that the 9H-AMZ, during its prolonged flare, was caught by the wingtip vortices of the previously departing Airbus A319 and was subjected to a severe rolling movement on its longitudinal axis to the right and shortly afterwards to the left.

The geometry of the Global 6000, with the pronounced sweep of its wings, facilitates a wingtip strike even at a low bank angle, although the aircraft flew with only a slightly increased pitch attitude.

2.2.2 Flight crew

Five months after completing a difference training course that was stipulated due to new avionics, the PIC carried out his first flight in a Global 6000 aircraft on

6th April 2017. He had extensive experience of flying the two other variants of the Bombardier Global family of aircraft, the Global Express and the Global 5000, which can all be flown with the same type rating. On these aircraft he had completed a total of 2,341 flight hours and 656 landings. As the flight characteristics of the different aircraft variants are almost identical, the fact that the PIC was carrying out his first flight in a Global 6000 probably had no influence on the course of the accident.

The FO, who was sat in the right-hand seat during the landing at Geneva as pilot monitoring (PM), had already flown the Global 6000 variant on multiple occasions and in both seats. He had flown 9H-AMZ from the United States to Malta two days before the accident and also carried out three more flights on the morning of 6th April 2016, therefore he possessed sufficient actual training.

2.2.3 Separation minima

Since the aircraft types of the departing A319 and the landing Global 6000 are assigned to the same wake turbulence category MEDIUM (see chapter 1.18.2), no minimum separation regarding wake turbulence had to be observed. The fact that 9H-AMZ must have been affected by the wake turbulence of the recently departed A319 (see chapter 2.2.1) shows that the lack of a minimum separation distance is risky in the prevailing low wind and low turbulence weather conditions. For this reason, safety recommendations were made (see chapter 4.1).

However, the runway separation minima, which primarily serves to prevent collisions, was applied. When 9H-AMZ was touching down, the A319 was already 3 NM beyond the end of runway 05 and 9,100 m beyond runway 05's threshold for landing aircraft. The separation minimum of 2,400 m between a departing category 3 lead aircraft and a landing aircraft following, as stipulated in the Air Traffic Management Manual (ATMM) for Geneva Airport (LSGG), was therefore observed.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The aircraft had the required permissions for IFR traffic.
- At the time of the accident, both the mass and centre of gravity of the aircraft were found to be within the permissible limits of the AFM.
- The investigation did not find any indication of pre-existing technical defects which could have influenced the accident.

3.1.2 Crew

- The flight crew possessed the necessary licences for the flight.
- There is no evidence that the pilots experienced any health problems during the accident.
- The crew worked together in the cockpit in a calm, relaxed and professional manner.

3.1.3 History of the flight

- The business aircraft of type BD-700-1A10 (Global 6000), registered as 9H-AMZ, was in a stable final approach to runway 05 at Geneva Airport (LSGG).
- Around 90 seconds before 9H-AMZ landed, an Airbus A319 had taken off from runway 05 near the junction with TWY D. At this time, 9H-AMZ was around 2.5 NM from the runway threshold.
- At a radio altitude (RA) of 50 ft, the PF moved the thrust levers to the idle position.
- At an RA of 10 ft, the PF increased the pitch attitude for the flare by around 2° to an ANU of 7.3°.
- 9H-AMZ subsequently continued horizontally at the same altitude for 4 seconds, before descending further to an RA of 1 ft.
- At an RA of around 1 ft, the aircraft was caught by a positive wind shear of 13 kt. At the same time, the aircraft rolled into a bank angle of 4.9° RWD, which the PF countered with an immediate aileron deflection of 25° to the left.
- Within the next 2 seconds, 9H-AMZ assumed a bank angle of 12.1° LWD with a high roll rate, which the PF countered by moving the control stick sharply to the right by 59°. At the same time, 9H-AMZ yawed to the right by 4.8°.
- At this moment, the aircraft made contact with the runway with the tip of its left wing, causing slight damage to the outer leading-edge slat.
- Another 2 seconds later, 9H-AMZ touched down on the runway with both the left- and right-hand side main landing gear wheels simultaneously and wings level at the point where the departing A319 had initiated rotation just 90 seconds earlier.
- When 9H-AMZ was touching down, the A319 was already 3 NM beyond the end of runway 05 and 9,100 m beyond runway 05's threshold for landing aircraft.

3.1.4 General conditions

- At the time of landing of 9H-AMZ, light wind weather conditions prevailed.
- In the FCOM for the Global 6000, the chapter on normal landing technique states that the flare should only be initiated partially and only when in the immediate vicinity of the runway for the aircraft to touch down immediately.
- The reduced runway separation minima defined in the Geneva Airport Air Traffic Management Manual (LSGG) was maintained between the A319 and the 9H-AMZ.

3.2 Causes

The accident, in which a business aircraft touched the runway with one wingtip (wingtip strike), can be attributed to a high bank angle during the landing flare. The most probable cause for this high bank angle was found to be wake turbulence from a commercial aircraft that had previously taken off on the runway, which caused the business aircraft to roll around its longitudinal axis.

The accident was caused by the combination of the following factors:

- Light wind weather conditions, which delayed the decay of wingtip vortices;
- A prolonged landing flare near the ground, which led to a touchdown at the end of the landing zone at low airspeed;
- Insufficient distance between the displaced runway threshold and the point of rotation of an aircraft, which had previously taken off.

4 Safety recommendations, safety advice and measures taken since the accident

4.1 Safety recommendations

In accordance with the provisions of Annex 13 of the International Civil Aviation Organisation (ICAO) and Article 17 of Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20th October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC, all safety recommendations listed in this report are intended for the supervisory authority of the competent state, which must decide on the extent to which these recommendations are to be implemented. Nonetheless, any agency, business and individual is invited to strive to improve aviation safety in the spirit of the safety recommendations expressed.

Swiss legislation stipulates the following regulation regarding implementation in the Ordinance on the Safety Investigation of Transport Incidents (OSITI):

"Art. 48 Safety recommendations

1 The STSB shall submit the safety recommendations to the competent federal office and notify the competent department of the recommendations. In the case of urgent safety issues, it shall notify the competent department immediately. It may send comments to the competent department on the implementation reports issued by the federal office.

2 The federal offices shall report to the STSB and the competent department periodically on the implementation of the recommendations or on the reasons why they have decided not to take measures.

3 The competent department may order the competent federal office to implement recommendations."

The STSB shall publish the answers of the relevant federal office or foreign supervisory authorities at http://www.sust.admin.ch to provide an overview of the current implementation status of the relevant safety recommendation.

4.1.1 Risk of wake turbulence on landing

4.1.1.1 Safety deficit

A business jet touched the runway with the tip of one wing during landing (wingtip strike). The most likely cause was wake turbulence from a previous commercial aircraft taking off on the same runway.

It was found that there is no minimum separation requirement for wake turbulence between a preceding departing and a landing aircraft. In addition, there are generally no minimum separation requirements regarding wake turbulence between aircraft of the same weight category. In the case of the MEDIUM weight category, this includes all aircraft with a maximum take-off mass (MTOM) between 7 t and 136 t according to EASA regulations[17].

[17] In Switzerland there is an additional wake turbulence category SMALL for a MTOM between 7,000 kg and 40,000 kg. The MEDIUM category includes a MTOM from more than 40,000 kg to 136,000 kg.

4.1.1.2 Safety recommendation no. 558

The Federal Office of Civil Aviation (FOCA), together with air traffic control and the airport operator of Geneva, should take appropriate measures to reduce the risk of a landing aircraft being endangered by the wake turbulence of a previously departing aircraft.

4.1.1.3 Safety recommendation no. 559

The Federal Office of Civil Aviation (FOCA), together with air traffic control and the operators of all national and regional airports in Switzerland, should review the existing operational procedures regarding the hazard of wake turbulence.

4.1.1.4 Safety recommendation no. 560

The European Union Aviation Safety Agency (EASA) should reconsider and adapt the insufficiently differentiated minimum separation requirements regarding wake turbulence, especially in the case of displaced runway thresholds.

4.2 Safety advice

None

4.3 Measures taken since the accident

The measures taken, which are known to the STSB, are mentioned below without further comment.

The European Organisation for the Safety of Air Navigation (EUROCONTROL), in consultation with its stakeholders, has developed a re-categorisation of the minimum separation level regarding wake turbulence for approaching and departing aircraft. The procedure called RECAT-EU is based on the fact that the assessment of the strength and the spread of wake turbulence of an aircraft takes into account not only its weight but also other characteristics such as flight speed or wing span. In addition, the specific behaviour of an aircraft type when entering wake turbulence is taken into account in the re-categorization.

This leads to a new division into six categories (CAT A "Super Heavy" to CAT F "Light"), in which aircraft types are classified according to their characteristics. This results in a lower minimum separation between certain aircraft types, which leads to an increase in capacity at airports. Conversely, certain minimum separation ratios are increased, which leads to an increase in safety, especially for smaller aircraft types.

RECAT-EU does not stipulate a minimum separation regarding wake turbulence between a previously started and an approaching aircraft.

RECAT-EU is currently used at some European airports such as Paris-CDG (LFPG) or Leipzig-Halle (EDDP).

This final report was approved by the Board of the Swiss Transportation Safety Investigation Board STSB (Art. 10 lit. h of the Ordinance on the Safety Investigation of Transportation Incidents of 17 December 2014.

Bern, 15 September 2020 Investigation Bureau of the STSB

Annexes

Annex 1: DFDR data evaluation