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Swiss Transportation Safety Investigation Board STSB

Final Report No. 2370 by the Swiss Transportation Safety Investigation Board STSB

on the accident involving
the Junkers Ju 52/3m g4e
commercial aircraft, HB-HOT,

operated by Ju-Air,

on 4 August 2018

1.2 km south-west of Piz Segnas,
within the municipality of Flims
(in the canton of Grisons), Switzerland

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Acknowledgement

Observations, photographs and videos provided to the Swiss Transportation Safety Investigation Board (STSB) by citizens during the investigation significantly contributed to the investigation and to the final report that is now available. The STSB would like to thank everyone who spontaneously or upon corresponding request provided information and visual material for the investigation.

The following authorities, organisations and companies have significantly and in an exemplary manner contributed to the success of the investigation:

The *Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile* (BEA)
Zurich Forensic Science Institute (FOR)
The cantonal police of Grisons
The municipality of Flims
Flims Electric AG, Flims (canton of Grisons)
MatExpert GmbH, Thun (canton of Bern)
Mountain Lodge, Segnes pass
Zurich University of Applied Sciences (ZHAW)

General information on this report

In accordance with

Article 3.1 of the 12th edition of annex 13, effective from 5 November 2020, to the Convention on International Civil Aviation of 7 December 1944 which came into force for Switzerland on 4 April 1947, as amended on 18 June 2019 (SR 0.748.0);

Article 24 of the Federal Act on Civil Aviation of 21 December 1948, as amended on 1 January 2020 (CAA, SR 748.0);

Article 1, point 1 of Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC, which came into force for Switzerland on 1 February 2012 pursuant to a decision of the Joint Committee of the Swiss Confederation and the European Union (EU) and based on the agreement of 21 June 1999 on air transport between Switzerland and the EU (Air Transport Agreement); as well as

Article 2, paragraph 1 of the Ordinance of 17 December 2014 on the Safety Investigation of Transportation Incidents, as amended on 1 February 2015 (OSITI, SR 742.161);

The sole purpose of an investigation into an aircraft accident or serious incident is to prevent further accidents or serious incidents from occurring. It is expressly not the purpose of the safety investigation and this report to establish blame or determine liability.

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

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

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

LT = CEST = UTC + 2 h

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

Structure of this final report

This final report, prepared in accordance with the International Civil Aviation Organization's guidelines, consists of a main part and annexes. The report was produced according to the following principles:

- The main part of this report presents in concentrated form the essential elements necessary in order to explain the accident. It is designed to allow the overall context to be understood as simply as possible. In the process, the extensively collected facts were summarised and analysed, and conclusions were drawn.
- The two sections '2 Analysis' and '3 Conclusions' of the main part concisely sum up all of the key information and should enable the accident, its preconditions and the systemic interrelations influencing it to be understood.
- In order to rectify the safety deficits identified, the Swiss Transportation Safety Investigation Board has formulated corresponding safety recommendations and safety advice, which are presented in section 4, 'Safety recommendations, safety advice and measures taken since the accident'.

- The nine annexes are assigned to subsections 1.1 to 1.19 of the main section and provide details of the facts and the investigation methods used. Some of them also include brief evaluations of the facts presented, which are intended to aid the understanding of the accident and increase what can be learnt from it in order to improve safety.
- The majority of the values determined in this final report and its annexes, such as flight altitudes, airspeeds, attitudes, etc., have been rendered as unrounded values, regardless of their individual accuracies. This is not to suggest an increased level of accuracy. Rather, it allows for the values determined to be reproduced and correlated to their corresponding sources. For details including the associated error margins and tolerances, see annex A1.19 (sections A1.19.3, A1.19.4 and A1.19.5.1) and annex A1.18 (section A1.18.5).
- All abbreviations used in this final report as well as key technical terms have been summarised in a glossary.

Contents

Summary

Overview

Owner	Swiss Air Force, P.O. Box 1072, 8600 Dübendorf, Switzerland
Operator	*Verein der Freunde der Schweizerischen Luftwaffe* (Association of the Friends of the Swiss Air Force or VFL), Überlandstrasse 271, 8600 Dübendorf, Switzerland, operated the Ju 52 aeroplanes under the name Ju-Air
Manufacturer	Junkers Flugzeug- und Motorenwerke AG, Dessau, Germany
Aircraft type	Ju 52/3m g4e
Country of registration	Switzerland
Registration	HB-HOT
Location	1.2 km south-west of Piz Segnas, at 2,475 m AMSL
Date and time	4 August 2018, 16:57
Type of operation	Commercial
Flight rules	Visual flight rules (VFR)
Departing from	Locarno Aerodrome (LSZL)
Destination	Dübendorf Air Base (LSMD)
Flight phase	Cruise
Type of accident	Loss of control

Investigation

The accident occurred at 16:57 on 4 August 2018. The STSB officer on duty received the notification at 17:04. In collaboration with the cantonal police of Grisons, the Swiss Transportation Safety Investigation Board (STSB) opened the investigation at 17:55 on 4 August 2018. The STSB informed the following states about the accident: Germany and Austria. Both countries nominated accredited representatives. The French accident investigation authority, the *Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile* (BEA), was invaluable in assisting the STSB to recover and read the data from devices found at the scene of the accident belonging to the passengers and crew members.

The following were available for the investigation:

- Evidence collected at the scene of the accident;
- Radar recordings;
- GPS recordings;
- Images, videos and audio recordings;
- Interviews;
- Documents from the companies involved, supervisory authorities and archives;
- Technical analysis of the aircraft wreckage;
- In-depth analyses and technical reports.

Despite the lack of impact-resistant recording devices in the aircraft, the aforementioned data made it possible to reconstruct the accident.

As the reconstruction of the actual accident flight was complex, investigation activities were initially centred around a detailed analysis of the wreckage in order to gain information on technical factors in relation to the accident or about systemic risks associated with flight operations and maintenance. These examinations uncovered certain systemic safety deficits. The STSB therefore published an interim report containing one safety recommendation and one piece of safety advice on 20 November 2018 in order to improve aviation safety whilst the investigation was still ongoing.

Similarly, the relevant managers within the air operator Ju-Air, the maintenance organisations and the Federal Office of Civil Aviation (FOCA) were informed to the fullest extent in September 2019 about the investigation results available up to that point and the safety deficits identified so that effective measures to improve safety could already be taken prior to or by the time of the final report's publication.

This final report is published by the STSB.

Synopsis

At 16:14 on 4 August 2018, the historic Junkers Ju 52/3m g4e commercial aircraft, registered as HB-HOT and operated by Ju-Air, took off from Locarno Aerodrome for a flight to Dübendorf Air Base. Approximately 40 minutes later, the aircraft entered the basin south-west of Piz Segnas following a north-north-easterly heading. Towards the northern end of the basin, the aircraft began a left turn that developed into a downward spiral trajectory. A few seconds later, the aircraft hit the ground almost vertically. All 20 people on board lost their lives. The aircraft was destroyed.

Causes

Direct cause

The accident is attributable to the fact that after losing control of the aircraft there was insufficient space to regain control, thus the aircraft collided with the terrain.

The investigation identified the following direct causal factors of the accident:

- The flight crew piloted the aircraft in a very high-risk[1] manner by navigating it into a narrow valley at low altitude and with no possibility of an alternative flight path.
- The flight crew chose a dangerously low airspeed as regard to the flight path.

Both factors meant that the turbulence which was to be expected in such circumstances was able to lead not only to a short-term stall with loss of control but also to an unrectifiable situation.

Directly contributory factors

The investigation identified the following factors as directly contributing to the accident:

- The flight crew was accustomed to not complying with recognised rules for safe flight operations and taking high risks.
- The aircraft involved in the accident was operated with a centre of gravity position that was beyond the rear limit. This situation facilitated the loss of control.

[1] The definitions of the terms 'moderate-risk', 'high-risk' and 'very high-risk' with regard to the choice of flight path can be found in sections A1.18.5 and A1.18.4.

Systemic cause

The investigation identified the following systemic cause of the accident:

- The requirements for operating the aircraft in commercial air transport operations with regard to the legal basis applicable at the time of the accident were not met.

Systemically contributory factors

The investigation identified the following factors as systemically contributing to the accident:

- Due to the air operator's inadequate working equipment, it was not possible to calculate the accurate mass and centre of gravity of its Ju 52 aircraft.
- In particular, the air operator's flight crews who were trained as Air Force pilots seemed to be accustomed to systematically failing to comply with generally recognised aviation rules and to taking high risks when flying Ju 52 aircraft.
- The air operator failed to identify or prevent both the deficits and risks which occurred during operations and the frequent violation of rules by its flight crews.
- Numerous incidents, including several serious incidents, were not reported to the competent bodies and authorities. This meant that they were unable to take measures to improve safety.
- The supervisory authority failed to some extent to identify the numerous operational shortcomings and risks or to take effective, corrective action.

Other risks

The investigation identified the following factors to risk, which had no or no demonstrable effect on the occurrence of the accident, but which should nevertheless be eliminated in order to improve aviation safety:

- The aircraft was in poor technical condition.
- The aircraft was no longer able to achieve the originally demonstrated flight performance.
- The maintenance of the air operator's aircraft was not organised in a manner that was conducive to the objective.
- The training of flight crews with regard to the specific requirements for flight operations and crew resource management was inadequate.
- The flight crews had not been familiarised with all critical situations regarding the behaviour of the aircraft in the event of a stall.
- The supervisory authority failed to identify numerous technical shortcomings or to take corrective action.
- The expertise of the individuals employed by the air operator, maintenance companies and the supervisory authority was in parts insufficient.

Safety recommendations and safety advice

The interim report of 20 November 2018 included one safety recommendation and one piece of safety advice. This final report provides seven safety recommendations and six pieces of safety advice.

1 Factual information

1.1 Background and history of the flight

1.1.1 Background

On the morning of 3 August 2018, a two-day tour run by Ju-Air began, taking its passengers from Dübendorf, north of the Alps, to the canton of Ticino on the south side of the Alps. Both the outward flight on Friday and the return flight on Saturday were scheduled to take place on the historic Junkers Ju 52/3m g4e commercial aircraft, registered as HB-HOT, conducted as a commercial air transport (CAT) operation under visual flight rules (VFR). Pilots A and B had been entrusted to perform both flights, alternating their roles as commander, or pilot flying (PF), and co-pilot, or pilot monitoring (PM).

Pilot A prepared the operational flight plan (OFP) using the Ju-Air flight planning software. Determination of mass and centre of gravity (balance) was part of flight preparation. This calculation was incomplete, and was also compromised by further systemic errors. The OFP prepared for the take-off in Dübendorf stated a mass of 9,965 kg and the centre of gravity at 1.99 m behind the leading edge of the wing. The reconstructed value for mass at take-off from Dübendorf was 9,714 kg and the centre of gravity at 2.098 m behind the wing's leading edge. According to the aircraft manufacturer, the aft centre of gravity limit was at 2.060 m behind the wing's leading edge (see annexes A1.1 and A1.6).

After the passengers had arrived and their luggage had been stowed on the aircraft, HB-HOT took off from Dübendorf Air Base (LSMD) at 08:59 for the flight over the Alps to Locarno Aerodrome (LSZL). Seventeen passengers and one flight attendant (ISP), as well as pilot B, acting as the commander and pilot flying, and pilot A, assisting him as the co-pilot and pilot monitoring, were on board.

From Dübendorf, the flight initially passed Wädenswil. It then continued in a southwesterly direction past Mount Rigi and over the Roselaui region (see figure 1). It eventually reached an altitude of approximately 2,990 m AMSL[2]. At 09:37, the flight crew navigated HB-HOT past the Ritzlihorn at a separation of 30 to 50 m from the rock face. The flight continued over the Grimsel pass and through the Cristallina region, passing various parts of the terrain in close proximity. After a descent along the Maggia valley, HB-HOT landed at Locarno Aerodrome at 10:13 (see annex A1.1).

The two pilots had agreed to carry out the flights for the two-day tour only under the proviso that the air operator would pay for their air transfer to northern Switzerland on 3 August 2018 and a return flight to Locarno on 4 August 2018. The Ju-Air management agreed to this condition and so pilot A, who as a flight instructor had begun to familiarise a trainee pilot with the Robin DR400 aircraft on 1 August 2018, took the opportunity offered by this agreement to continue this training. At 09:00 on 3 August 2018, pilot A's trainee pilot therefore took off from Lommis Airfield (LSZT) in north-eastern Switzerland alone on board a single engine Robin DR400/140 B aircraft heading to Locarno, where he landed shortly before HB-HOT arrived.

At 10:52, pilot A's trainee pilot took off, together with pilot A as his flight instructor and pilot B as a passenger, for a VFR flight to Lommis. They landed there at 11:45.

The two HB-HOT pilots spent the rest of the day in northern Switzerland. During this time, the 17 passengers and the flight attendant (ISP), who also acted as the tour guide, completed the ground-based programme of their trip to Ticino.

[2] AMSL: Above mean sea level

The statements from their families suggest that the two pilots had had sufficient sleep and got up at approximately 07:00 on 4 August 2018.

Pilot B then went to Dübendorf Air Base, where he carried out the first of three Ju-Air sightseeing flights on a sister aircraft of HB-HOT at 09:15. These three flights led from Dübendorf to the Alps and back to Dübendorf. On all three flights, the aircraft was piloted by the flight crew in such a way that it flew significantly below the safety margin of at least 1,000 ft AGL (300 m above ground level) in mountainous areas on several occasions. In addition, the crew disregarded essential principles for safe mountain flying. The co-pilot on these flights was not pilot A, but another pilot from the Ju-Air cohort of pilots.

At 13:30, pilot A and the trainee pilot took off in a Robin DR400/140 B aeroplane for the flight from Lommis to Dübendorf, where they landed at 13:42. There, they collected pilot B, who had just completed his third sightseeing flight, and they took off from Dübendorf towards Locarno at 13:55. The route took them southwards over the Alps via Muotathal and the Lukmanier pass, and they flew at an altitude of approximately 9,500 ft AMSL (2,900 m). During the flight, pilots A and B discussed the route for their return flight in HB-HOT. They agreed that the flight time stated in the brief should be used and realised by flying a correspondingly longer route. Pilots A and B were, however, not more specific. The Robin DR400/140 B landed in Locarno at 14:38. Subsequently, pilots A and B went to the aerodrome control office, where – making allowances for the obstacles at the end of the runway and the high air temperature – they arranged for HB-HOT to take off from the concrete runway. The two pilots then prepared the aircraft for their return flight to Dübendorf. At around 15:45, the tour group arrived at Locarno Aerodrome and the pilots stowed the passengers' luggage in various places on the aircraft.

Pilot A had prepared the operational flight plan (OFP) for the return flight the day before. Just like the OFP for the outward flight, this OFP too contained an incomplete calculation for mass and centre of gravity, and was also compromised by further systemic errors.

The OFP prepared for the take-off in Locarno included a mass of 9,737 kg and centre of gravity at 1.98 m behind the wing's leading edge. The reconstructed value for the mass at take-off from Locarno was 9,387 kg and the centre of gravity at 2.077 m. The rearmost permissible centre of gravity is at 2.060 m behind the reference line (see annexes A1.1 and A1.6).

HB-HOT's fuel cells still contained approximately 1,140 litres of fuel, corresponding to a remaining endurance of roughly three hours.

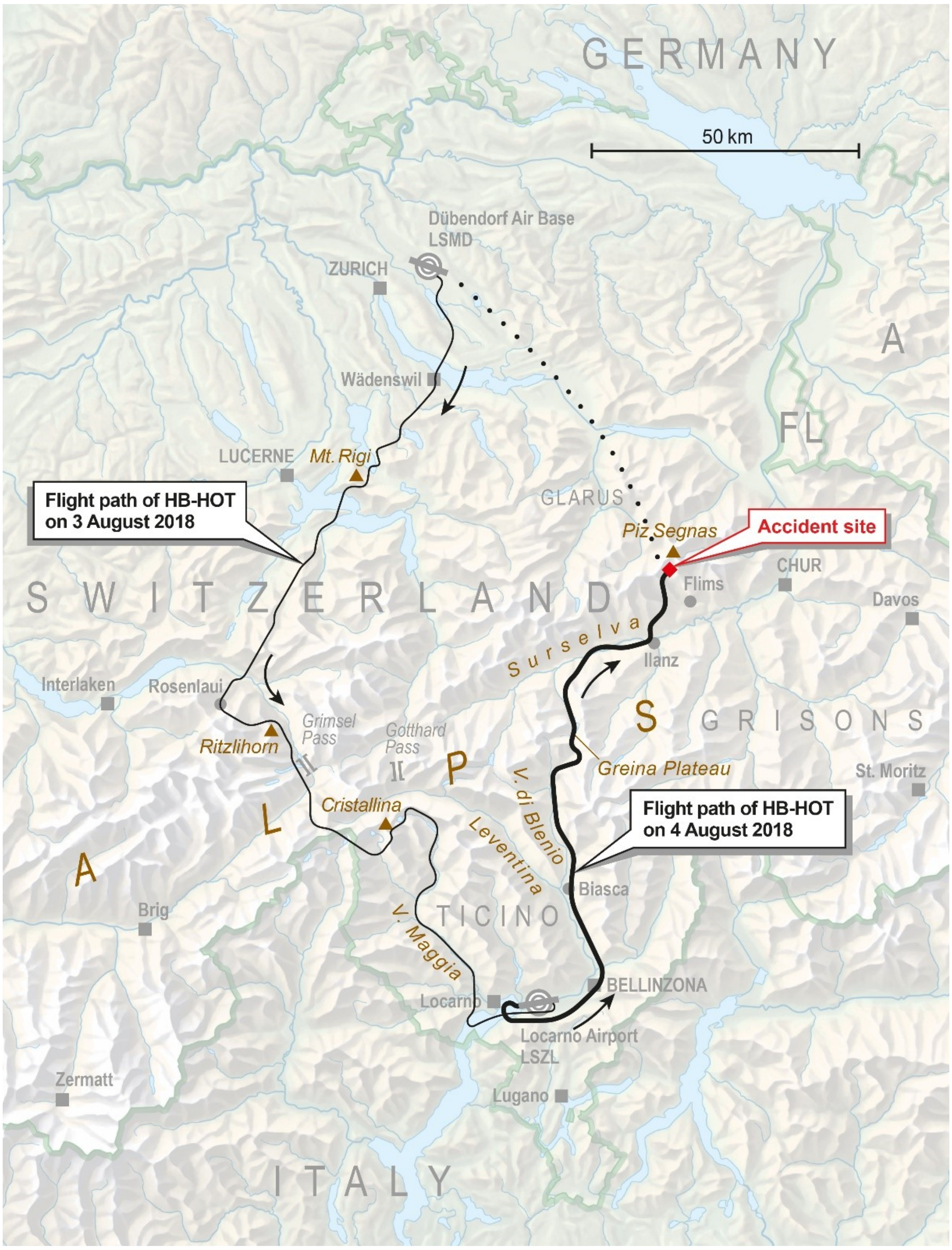

Figure 1: Overview of the flight on 3 August 2018 from Dübendorf Air Base to Locarno Aerodrome and the accident flight on 4 August 2018. Source of the base map: relief map from the Swiss Federal Office of Topography.

1.1.2 History of the flight

At 16:14 on 4 August 2018, the historic Junkers Ju 52/3m g4e commercial aircraft, registered as HB-HOT and operated by Ju-Air, took off from Locarno Aerodrome (LSZL) for a commercial VFR flight to Dübendorf (LSMD). On this flight, pilot A was sitting in the left-hand seat in the cockpit and piloting the aircraft as the commander, while pilot B was assisting him as the co-pilot sitting on the right.

Following take-off from concrete runway 26R westwards and a 180-degree turn over Lake Maggiore, the flight led into the Blenio valley via Bellinzona and Biasca.

HB-HOT steadily gained altitude in the process. North of Olivone, the aircraft turned into the valley of the Lago di Luzzone reservoir and thus into the Adula/Greina/Medels/Vals countryside preservation quiet zone. This zone was crossed at between 120 and 300 m above ground and at times with a minimal lateral separation from the terrain.

At 16:45, as the aircraft was flying over Alp Nadels, the ISP sent a text message to a friend in Ruschein (municipality of Ilanz) to say that the Ju 52 was approaching the area. The flight subsequently continued eastwards into the Surselva region at approximately 2,500 m AMSL. At 16:51, the aircraft crossed the Vorderrhein valley in the region of Ilanz on a north-easterly heading and initially made a relatively tight left turn, taking it over Ruschein. The flight path then led generally northwards past the Crap Sogn Gion mountain and towards the basin south-west of Piz Segnas. At first, the aircraft approached this basin on the left-hand, western side of the valley. HB-HOT was climbing at this time, and reached an altitude of 2,833 m AMSL in the Nagens region.

The aircraft made a slight right turn when flying past the Berghaus Nagens lodge (see figure 2). During this phase, at 16:55, one of the pilots informed the passengers of the scenery over the speakers in the cabin and through the passengers' personal headphones.

To start with, the aircraft was flying at a ground speed of 165 km/h during this phase. By point F2, the ground speed had decreased to 135 km/h, and roughly remained so until shortly before point F3.

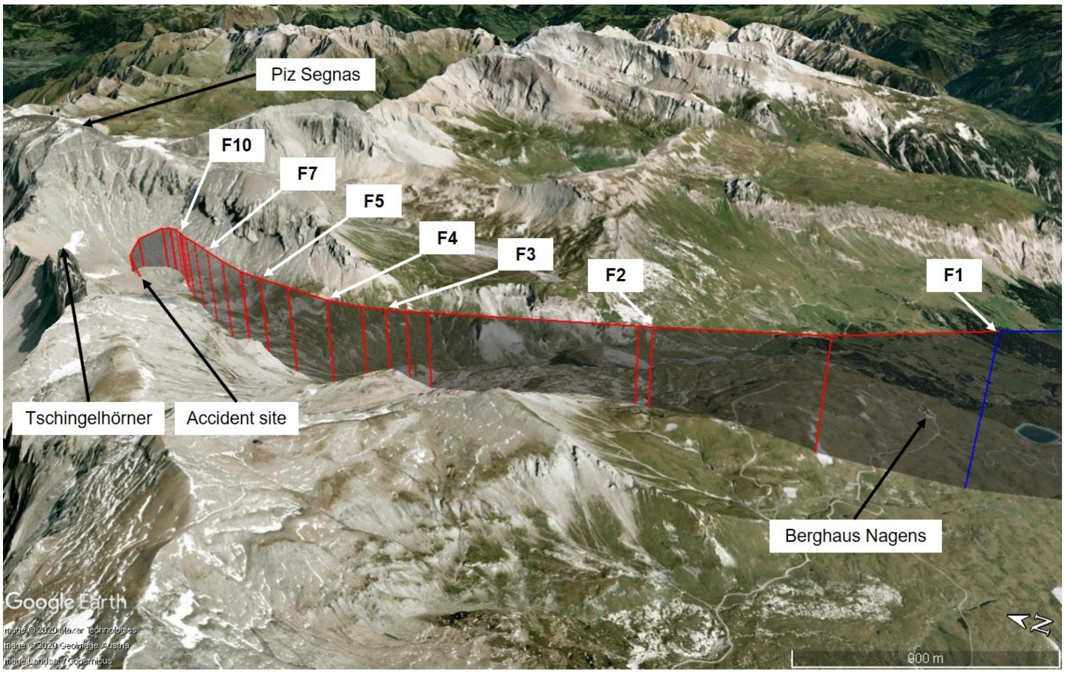

Figure 2: Reconstructed flight path of HB-HOT (red) from the Berghaus Nagens lodge to the site of the accident on 4 August 2018, shown on Google Earth. Point F1 is the first of a total of 29 points determined through photogrammetry. The flight altitude at point F1 was 2,833 m AMSL.

Towards point F3, the aircraft's altitude dropped slightly and the ground speed briefly increased by around 65 km/h to approximately 200 km/h. During this time, its pitch attitude[3] was 5 to 7 degrees. Towards the end of this phase, just before point F4, the flight path angle[4] changed from -3 degrees to approximately -1 degree and the speed of each of the three engines decreased steadily by approximately 20 revolutions per minute (rpm). At point F4, the aircraft was at an altitude of 2,742 m AMSL.

At 16:56:02, shortly after point F4, the speed of each of the three engines increased by approximately 40 rpm. At 16:56:09, HB-HOT entered the basin southwest of Piz Segnas at an altitude of 2,755 m AMSL (point F5, see also figure 14) and was therefore approximately 130 m above the elevation of the Segnes pass. The flight crew then navigated the aircraft on a north-north-easterly heading almost in the centre of the valley. HB-HOT climbed slightly during this phase and its flight path angle was approximately 2 degrees; its pitch angle remained at 5 to 7 degrees. At 16:56:17, the aircraft reached an altitude of 2,767 m AMSL at point F7 and was therefore approximately 140 m above the elevation of the Segnes pass.

HB-HOT flew past the Tschingelhörner mountain peaks and began to reduce in altitude, dropping more than 15 m in approximately 6 seconds. During this phase, the power of the engines was rapidly reduced by 30 to 50 rpm, which meant that the engines were increasingly running at a similar speed[5]. During this process, the pitch angle increased and the flight path angle continuously became more negative.

When the aircraft was approximately abeam the Martinsloch and at an altitude of approximately 2,766 m AMSL (point F8), the flight crew initiated a right turn during their descent and then made a left turn (point F109, see figure 5). The ground speed was approximately 170 km/h and the difference between the aircraft's pitch and flight path angles increased to approximately 15 degrees during the right turn. When transitioning into the left turn (between points F9 and F10), the pitch angle was approximately 11 degrees and the flight path angle was around -10 degrees. At this time, the aircraft was flying at approximately 125 m above the elevation of the Segnes pass (see figure 3).

[3] Pitch attitude, pitch angle, pitch: Angle between the aircraft's longitudinal axis and the horizontal plane in the geodetic coordinate system. Positive values indicate a nose-up attitude, whilst negative values denote a nose-down attitude. See figures 22 and 23 for exemplification and the illustrations in section 1.11.2 for detailed measured values.

[4] Flight path angle (FPA): Angle between the tangent to the flight path and the horizontal plane in the geodetic coordinate system. Negative values correspond to angles below the horizontal plane, i.e. a descending flight path, whilst positive values equate to angles above the horizontal plane, or a climbing trajectory. See figures 22 and 23 for exemplification and the illustrations in section 1.11.2 for detailed measured values.

[5] This course of events is typical when synchronising the speeds of the engines.

Figure 3: Still image from a video at point F10, recorded from the cabin of HB-HOT looking towards the Martinsloch (red arrow). The pitch attitude was 11.0 degrees, the left bank attitude 4.8 degrees and the altitude 2,749 m AMSL. The difference between the flight path angle and the pitch angle was 20.6 degrees.

During roughly the next 4 seconds, the aircraft descended by 25 m and the already negative flight path angle became even more negative, which is clearly apparent when comparing figures 3 and 4 as well as in figure 5.

Figure 4: Still image from a video at point F13, recorded from the cabin of HB-HOT looking towards the Martinsloch (red arrow), 4.3 seconds after the image shown in figure 3 was taken. The pitch attitude was 12.1 degrees, the left bank attitude 32.7 degrees and the altitude 2,724 m AMSL.

After point F13, the roll to the left increased steadily and did not decrease even when a significant aileron deflection to the right was made. The ailerons were then brought into a neutral position and temporarily deflected into a position for a left turn.

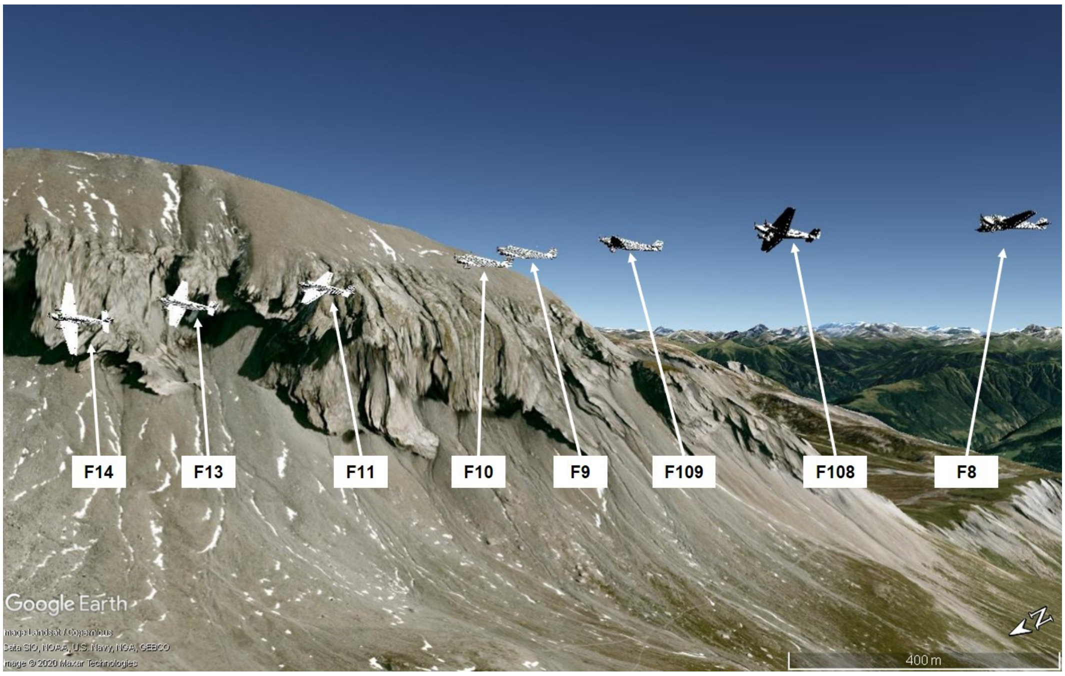

Figure 5: Photogrammetrically reconstructed flight attitude at example positions, shown on Google Earth. The aircraft has been enlarged by a factor of 2 to make it easier to see.

At the same time, the pitch attitude began to decrease and the flight path ran increasingly steeper downwards whilst the left bank attitude constantly increased (see figure 6).

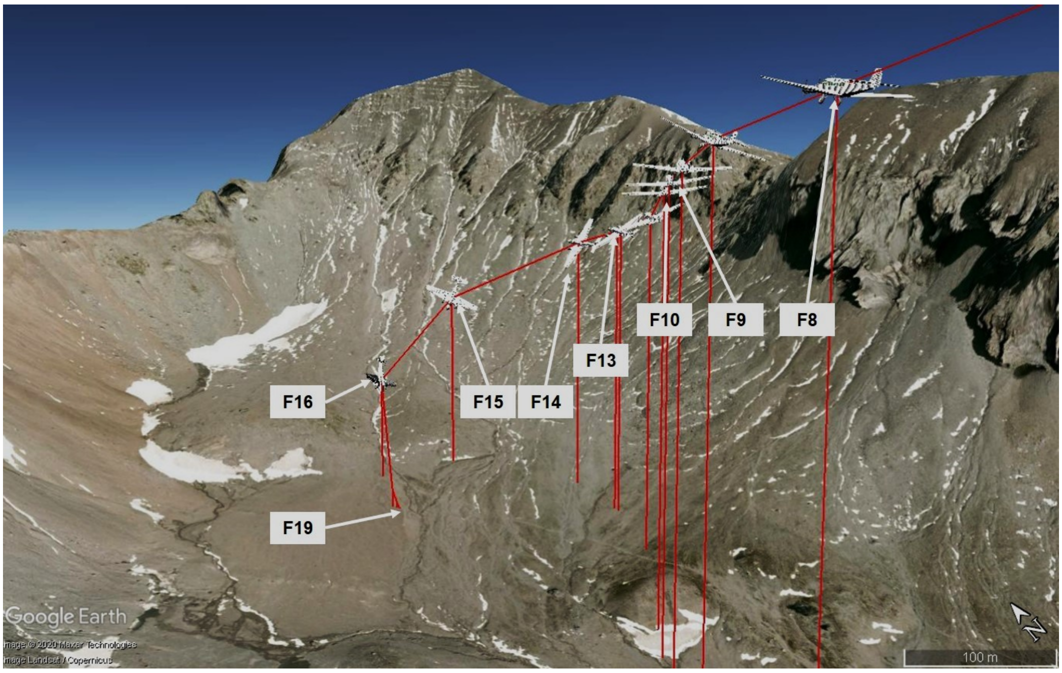

Figure 6: Photogrammetrically reconstructed flight path of HB-HOT on 4 August 2018 (red) between point F8 and the site of the accident (F19), with Piz Segnas in the background; shown on Google Earth. The aircraft has been enlarged by a factor of 2.5 to make it easier to see.

During this last flight phase, the aircraft experienced low-frequency vibrations. Ultimately, when the aircraft was 108 m above ground (point F16, see figures 6 and 7), its longitudinal axis was pointing downwards by 68 degrees from horizontal. By this time, the elevator had deflected upwards by approximately 13 degrees and the rudder was pointing 2 degrees to the right.

Figure 7: Image showing HB-HOT at point F16, including a superimposed three-dimensional model of an identical Ju 53/3m g4e (light blue) for the purpose of determining attitudes, wing deflection and deflections of the control surfaces. The direction of view is north-eastwards, the southern spur of Piz Segnas is visible in the background.

The speeds of the three engines had increased slightly compared to the beginning of the downward spiral trajectory and were between 1,720 and 1,750 rpm shortly before impact.

The roll to the left accelerated significantly during this phase. Shortly after 16:57, the aircraft hit the ground in a vertical flight attitude with an almost vertical flight path and at a speed of approximately 200 km/h (see figure 8).

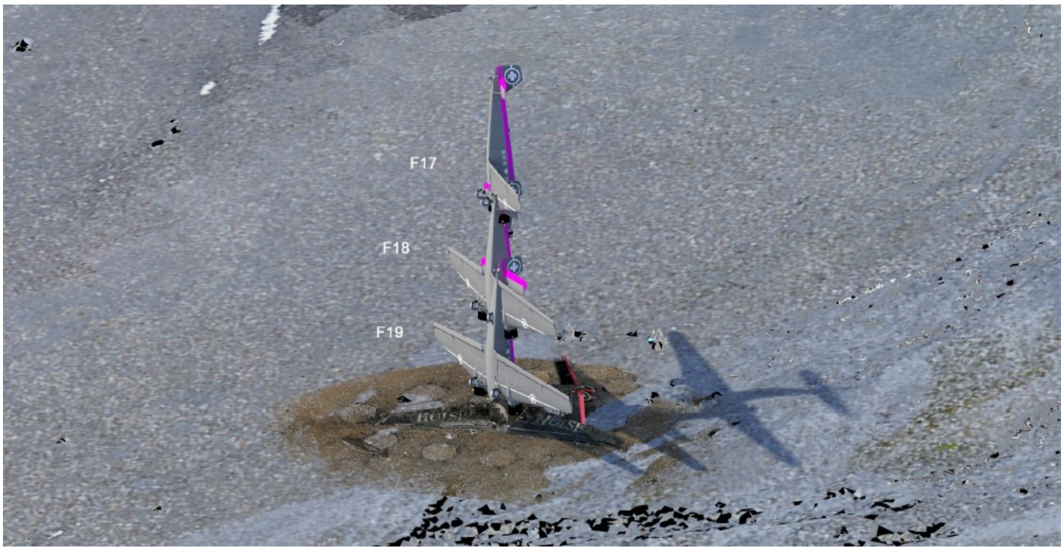

Figure 8: Reconstructed spatial positions and flight attitudes of HB-HOT before impact at points F17, F18 and F19. The three-dimensional model of an identical Ju 52/3m g4e is shown in the reconstructed 3D terrain model with a direction of view to the north. The final position of the wreckage and debris were left vague for a better overview.

All 20 people on board the aircraft lost their lives in the accident. The aircraft was destroyed. Fire did not break out.

Reconstructions revealed that, at the time of the accident, HB-HOT's centre of gravity was at 2.071 m behind the wing's leading edge (see annex A1.6). In the images and video footage available that had been captured from inside HB-HOT, there was no evidence of anyone moving within the aircraft or not sitting in their seat between the period when the aeroplane entered the basin south-west of Piz Segnas and up to the beginning of its downward spiral trajectory.

A detailed description of the reconstruction of the flight path and an illustration of the relevant parameters between position F1 and the site of the accident can be found in section 1.11.2. More information regarding the background and history of the flight can be found in annex A1.1.

1.1.3 Time and location of the accident

Date and time	4 August 2018, 16:57
Light conditions	Day
Coordinates[6]	195 793 / 736 424 (Swiss grid 1903) N 46° 53' 57'' / E 009° 13' 45'' (WGS[7] 84)
Altitude[8]	2,475 m AMSL, equating to 8,120 ft AMSL

1.2 Injuries to persons

Injuries	Crew	Passengers	Total no. of occupants	Others
Fatal	3	17	20	0
Serious	0	0	0	0
Minor	0	0	0	0
None	0	0	0	n/a
Total	3	17	20	0

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

There was minor damage to the terrain.

1.5 Personnel information

1.5.1 Flight crew

1.5.1.1 Pilot A

Person	Male, born 1955
Role on the accident flight	Commander, i.e. pilot flying (PF)
Licence	Airline transport pilot licence aeroplane (ATPL (A)) according to the standards of the European Union Aviation

[6] The coordinates given correspond to the final position of the centre engine and thus approximately to the vertical projection of the spatial centre of all wreckage.

[7] WGS: World geodetic system. The WGS 84 standard was adopted in aviation by a resolution issued by the International Civil Aviation Organization (ICAO) in 1989.

[8] Altitude according to the national map of Switzerland

	Safety Agency (EASA), initially issued by the Federal Office of Civil Aviation (FOCA) on 20 May 1992

Flying experience	Total	20,714 h
	On the accident type	297 h (A)
	During the last 90 days	90:02 h
	On the accident type	42:50 h

(A) Purely flight hours (not including taxiing before and after the flight)

In the last two months prior to the accident flight, pilot A carried out a total of 33 flights on the accident type; 28 of these were with pilot B, who carried out the accident flight with him.

In the months and years prior to the accident flight, various safety-critical flights had been documented on which pilot A had been part of the crew, flying below a safe altitude[9] or taking high risks. Between April 2018 and including the day of the accident, at least six flights have been logged which involved flight paths with a risk score of 8 to 10 (see section A1.18.4); on four of these flights, he was working with pilot B. On 6 July 2018, pilot A acting as commander flew, together with pilot B acting as co-pilot, over Munich in the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, at an altitude considerably below the minimum required level (see section A1.17.1.18.6).

During his last line check on 7 April 2018, pilot A flew significantly below the safety altitudes as specified in the Aeronautical Information Publication (AIP) VFR guide. Furthermore, he disregarded essential principles for safe mountain flying. These principles have been published since 1981 and, at the time of the accident, were listed under RAC 6-3[10] in the AIP VFR guide (see section A1.17.6.2.2). The Ju-Air training captain entrusted to carry out pilot A's line check was, among other things, also a TRI[11] and TRE[12] for Ju 52 aeroplanes. This training captain rated the performance of pilot A as 'standard' to 'high standard'. The choice of flight path was described as *"appropriate"* and *"sensible"*.

Further information on training and relevant events in pilot A's career can be found in annex A1.5.

1.5.1.2 Pilot B

Person	Male, born 1956
Role on the accident flight	Co-pilot, i.e. pilot monitoring (PM)
Licence	Airline transport pilot licence aeroplane (ATPL (A)) according to the standards of the European Union Aviation Safety Agency (EASA), initially issued by the Federal Office of Civil Aviation (FOCA) on 17 September 1992

9 A deliberate choice of words referring to the altitude required for safe piloting. Depending on the situation, this may be the legal minimum required flight altitude or another safe distance from the ground in mountainous areas.

10 At the time this final report was published, these principles were listed under RAC 4-5-2 om the AIP VFR guide.

11 Type rating instructor

12 Type rating examiner – Depending on their needs, air operators or training centres can request for the Federal Office of Civil Aviation to appoint a suitable specialist to act as their examiner. FOCA also refers to these specialists as 'examiners for pilot examinations' or just 'examiners'. Examiners are appointed and trained by FOCA; FOCA also monitors their work. The role of an examiner is to ensure that the assessed pilots meet and maintain nationally and internationally stipulated qualification and training standards.

Flying experience	Total	19,751 h
	On the accident type	945 h [(A)]
	During the last 90 days	60:45 h
	On the accident type	52:17 h

[(A)] Purely flight hours (not including taxiing before and after the flight)

In the last two months prior to the accident flight, pilot B carried out a total of 41 flights on the accident type; 28 of these were with pilot A, who carried out the accident flight with him.

In the months and years prior to the accident flight, various safety-critical flights had been documented on which pilot B had been part of the crew, flying below a safe altitude or taking high risks. Between April 2018 and including the day of the accident, at least eight flights have been logged which involved flight paths with a risk score of 8 to 10 (see section A1.18.4); on four of these flights, he was working with pilot A.

During his last line check on 12 May 2018, pilot B flew significantly below the safety altitudes as specified in the Aeronautical Information Publication (AIP) VFR guide. Furthermore, he disregarded essential principles for safe mountain flying. These principles have been published since 1981 and, at the time of the accident, were listed under RAC 6-3 in the AIP VFR guide (see section A1.17.6.2.2). The Ju-Air training captain who was entrusted to carry out pilot B's line check and also worked as a ground instructor for the air operator, rated the flight as 'high standard'. The choice of flight path was described as *"considerate"* and *"anticipatory"*.

During a climb in sister aircraft HB-HOP on 6 July 2013, pilot B as commander, together with pilot A in the role of co-pilot at the time, entered the basin south-west of Piz Segnas in a similar manner to during the accident flight and flew over the ridge of the Segnes pass at approximately 30 m above ground (see figure 9).

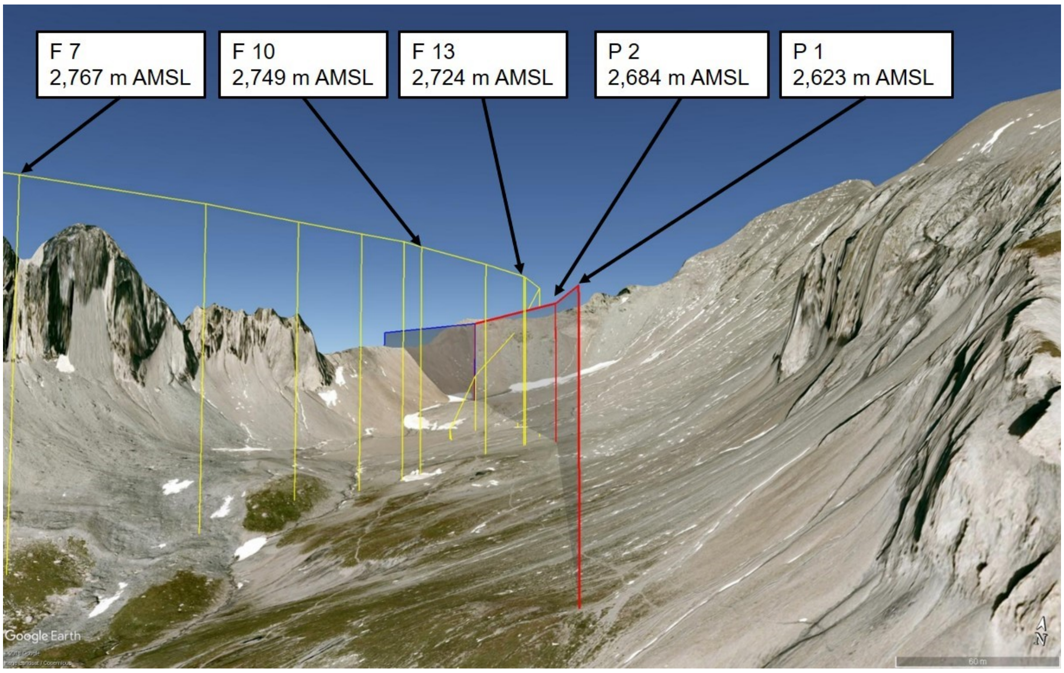

Figure 9: Comparison between the reconstructed flight paths of 6 July 2013 (red, points labelled 'P'), including extension of the flight path (blue), and the accident flight on 4 August 2018 (yellow, points labelled 'F'); shown on Google Earth.

During this flight, a 180-degree turn or an alternative flight path in the northern section of the basin south-west of Piz Segnas would not have been possible.

Further information on training and relevant events in pilot B's career can be found in annex A1.5.

1.5.2 Cabin crew

1.5.2.1 Flight attendant

Person	Female, born 1952
Role on the accident flight	In-flight service personnel (ISP)

1.5.3 Air operator employees

The following employees of air operator Ju-Air were investigated in greater detail with regard to their systemic significance in the development of the accident:

- Accountable manager (ACM);
- Nominated person flight operation (NPFO);
- Nominated person ground operation (NPGO);
- Nominated person continuing airworthiness (NPCA);
- Safety manager (SM) and compliance monitoring manager (CMM)

Information on the roles and qualifications of the air operator's employees is given in annex A1.17.

1.5.4 Employees of the maintenance organisations

The following individuals of the Ju-Air and Naef Flugmotoren AG maintenance organisations were investigated in greater detail with regard to their systemic significance in the development of the accident:

- Ju-Air operations manager;
- Ju-Air aircraft maintenance manager;
- Ju-Air workshop manager;
- Naef Flugmotoren AG technical manager;
- Auditor from the two organisations.

Information on the roles and qualifications of the maintenance organisations' employees is given in annex A1.17.

1.5.5 Federal Office of Civil Aviation employees

The following roles of the Federal Office of Civil Aviation, as the national supervisory authority[13], were investigated in greater detail with regard to their systemic significance in the development of the accident:

- Head of operational supervision;
- Head of technical supervision;

[13] The term 'supervisory authority' refers to the national or supranational authority responsible for issuing operational and technical approvals and for the operational and technical supervision of the relevant companies or organisations.

- Operational inspectors;
- Technical inspectors.

Information on the significance of these roles in this investigated accident can be found in annex A1.17.

1.6 Aircraft information

1.6.1 Historical background

The Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, was built in Germany in 1939 by the state-owned company Junkers Flugzeug- und Motorenwerke AG (JFM) – as were the two identical aircraft HB-HOS and HB-HOP. That year, the Swiss Confederation procured these three aircraft for their air defence corps[14]. HB-HOT was then registered as A-702 and was originally intended as an aircraft for training observers and radio operators. The version procured by Switzerland was equipped with three BMW 132 A3 nine-cylinder radial engines, each designed for a nominal output of 660 PS[15]. The three Ju 52 aircraft were temporarily registered as civilian aircraft for operations abroad. In 1981, the air defence corps decommissioned the three Ju 52/3m g4e aeroplanes. HB-HOT, had accumulated 3,545 operating hours at that time.

The *Verein der Freunde des Museums der Schweizerischen Fliegertruppen* (association of the friends of the Swiss air corps museum, or VFMF) was founded in 1979, first using HB-HOS and HB-HOP for commercial flights starting in 1982, and then also HB-HOT from 1985. HB-HOT was given to the VFMF by the Swiss air defence corps on permanent loan.

The two associations, VFMF and the VF Flab (*Verein der Freunde der Fliegerabwehrtruppen*), merged in 1997 to form a new association, the VFL (*Verein der Freunde der Schweizerischen Luftwaffe*). Its purpose is to preserve Swiss military aircraft and related equipment.

Under the name Ju-Air, the VFL was responsible for flight operations, aircraft maintenance and the continuing airworthiness management organisation (CAMO).

When the air operator began using the type Ju 52/3m g4e aircraft for civil aviation, the manufacturer or type certificate holder had long since ceased to exist.

At the time of the accident, the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, had recorded approximately 10,189 operating hours.

1.6.2 Flight characteristics

The Junkers Ju 52/3m g4e is generally regarded as robust and easy to handle. It has a mass-to-power ratio of 5.3 kg/PS at the maximum take-off mass and nominal power of the three engines. This means the Ju 52 is considered a less powerful aircraft and in this respect is seen as comparable to a Cessna 152 (mass-to-power ratio 6.9 kg/PS) or a Piper Super Cub (mass-to-power ratio 4.5 kg/PS to 5.4 kg/PS).

For climb, the manufacturer's original operating instructions recommend an indicated airspeed of 140 km/h.

According to the aircraft flight manual, the aircraft type's stall speed is an indicated airspeed of 107 km/h under the following conditions:

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[14] The then air defence corps was renamed the Air Force on 1 January 1996.

[15] PS: Metric horsepower, a historical unit of power; 1 PS corresponds to 0.736 kW

- The mass of the aircraft is 9,200 kg;
- All three engines are delivering a power output corresponding to 1,750 rpm;
- The auxiliary wings are retracted.

From this information, it can be calculated that, at an altitude of 2,800 m AMSL and under otherwise identical conditions, the critical angle of attack for a stall in horizontal flight is reached at a true airspeed of 125 km/h.

A manoeuvring speed is not specified in the aircraft flight manual. For an aircraft with a flight mass of 9,200 kg and a normal acceleration of 2.5 G, this can be calculated as an indicated airspeed of 169 km/h. Under the given conditions, this corresponds to a true airspeed of 197 km/h.

According to statements from the air operator's experienced pilots, the flight characteristics of the three sister Junkers Ju 52/3m g4e aircraft, registered as HB-HOP, HB-HOS and HB-HOT, did not differ significantly. When approaching a stall in straight flight, Ju-Air's Ju 52/3m g4e aircraft exhibited slight vibrations (buffeting) before entering into a deep stall. They could be quickly brought back into controlled flight by releasing or gently pushing the elevator control, which reduces the angle of attack. In the event of a stall during a turn, the Junkers Ju 52/3m g4e tended to roll towards the inside of the turn.

1.6.3 Structural features

The structure of the type Ju 52/3m g4e was designed as an all-metal aircraft, featuring an airframe covered in corrugated sheet panelling. The components were mainly manufactured out of aluminium and steel. For the structural parts made of aluminium, the high-strength alloy Duralumin was used. The steel components were mainly welded constructions fabricated in sheet metal.

The components were riveted together, using both Duralumin and steel rivets. All of the components were coated with an anti-corrosion paint. During manufacturing, the sheets for the panelling and profiles were plated on both sides using thin, more corrosion-resistant aluminium alloy.

Duralumin is an alloy of aluminium with copper and magnesium that is high in strength and features good plastic elongation values. The disadvantage of this aluminium alloy is its limited corrosion resistance. However, this can be increased by a suitable and intact protective coating. The material's susceptibility to corrosion is significantly increased under thermal stress.

Further information concerning the structural features, performance data and in particular detailed descriptions of the aircraft systems and engines can be found in annex A1.6.

1.6.4 Certificate of airworthiness and aircraft category

In order for the Ju 52/3m g4e, registered as HB-HOT, to be used for civil commercial air transport, the Federal Office of Civil Aviation (FOCA) issued a national certificate of airworthiness (CofA) on 21 August 1985 that declared compliance with the Convention on International Civil Aviation of 7 December 1944. This certificate of airworthiness classified HB-HOT in the 'Normal' subcategory of the 'Standard' airworthiness category.

After the civil aviation authorities merged to form the joint aviation authorities (JAA), Switzerland was also a member of the JAA until 1 December 2006. HB-HOT's classification remained unchanged during this time.

Since 1 December 2006, Switzerland has been affiliated to the supranational licensing and regulatory authority, the European Aviation Safety Agency (EASA), on the basis of a civil aviation agreement. As a result of this civil aviation agreement, certain European legal standards became binding in Switzerland. According to the then valid Regulation (EU) No. 216/2008[16], Ju-Air's Ju 52 aircraft were among the aircraft listed in annex II, more precisely in categories (a)(ii) ("*aircraft having a clear historical relevance*") and (d) ("*aircraft that have* [formerly] *been in the service of military forces*"). Annex II aircraft were excluded from the scope of certain European regulations. For the operation and equipment, however, the European regulations were applicable. With regard to airworthiness and the corresponding categorisation, the national DETEC[17] Ordinance on the Airworthiness of Aircraft (VLL, SR 748.215.1) formed the applicable legal basis.

The VLL distinguishes between the 'Standard' and 'Special' airworthiness categories. Aircraft in the 'Standard' category must meet the requirements of the EU regulations applicable to Switzerland and are approved for civil aviation through a certificate of airworthiness (CofA).

Aircraft which fail to or do not fully comply with the requirements of the 'Standard' category belong to the 'Special' category. Every aircraft in the 'Special' category is assigned to a subcategory and approved for operation through a permit to fly.

Because Ju-Air's Junkers Ju 52/3m g4e aircraft did not meet the European specifications, they should have been assigned to the 'Special' category, in the 'Historical' subcategory.

However, on 7 June 2007, the Federal Office of Civil Aviation renewed the airworthiness certificate dating from 21 August 1985 for the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT. The aircraft remained in the 'Standard' category and the certificate of airworthiness declared conformity with the Convention on International Civil Aviation of 7 December 1944.

Further information on the background of the aircraft category can be found in annex A1.6.

1.6.5 Maintenance

1.6.5.1 Operating times for the engines

In the operating instructions for the BMW 132 A3 nine-cylinder radial engines installed in Ju-Air's Junkers Ju 52/3m g4e aircraft, the manufacturer of these engines had stipulated that they would require a major overhaul every 200 to 300 operating hours.

Following the transition to civilian operations, the air operator requested approval from the Federal Office of Civil Aviation (FOCA) on several occasions to increase the operating time between major overhauls. FOCA approved a gradual increase in operating time up to 1,500 operating hours.

The available documents concerning the engines fitted in the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, reveal that the approved operating time of 1,500 hours since the last major overhaul has not been reached. Instead, it has been necessary to continuously repair and, in particular, replace important components outside the scope of a major overhaul.

[16] Regulation (EC) No. 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No. 1592/2002 and Directive 2004/36/EC. This regulation was repealed shortly after the accident on 4 August 2018. The succeeding Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 came into force in the EU on 11 September 2018 and in Switzerland on 1 September 2019. Annex I lists aircraft which belong to the 'Special' category in Switzerland. Annex II now describes the essential requirements for airworthiness.

[17] DETEC: Federal Department of the Environment, Transport, Energy and Communications

Further information on the investigation of the engines can be found in annex A1.6.

1.6.5.2 Malfunctions

Numerous engine faults on Ju-Air aircraft were recorded between 2008 and the accident. The investigation revealed that 17 safety-related engine malfunctions or system faults in relation to an engine took place during flight. On each of these occasions, it was necessary to shut down an engine or run it at reduced power. In 14 out of these 17 instances, the flight was aborted. On one occasion, an engine failed completely.

Several cases of pronounced vibrations caused by loose propeller blades occurred during flights between 2012 and 2018. Further information on these can be found in annex A1.6.

Detailed information on these incidents can be found in annex A1.17.

1.6.5.3 Flight performance

The maintenance documents and in particular the records of the test runs and static tests for the engines fitted in the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, prove that at the time of the accident it was no longer possible to achieve the flight performance that was originally demonstrated.

Further information on the aircraft's flight performance can be found in annex A1.6.

1.6.5.4 Spare parts management

Shortly after commencing commercial air operations, Ju-Air began to manufacture spare parts for the engines and the airframe based on pattern parts or had old components reconditioned because such parts had not been available for some time. Not all of the companies that produced or reconditioned such parts had the appropriate certification to provide parts for use in aviation.

As there was no longer a manufacturer of the aircraft type or engines and no type certificate holder, the air operator described the corresponding procedures in 41 service bulletins (SBs) between 1984 and 2001. These were all submitted to and approved by FOCA. In 2005, another, new SB was approved by FOCA. An existing SB was updated in 2018 regarding the processes and subcontractors. Numerous other remanufactured components have, however, still been produced without being accompanied by a service bulletin. The Federal Office of Civil Aviation failed to comment on or challenge this procedure.

Details and examples of spare parts management can be found in annex A1.6.

1.6.5.5 Quality and documentation

The investigation of the HB-HOT wreckage relating to the documentation for the maintenance work carried out revealed numerous deficits. In particular, Ju-Air's aircraft maintenance programme lacked essential information on topics such as partial and major overhauls of the airframe, surface protection and supplemental structural inspection documentation (SSID). The condition of the majority of the parts was checked visually during the respective inspections and replaced, repaired or overhauled as required.

In general, it was difficult to trace the maintenance work performed as well as the modifications and repairs made because the maintenance documentation was flawed, incomplete or kept in an unsystematic manner.

Examples of quality issues and deficits in documentation can be found in annex A1.6.

1.7 Meteorological information

1.7.1 General weather conditions

A front of the Azores high extended over the Alps. There were no pressure differentials on the ground and the vertical stratification of the air mass favoured the formation of cumulus clouds. At the height of the alpine ridge, the wind was from the north-west to north-east. The zero-degree isotherm ranged between approximately 4,400 m AMSL south of the Alps and 4,600 m AMSL in the north.

1.7.2 Weather at the time and location of the accident

The following information on the weather at the time and location of the accident is based on a spatial and chronological interpolation of various pieces of weather information which are detailed in annex A1.7.

In the Grisons and Glarus Alps, the weather was sunny and warm with cumulus clouds, with a base at approximately 10,000 ft AMSL (2,800 to 3,400 m AMSL). Between the Vorab mountain and Piz Segnas, the wind blew from north to north-west at the level of the pass and the initial altitude of the aircraft. Together with the still active thermals, this led to turbulent wind conditions in the basin south of the Segnes pass. At 9,000 ft AMSL (2,750 m AMSL), the air was approximately 13 °C warmer than the ICAO[18] standard atmosphere, which corresponds to a density altitude of 10,100 ft AMSL (3,080 m AMSL).

The archived images of the MeteoSwiss weather radar network show that there were light rain showers approximately 7 km west of the accident site and again 15 to 20 km west of the accident site, in the Linthal area. The cumulus cloud over Piz Segnas and the surrounding area can be seen on the webcam images (see annex A1.7).

Weather/clouds	3/8 to 4/8 cumulus cloud cover with a base at approximately 10,000 ft AMSL (3,000 m AMSL)
Visibility	More than 10 km
Wind	Crap Masegn station[19], from 009 degrees at 16 kt, gusts of up to 26 kt COSMO analysis[20] at flight level when entering the basin, from 340 degrees at 18 kt (± gusts) at a measuring station 3 km south[21], gusts of up to 10 kt from the north at the accident site on the ground[22], from 060 degrees at 17 kt
Temperature / dew point	Crap Masegn station 14.9 °C / 6.7 °C COSMO analysis at flight level 10.5 °C / 7.4 °C

[18] ICAO: International Civil Aviation Organization

[19] Nearest similarly exposed MeteoSwiss measuring station at 2,480 m AMSL (wind at 2,495 m AMSL; temperature and pressure at 2,482 m AMSL)

[20] MeteoSwiss high-resolution weather model

[21] Flims Electric AG measuring station

[22] From analysis of the motion of the dust cloud after impact

Atmospheric pressure	Crap Masegn station, 762.3 hPa (corresponding to a QNH[23] of 1,030.8 hPa)
	COSMO analysis at 2,750 m AMSL, 738.3 hPa
	QNH on the south side of the Alps (LSZL), 1,014 hPa QNH on the north side of the Alps (LSMD), 1,017 hPa
Hazards[24]	*"Isolated showers and thunderstorms, especially over the mountains. Temperature above 30 degrees (note density altitude)"*

1.7.3 Astronomical information

Position of the sun	Azimuth: 252°	Elevation: 39°
Light conditions	Day	

1.7.4 Weather observations by other flight crews

At 16:55 on 4 August 2018 – immediately before the accident involving HB-HOT – a single-engine, two-seater Cessna 152 aeroplane flew over the Segnes pass from the south. A trainee pilot on an alpine familiarisation flight and their flight instructor were on board. The aircraft encountered areas of downdraught in the Flims region and the crew decided to fly along the east side of the basin south-west of Piz Segnas, so that it would have been possible to turn back at any time even if the downdraught continued. At the selected altitude of 9,100 ft AMSL (2,800 m AMSL) the Cessna 152 flew into updraughts, which were interrupted again briefly by a weak area of downdraught just before the Segnes pass. The aircraft could cross the crest of the Segnes pass without any problems. No shear or turbulence was encountered at this altitude (see figure 10 and annex A1.7).

Figure 10: Photograph of the Cessna 152 (red circle) in front of Piz Segnas shortly before crossing the crest to the east of the Segnes pass with the aircraft flying west on 4 August 2018 at 16:55. The cloud over Piz Segnas is the same as that on the webcam images (see annex A1.7). Although it is not possible to ascertain the situation behind the pass based on this photo, the webcam footage from Elm as well as the flight instructor's statement and figure 3 in this report indicate that there was good visibility above and behind the Segnes pass shortly before HB-HOT approached.

[23] QNH: Pressure reduced to sea level, calculated using values of the ICAO standard atmosphere

[24] Quote from the MeteoSwiss aviation weather forecast at 13:00 (see annex A1.7)

1.7.5 Further information and examinations

During this investigation, the weather forecasts valid for the accident flight, statements made by eyewitnesses, webcam footage and satellite images, as well as meteorological radar recordings and weather balloon readings were collected and analysed. In order to reconstruct the flight characteristics and the aerodynamic parameters prevailing at the time of the accident (e.g. angle of attack and true airspeed), the small-scale movements of the air masses in the basin south-west of Piz Segnas were determined as accurately as possible. For this purpose, the air currents at the Segnes pass were simulated using a high-resolution model. Between 17 July and 14 September 2019, measurements were taken in the area surrounding the accident site in order to validate and quantify the regularity and extent of the effects calculated during this process. A traditional weather station determined the wind, temperature and humidity on the ridge next to the Segnes pass. From a measuring point in the basin, a lidar[25] system recorded the three-dimensional flow conditions. Particular focus was placed on the typical vertical wind distribution in the area of the flight path shortly before the aircraft began its downward spiral trajectory. Further information on these analyses and the related measurements can be found in annex A1.7.

1.8 Aids to navigation

Not applicable

1.9 Communications

Radio communication between the flight crew of HB-HOT and the air traffic control authorities contacted was handled without any discernible difficulties until the aircraft left the frequency of Locarno Tower at 16:22 on 4 August 2018. At no time during the 2018 tour was HB-HOT in radio contact with the flight information service Zurich Information.

1.10 Aerodrome information

Locarno Aerodrome is located at an altitude of 650 ft AMSL or 198 m AMSL and is jointly used and operated by the Swiss Air Force and civil aviation. It has two grass runways (08C/26C and 08R/26L), each measuring 700 m x 30 m. There is also a concrete runway (08L/26R), which measures 800 m x 23 m. The take-off run available on runway 26R, which was used by HB-HOT, is 670 m.

Skyguide provides air traffic control services (ATS) during Air Force operating hours and when required by civil air traffic operations. The aerodrome control tower was manned at the time of HB-HOT's departure on 4 August 2018.

1.11 Flight recorders and recorded information

1.11.1 Reconstruction of the flight path

1.11.1.1 Procedure

As the historic Junkers Ju 52/3m g4e commercial aircraft, registered as HB-HOT, involved in the accident was not equipped with any recording devices, the flight paths for the outward flight to Locarno on 3 August 2018 and the accident flight on 4 August 2018 had to be based on other data sources:

[25] Lidar: Laser detection and ranging – a measuring system that emits laser pulses and evaluates the backscattered light from the atmosphere, in this case with regard to the Doppler effect. In this investigation, it was used for the three-dimensional measurement of wind above the site.

- Large sections of HB-HOT's flight paths were reconstructed using radar data from a multi-radar tracker (MRT) or from individual radar stations.
- A wide range of images and video footage as well as statements from numerous eyewitnesses, who were watching HB-HOT from the ground, were evaluated.
- In addition, 44 electronic devices including mobile phones and video cameras belonging to the passengers and crew members were secured at the scene of the accident. Some of these recording devices had been severely damaged in the accident. Ultimately, the data from ten of these data storage units could be read and recovered.

In order to determine the positions of the aircraft in space, its attitude in relation to three axes and its speed relative to the ground, complex photogrammetric evaluations were carried out, especially for the decisive flight phase before the accident.

The methodology of the evaluation used for the reconstruction of flight paths and photogrammetric analysis is described in annex A1.19.

1.11.1.2 Flight phase from the Vorderrhein valley to the Segnes pass

Based on the height-corrected MRT data points (blue dots in figures 11 and 12), HB-HOT flew past the mountain station on Crap Sogn Gion (2,215 m AMSL, see figure 12) at 16:54 on 4 August 2018. The aircraft had a flight altitude of approximately 2,740 m AMSL and was following a slight left turn. At the first photogrammetric point, F1[26], HB-HOT was at an altitude of 2,833 m AMSL on a true track (TT) of 335 degrees (see figure 12). The ground speed (GS) calculated by the MRT a few seconds before point F1 was 94 kt (corresponding to 48.4 m/s, or 174.1 km/h).

[26] The photogrammetrically determined points are marked with the letter 'F' and numbered in the report.

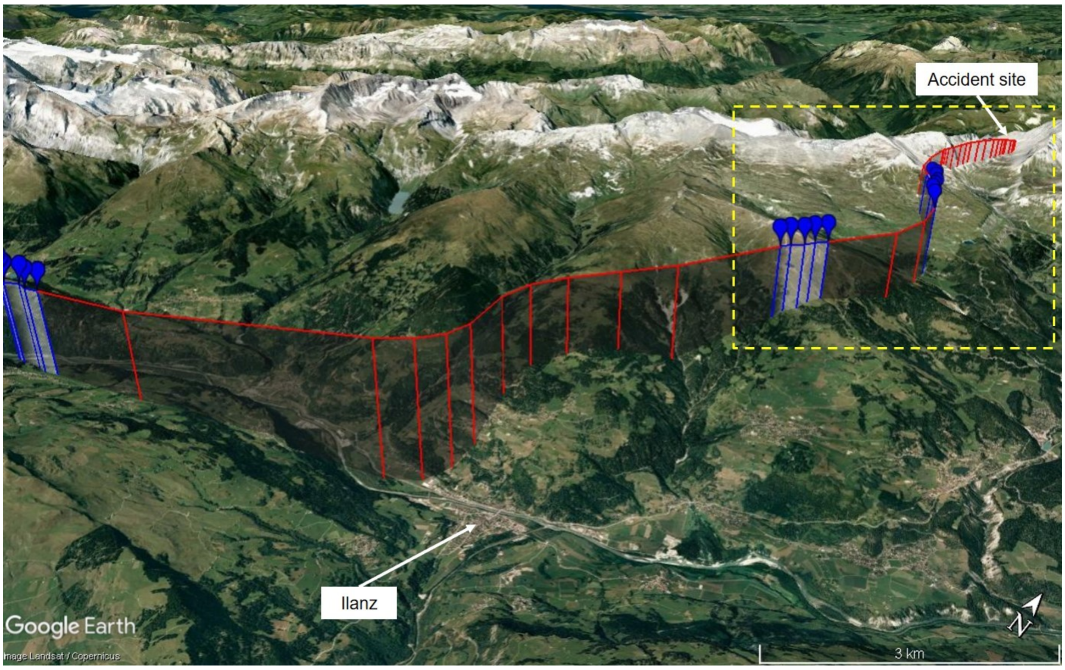

Figure 11: Reconstructed flight path of HB-HOT on 4 August 2018 near Ilanz (canton of Grisons) and leading up to the location of the accident with height-corrected MRT data points (blue), flight path sections reconstructed from witness statements and image material as well as photogrammetrically determined flight path sections (red), plotted on Google Earth. The area shown below in figure 12 is marked by the yellow dashed rectangle.

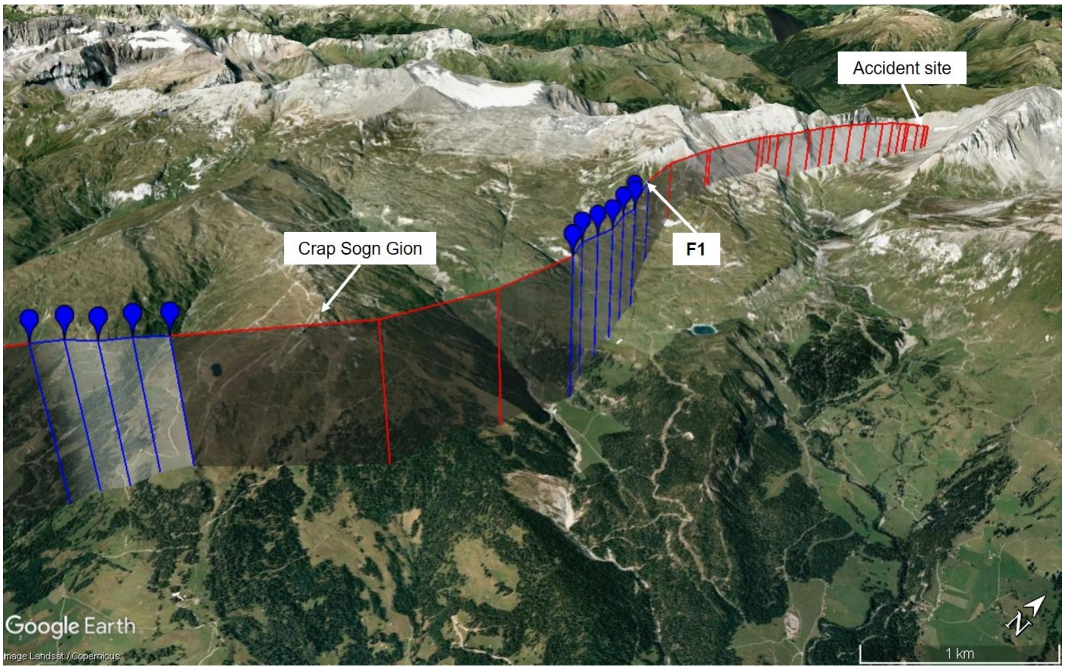

Figure 12: Reconstructed flight path of HB-HOT on 4 August 2018, shown on Google Earth. F1 denotes the first photogrammetrically determined point.

1.11.1.3 Flight phase in the section of terrain leading up to the Segnes pass

In order to reconstruct the last section of the flight path before the location of the accident, images and video footage from eyewitnesses who had been watching the aircraft from the ground as well as two videos recorded by passengers were used. There is a time gap between the two videos recorded from HB-HOT's cabin.

The first video recording ends shortly after point F101 and the second begins at point F102 (see figure 13).

During the gap in the recordings between points F101 and F102, radar data from HB-HOT's transponder were received. In addition to the usual data, on two occasions at known times, the mode-S transponder transmitted precise figures computed by the connected GPS device. This transmitted data included the true track (TT) and the GPS ground speed (GS). The relayed altitude was generated by the transponder's pressure probe. The GPS position itself was not transmitted. A radar station in a geometrically unfavourable location recorded the position of the aircraft when it transmitted these two data packets. However, the position could not be used as it was not sufficiently accurate. The transmitted values regarding time, TT and GS, on the other hand, are exact and were therefore used. Thus, two additional data packets containing time, TT and GS are available for this area:

- 14:55:34 UTC: TT = 353 degrees, GS = 74 kt (38.0 m/s or 137.0 km/h);
- 14:55:39 UTC: TT = 354 degrees, GS = 76 kt (39.1 m/s or 140.8 km/h).

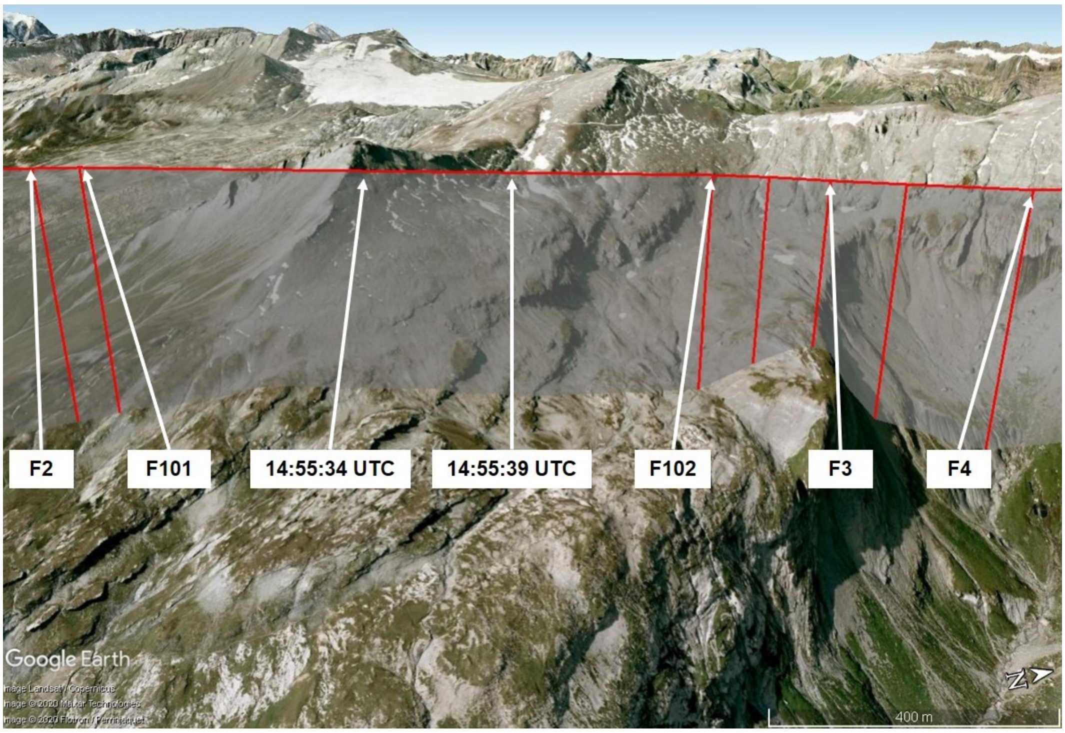

Figure 13: Photogrammetrically reconstructed flight path of HB-HOT on 4 August 2018 (red) between points F2 and F4, shown on Google Earth. The two additional data packets at 14:55:34 UTC and 14:55:39 UTC were transmitted by the transponder.

Later in the flight, the aircraft's GPS data were transmitted a third and final time just before point F10 with the following values:

- 14:56:27 UTC: TT = 43.4 degrees, GS = 92 kt (47.3 m/s or 170.4 km/h).

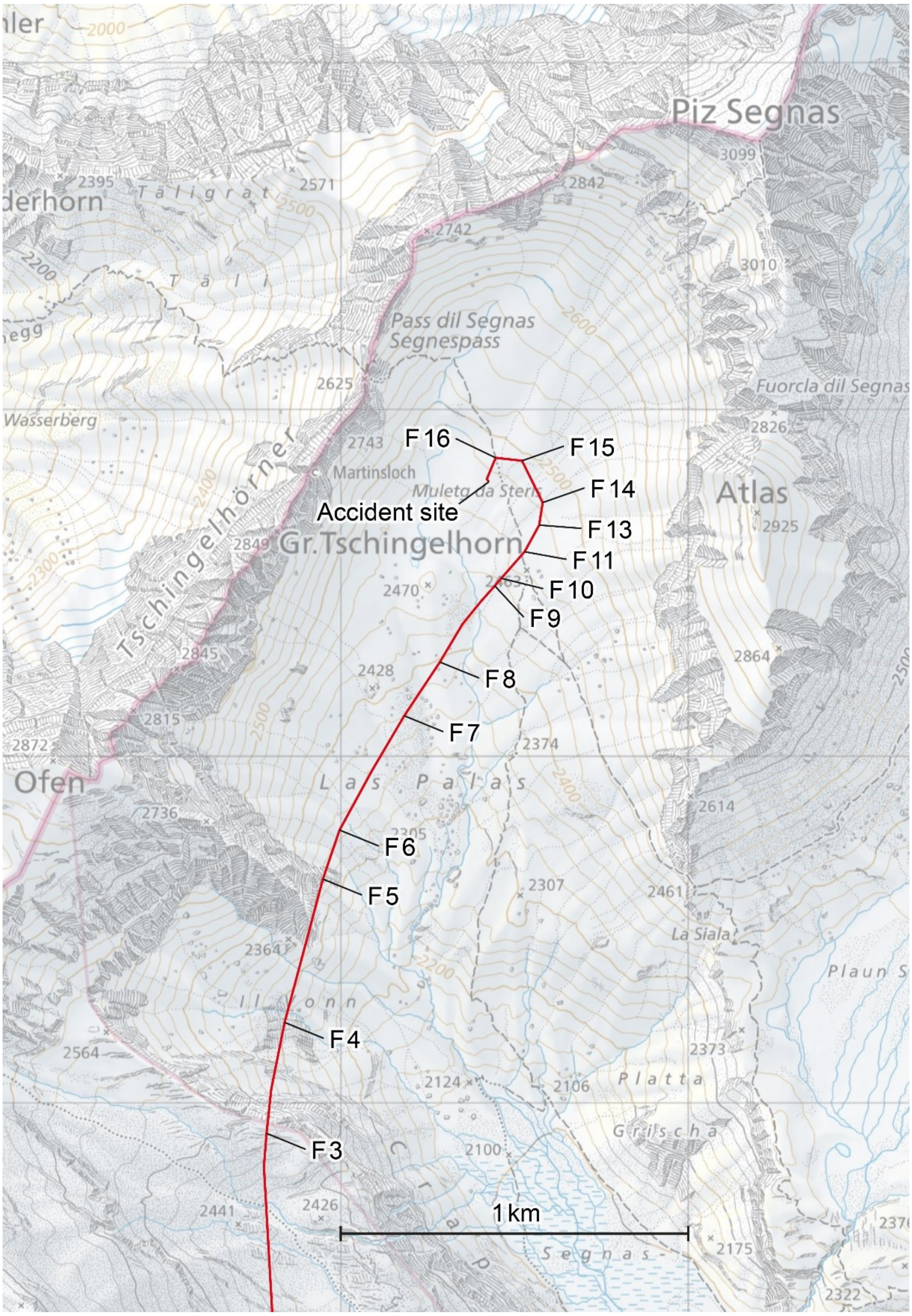

Figure 14: Reconstructed flight path of HB-HOT on 4 August 2018 (red) between point F3 and the site of the accident. Source of the base map: Swiss Federal Office of Topography.

1.11.1.4 Final flight phase

An eyewitness photographed HB-HOT during its final flight phase. The high-resolution image was photogrammetrically analysed. The evaluation ascertained the spatial position and flight attitude at point F16 (see figure 7) as well as the following parameters:

- The pitch attitude was 68.0 degrees, nose down;
- There was a bank attitude of 50.8 degrees to the left;
- The flight altitude was 2,583 m AMSL, which is approximately 108 m above the elevation of the accident site (2,475 m AMSL);
- The elevator was pointing upwards with a deflection of approximately 13 degrees at this time; this is half of the maximum possible deflection;
- The rudder had deflected by 2 degrees to the right;
- In relation to its initial position when the aircraft is on the ground, the wing deflection was 0.6 degrees upwards; a comparative value from a recording in unaccelerated horizontal flight showed a wing deflection of about 1.2 degrees upwards in relation to its initial position.

HB-HOT's impact was captured on video by an eyewitness who was on the Segnes pass. The video shows HB-HOT's final 0.4 seconds before the impact in single frames. These images were used to determine spatial positions and flight attitudes F17 to F19 (see figure 8). The impact occurred at a height of 2,475 m AMSL with a nose-down attitude of 84.2 degrees and whilst rolling to the left. The impact speed determined using this video sequence was approximately 55.7 m/s (200 km/h). Due to the distance between the location from which the video was recorded and the location of the impact, audio was available for the last 1.6 seconds before the impact.

1.11.2 Numerical evaluations

The numerical evaluations are based on data determined through photogrammetry, in particular the positions and attitudes of the aircraft in space. The following pieces of additional data were used to assess the flight phase from the accident flight in which the aircraft entered the section of terrain surrounding the Segnes pass:

- Results of the meteorological evaluations, in particular the wind speeds and wind directions at flight altitude as well as the vertical wind speeds;
- Evaluation (sonograms) of acoustic data from a video filmed from inside the aircraft carried out by the French safety investigation authority, the *Bureau d'Enquètes et d'Analyses pour la Sécurité de l'Aviation Civile* (BEA);
- Visual assessment of the aileron deflection carried out by the STSB based on video footage recorded from inside the aircraft.

The numerical evaluation of a total of 29 data points determined for the flight phase of the accident flight in which the aircraft entered the section of terrain surrounding the Segnes pass is based on these four sources of data. From this, figures 15 to 20 were created, which represent the key parameters relating to the flight path and time.

Figure 15 shows the altitude, pitch and flight path angles as well as the difference between these two angles.

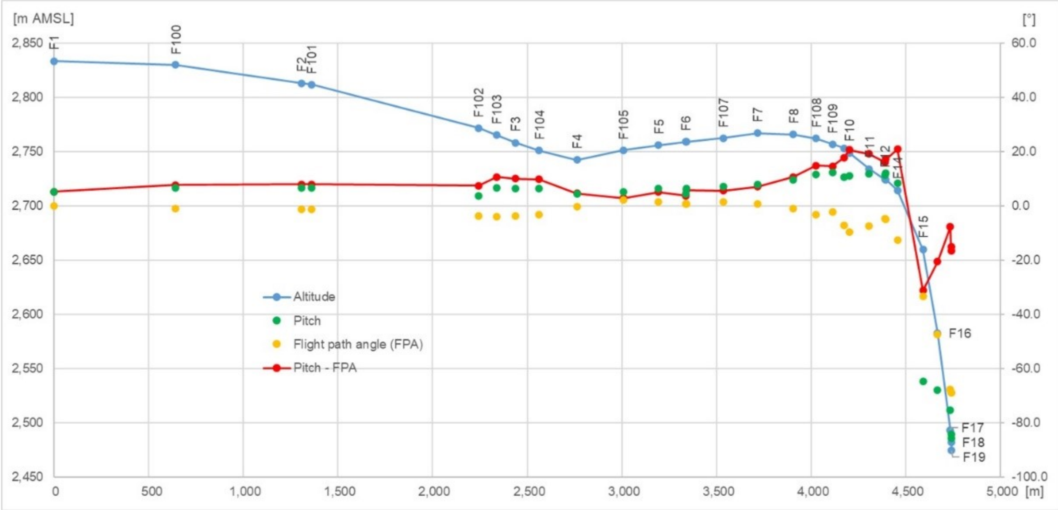

Figure 15: Altitude, pitch and flight path angle (FPA) in relation to of the horizontal distance travelled. The left-hand y-axis shows the values for altitude and the right-hand y-axis shows the values for the angles.

The parameters in figure 16 are shown in relation to the runtime of the video footage. F102 is the first point determined using this video. This is shown in figure 15 at a horizontal distance of 2,243 m. There are other points which have been determined from other data sources (e.g. F6 between points F5 and F106) between the unconnected points in figure 16. They are not illustrated as no runtime can be assigned to them.

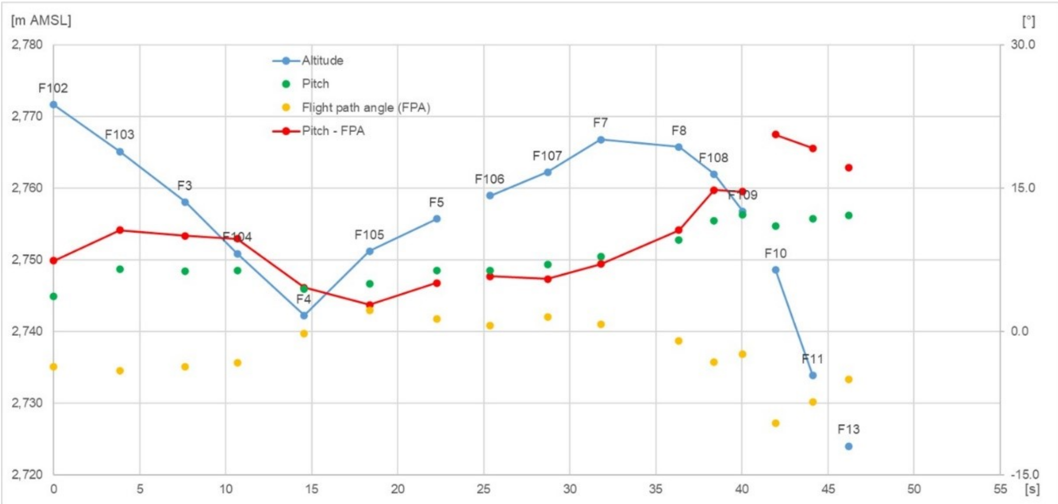

Figure 16: Altitude, pitch and flight path angle in relation to the video runtime. The left-hand y-axis shows the values for altitude and the right-hand y-axis shows the values for the angles.

Figure 17 shows the calculated course of the ground speed (GS). The three values for the GS received from HB-HOT's transponder were also considered.

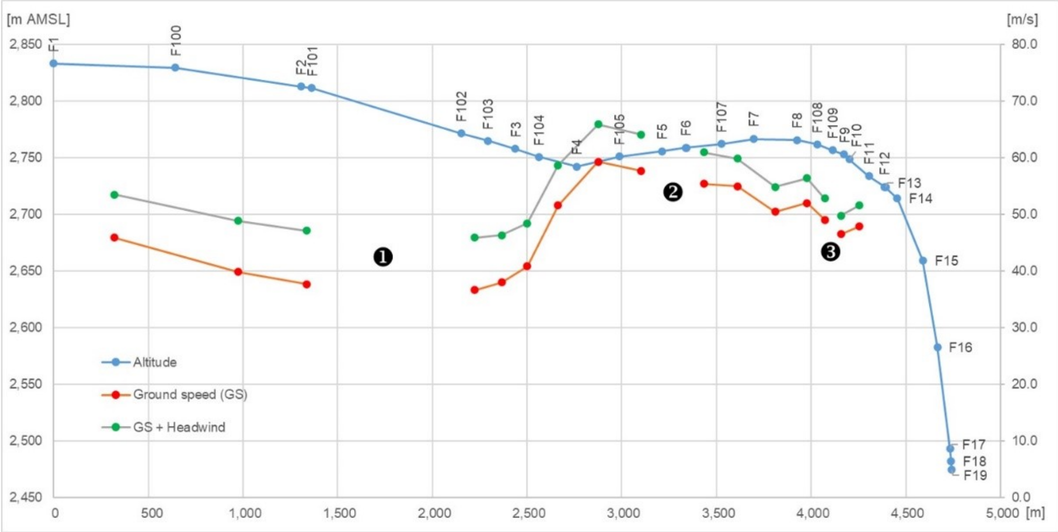

Figure 17: Altitude, calculated ground speed and ground speed + headwind in relation to the accumulated horizontal distance.

In area ❶ (see figure 17) where the ground speed graph is interrupted, no time difference – and thus no ground speed – could be calculated, because the data points were determined using two different, unconnected videos. For the other gaps (areas ❷ and ❸), the points have been determined from other data sources. They are not shown as no runtime can be assigned to them.

Figure 18 shows the course of the three engine speeds in relation to the video runtime. It was not possible to assign the speeds of engines A, B and C to the position of the engines (left, centre, right).

In addition to the pitch and FPA, figure 19 also shows the rate of ascent and descent in relation to the video runtime.

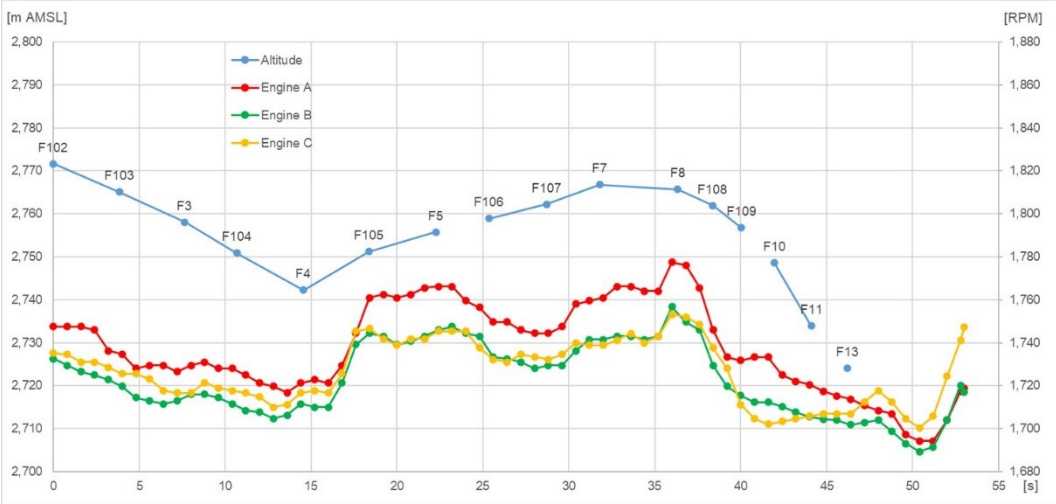

Figure 18: Altitude and engine speed in relation to the video runtime.

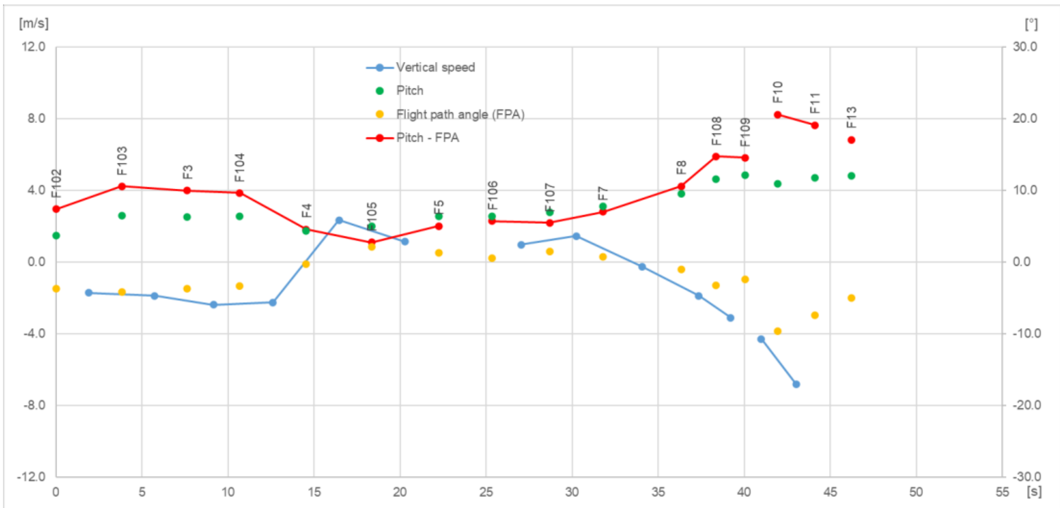

Figure 19: Vertical speed, pitch and flight path angle in relation to the video runtime.

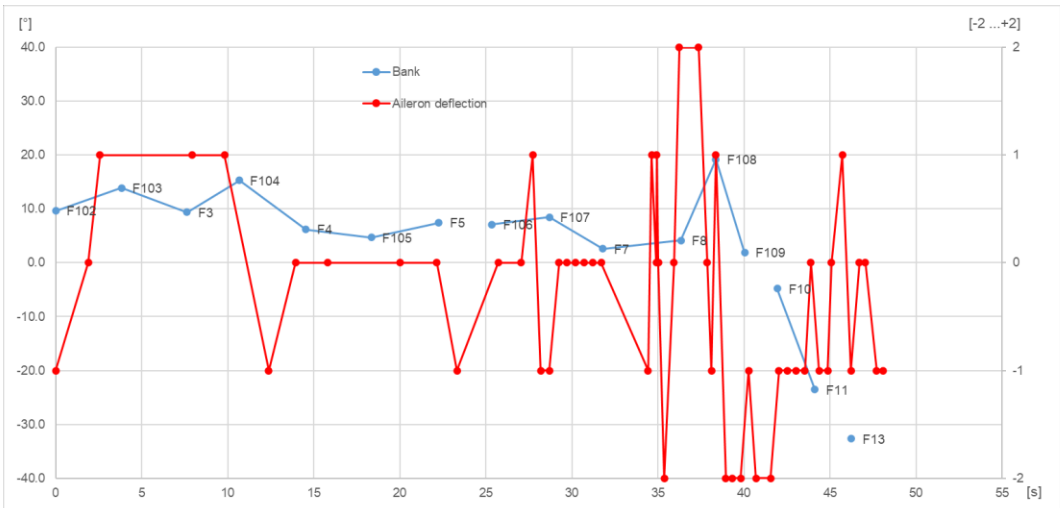

Figure 20: Bank and aileron deflection in relation to the video runtime. Positive values on the y-axis indicate bank to the right and aileron deflections for a right turn respectively. The bank angles were determined photogrammetrically.

The aileron deflections were qualitatively evaluated with values of - 2, - 1, 0, + 1 and + 2 (figure 20, right-hand y-axis) based on a video recorded from inside the aircraft. Positive values indicate an aileron deflection for a clockwise roll as seen in the direction of flight, i.e. for a right turn, whilst negative values indicate an aileron deflection for a left turn and a value of zero means the aileron position was neutral.

1.11.3 Lack of flight data recorders

The historic Junkers Ju 52/3m g4e commercial aircraft, registered as HB-HOT, involved in the accident was not equipped with any recording devices. Due to the stipulations in place when the aircraft's certificate of airworthiness was first issued, HB-HOT was not required to be fitted with a flight data recorder (FDR). A cockpit voice recorder (CVR), on the other hand, would have been required for commercial air transport operations. However, the Federal Office of Civil Aviation had granted an exemption, meaning that the air operator did not install such a device (see annex A1.6).

Thus, the investigation could not draw on data from an impact-resistant FDR. When investigating an incident involving a large aircraft, such a recorder would usually allow the flight path to be reconstructed and the positions of the aircraft in space and in relation to the air flow as well as the true airspeed and ground speed of the aircraft to be determined. There was also no CVR. Such a device could have provided information about the crew's conversations, the way they worked together and, if necessary, the nature of the problems that ultimately led to the accident.

As a result, the reconstruction of the flight path and the course of the accident was very complex and time-consuming. In addition, background information that would have been important to investigating the accident, specifically the conversations in the cockpit, which might have allowed conclusions to be drawn about decisive thought processes relating to the pilots entering the basin south-west of Piz Segnas, could not be determined even despite the use of these complex reconstruction procedures.

In the past, a lack of recorded data has often made it impossible to clarify accidents that occurred during commercial flight operations. As a result, safety investigation authorities have made recommendations on various occasions concerning equipping aircraft with recording devices of all types.

AAIB[27] safety recommendation 2005-101 (2005): *"The European Aviation Safety Agency[28] should promote the safety benefits of fitting, as a minimum, cockpit voice recording equipment to all aircraft operated for the purpose of commercial air transport, regardless of weight or age."*

TSB[29] safety recommendation A13-01: *"The Department of Transport* [should] *work with industry to remove obstacles to and develop recommended practices for the implementation of flight data monitoring and the installation of lightweight flight recording systems by commercial operators not currently required to carry these systems."*

TSB safety recommendation A91-13: *"The Department of Transport* [should] *expedite legislation for upgrading the flight recorder requirements for Canadian-registered aircraft."*

[27] AAIB: Air Accidents Investigation Branch of the United Kingdom

[28] The European Aviation Safety Agency was renamed to European Union Aviation Safety Agency (EASA) in 2018

[29] TSB: Transportation Safety Board of Canada

NTSB[30] safety recommendation A-06-017, addressed to the Federal Aviation Administration: *"Require all rotorcraft operating under 14 Code of Federal Regulations Parts 91 and 135 with a transport-category certification to be equipped with a cockpit voice recorder (CVR) and a flight data recorder (FDR). For those transport-category rotorcraft manufactured before October 11, 1991, require a CVR and an FDR or an onboard cockpit image recorder with the capability of recording cockpit audio, crew communications, and aircraft parametric data."*

In 2017, EASA published notice of proposed amendment (NPA) 2017-03, 'In-flight recording for light aircraft', as part of some legislative procedures (RMT[31].0271 (formerly MDM[32].073(a)) & RMT.0272 (formerly MDM.073(b)).

"This Notice of Proposed Amendment (NPA) addresses safety and regulatory harmonisation issues related to the need of in-flight recordings for accident investigation and accident prevention purposes. 12 safety recommendations were addressed to the European Aviation Safety Agency (EASA) by 7 safety investigation authorities, recommending an in-flight recording capability for light aircraft models which are outside the scope of the current flight recorder carriage requirements. In addition, new Standards (recently introduced in ICAO Annex 6) require the carriage of lightweight flight recorders for light aeroplanes and light helicopters. [...] *This NPA proposes to mandate the carriage of lightweight flight recorders for some categories of light aeroplanes and light helicopters when they are commercially operated and manufactured 3 years after the date of application of the amending regulation. In addition, this NPA proposes to promote the voluntary installation of in-flight recording equipment for all other light aeroplanes and light helicopters and for all balloons. The proposed changes are expected to increase safety with limited economic and social impacts."*

The necessary technical solutions exist today. This is also why the STSB believes that the legal requirements for equipping aircraft with flight data recorders, cockpit voice recorders or cockpit image recording systems should apply to historic commercial aircraft, which was not the case at the time of the accident. An exception, such as the one granted for Ju-Air's aircraft, does not constitute a safety-conscious solution.

1.11.4 Safety recommendation

In view of the safety recommendations that have already been made on a number of occasions and the planned changes to aviation law concerning the obligation to equip aircraft with flight recorders, the STSB is refraining from making any further safety recommendations that would aim to achieve a similar goal.

1.12 Wreckage and impact information

1.12.1 Accident site

The accident site was located in a basin approximately 1.2 km south-west of Piz Segnas in the canton of Grisons. The Martinsloch, a natural rock window in the Tschingelhörner range of mountain peaks, is located approximately 500 m west of the accident site, south-east of Elm (canton of Glarus).

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[30] NTSB: National Transportation Safety Board of the United States of America

[31] RMT: Rule-making tasks

[32] MDM: Multi-disciplinary measures

1.12.2 Impact

All evidence at the scene of the accident indicates that the aircraft hit the ground in a vertical flight attitude with an almost vertical flight path. These findings were confirmed by video footage.

1.12.3 Wreckage

All essential components of the aircraft could be identified at the scene of the accident. Numerous items of luggage, some of which were heavy, were found. The wreckage was cleaned, sorted according to its components and then subjected to separate detailed examinations. Further information on the above can be found in annex A1.12.

1.13 Medical and pathological information

Both pilots suffered immediate fatal injuries on impact.

The bodies of pilots A and B underwent forensic medical examination. The forensic toxicological investigations performed did not yield any relevant findings. In particular, there were no indications of any impairment of the pilots as a result of alcohol, medications, narcotics or carbon monoxide.

The medical history of the two pilots did not indicate any anomalies. According to statements made by the pilots' relatives, they had appeared healthy before the flights of the adventure tour.

1.14 Fire

Fire did not break out, although the cells contained a considerable amount of fuel that was released on impact.

1.15 Survival aspects

1.15.1 General

It would not have been possible to survive this accident.

1.15.2 Search and rescue

The accident was witnessed by several people who alerted the police immediately after the aircraft's impact and rushed to the scene of the accident to provide first aid. Within just a few minutes of the accident, several rescue helicopters were on site. The alpine rescue services, fire brigade and police arrived at the scene of the accident later.

The ELBA emergency transmitter installed in the aircraft was triggered and began transmitting a radio signal.

1.16 Tests and research

Forensic examination of the instruments and controls in the cockpit of the aircraft involved in the accident revealed the following significant information concerning the time of impact:

- The airspeed indicator that could still be evaluated showed a value of approximately 202 km/h.
- The three tachometers displayed speeds between 1,800 and 1,900 rpm.
- The full-throttle limiter was set to 'on' for all three main throttle levers. Details on the technical descriptions can be found in annex A1.6. Details on the forensic examinations can be found in annex A1.16.

In order to be able to assess the strength and ageing behaviour of the materials used in the Junkers Ju 52/3m g4e aircraft, registered as HB-HOT, and based on the defects identified on the wreckage, elaborate metallurgical examinations and corrosion analyses were carried out. The findings made included:

- Considerable corrosion damage was found on structural parts of the wing and fuselage;
- A lower spar on the left outer wing showed evidence of fatigue fractures;
- The material, which is prone to intergranular corrosion, had insufficient or no surface protection at all.

Furthermore, a simulation of the course of the flight revealed that based on realistic assumptions, it would have been impossible for the crew to prevent the collision with the terrain after initiating the last left turn.

The methods used and the detailed results are described in annex A1.16.

1.17 Organisational and management information

1.17.1 Air operator

1.17.1.1 Organisation

The Association of the Friends of the Swiss Air Force (*Verein der Freunde der Schweizerischen Luftwaffe* or VFL) is an association under Swiss law. The VFL operates Ju-Air by its board appointing a managing director. Consequently, Ju-Air is part of the VFL. For this reason, the supervisory authority issued all official certificates to the VFL.

Further details regarding the organisation and operational procedure of the air operator can be found in annex A1.17.

1.17.1.2 Requirements for commercial activities

Commercial air transport (CAT) operations such as those undertaken by Ju-Air must meet European requirements, particularly with regard to the following topics and areas:

- Air operator certificate and certificate of airworthiness;
- Safety management system and reporting obligation;
- System for monitoring compliance with the relevant requirements;
- Flight crew;
- Take-off roll, minimum rate of climb and minimum flight altitudes;
- Aircraft instruments and equipment;
- Operations manual.

The implementation of these requirements at Ju-Air is explained in sections 1.17.1.3 to 1.17.1.9 that are to follow.

1.17.1.3 Air operator certificate and certificate of airworthiness

The operator must hold an air operator certificate (AOC). In order to receive an air operator certificate, however, the operated aircraft are required to possess a certificate of airworthiness (CofA) in line with the requirements of European regulations.

Ju-Air's Ju 52 aircraft did not have certificates of airworthiness in accordance with European requirements. However, in order to be able to issue an AOC, FOCA made use of an exemption regulation issued by the European Commission (see annex A1.6). This exemption regulation's main stipulation was that the Ju 52 aircraft must have a certificate of airworthiness pursuant to ICAO annex 8 and be maintained by a maintenance organisation that is certified in accordance with European requirements (see annex A1.17). According to FOCA, the exemption regulation included a deviation from all design-related incompatibilities with the operational rules.

Ju-Air's Ju 52 aircraft had a certificate of airworthiness issued by FOCA stating that it was in compliance with the Convention on International Civil Aviation of 7 December 1944. According to FOCA, the aircraft was thus certified in accordance with annex 8 of this convention, although in actual fact it did not meet the requirements of that annex.

Ju-Air's Ju 52 aircraft were maintained by maintenance organisations that were certified by FOCA in line with European requirements. However, these maintenance organisations did not actually meet these requirements.

1.17.1.4 Safety management system and reporting obligations

The safety management system (SMS) used by Ju-Air included the usual aspects as are typical for a commercial air operator and was approved in this form by the Federal Office of Civil Aviation. Among other things, the SMS stipulated that all major hazards to flight operations were to be systematically recorded and their significance assessed. The air operator performed 22 risk assessments between 2012 and the time of the accident. Ju-Air has never assessed the specific risks of VFR flights or flying in mountains. Moreover, the Federal Office of Civil Aviation did not request any risk assessment in this respect, as it considered Ju-Air operations to be standard VFR operations (see section A1.17.7.4). Equally, FOCA had no records of any risk assessments for standard VFR flights.

In order to assess how the air operator used its SMS as well as the level of effectiveness of it, this safety investigation has identified more than 150 safety-related incidents in Ju-Air's flight operations. These events occurred between 2000 and the temporary discontinuing of Ju-Air's operations. Reports from the general public and complaints that had been made in the years prior to the accident because Ju-Air aircraft had, for example, crossed wildlife reserves at low altitude, were also investigated. To this end, inquiries were made into how these incidents had been reported to the competent authorities and how they had been handled internally. These inquiries revealed that the statutory reporting obligation had not been fulfilled and that no in-depth analysis of the events was ever carried out internally. These incidents also showed, among other things, that even the experienced and highly qualified Ju-Air flight crews made mistakes relating to basic flying skills. Ju-Air aircraft, for example, repeatedly violated controlled airspace around military airfields. Although the supervisory authority identified these deficits in individual cases, their scope and systematic patterns remained undetected. The supervisory authority did not request any effective corrective action.

In contrast to other roles within an air operator, policies and guidelines do not specify approval criteria for safety managers or compliance monitoring managers. Persons who are to perform these roles do not have to undergo any assessments either. In its measures to be taken, EASA recommends certain requirements for the role of safety manager only.

Detailed information on the air operator's safety management system and how it works can be found in annex A1.17.

1.17.1.5 System for monitoring compliance with the relevant requirements

Ju-Air had an internal compliance monitoring system in place to check that business activities conformed with legal standards and self-defined processes. Within the framework of this compliance monitoring, legal standards that were actually applicable to Ju-Air were declared inapplicable. In some cases, compliance with the rules was declared when the operator was, in fact, non-compliant. In some instances, checks only assessed whether processes had been described, but not whether these processes were actually being implemented.

Further information regarding the internal compliance monitoring system can be found in annex A1.17.

1.17.1.6 Flight crew

The training to obtain the type rating (TR) for the Junkers Ju 52/3m g4e consisted of a theoretical part and flight training. This included practising steep turns and familiarising flight crews with the behaviour of the aircraft during approach and stall at low speed as well as in unaccelerated straight flight. These elements of the training were performed with only the flight crew on board.

The handling of a stall was not practised as part of the annual proficiency checks.

Further information on the pilots' training can be found in annex A1.5.

1.17.1.7 Take-off roll, minimum rate of climb and minimum flight altitude

1.17.1.7.1 Take-off

According to European Regulation 965/2012, in the event of engine failure, the following applies for three-engined performance class C aeroplanes without any runway information in their aircraft flight manual used for commercial air transport: in order to achieve the required level of safety for take-off, the distance for the take-off roll required by the aircraft to reach a height of 50 ft above ground, as specified in the aircraft flight manual, multiplied by a factor of 1.25 shall not exceed the take-off run available (TORA).

Ju-Air's Ju 52 aircraft are three-engined aeroplanes of performance class C. According to the aircraft flight manual, the distance from the start of the take-off roll required by the aircraft to reach a height of 15 m (approximately 50 ft) above ground for the given (reconstructed) take-off mass and the ambient temperature was approximately 700 m, or 875 m when multiplied by a factor of 1.25. Calculated using the take-off mass based on the pilots' operational flight plan, these distances would have been 760 m and 950 m respectively.

Ju-Air's operations manual does not mention the above rule concerning the factor of 1.25.

Information on the TORA at Locarno Aerodrome can be found in section 1.10. Further information on the calculation of the minimum take-off run required and the systemic investigation in this context can be found in annex A1.17.

1.17.1.7.2 Cruise flight

In order to achieve the required level of safety for cruise flight, performance class C aeroplanes used for commercial air transport operations must be capable of a rate of climb of at least 300 ft/min at any point along the route. Ju 52 aircraft are performance class C aeroplanes. Ju-Air estimates that, at an altitude of 3,000 m AMSL[33] and in summer temperatures, Ju 52 aircraft can climb at a maximum rate of 100 to 300 ft/min. Corresponding proof or measured data are not available.

In addition to the minimum vertical and horizontal separation from terrain and obstacles applicable to non-commercial VFR flights, the rules of European Regulation 965/2012 for commercial air transport set out the following requirement for achieving the required level of safety: performance class C aeroplanes must be capable of flying over all obstacles within a lateral distance of 9.3 km on either side of the intended flight path at a vertical separation of 2,000 ft (approximately 610 m) in the event of engine failure and when the resulting rate of climb is negative. From approximately 2,500 m AMSL, the rate of climb for a Ju 52 is negative in the event of engine failure and the aircraft inevitably begins to lose altitude. As engine failure must be expected at any time, it follows that in the Alps the minimum altitude to be maintained at any point along the flight path is 2,000 ft higher than the highest obstacle to the left and right of the flight path. Along HB-HOT's flight path in the basin south-west of Piz Segnas, this minimum altitude was over 12,500 ft AMSL (3,800 m AMSL).

Ju-Air's operations manual does not mention these rules regarding minimum rate of climb and obstacle clearance.

Further information on minimum climb rate and minimum flight altitudes can be found in annex A1.17.

1.17.1.8 Aircraft instruments and equipment

As of 1997, the requirements for the instruments and equipment on commercial aircraft were outlined in the joint aviation requirements (JAR-OPS 1). As Ju-Air's Junkers Ju 52/3m g4e aircraft failed to meet numerous requirements due to their age, Ju-Air contacted FOCA in February 2004 to request permission for derogations and exemptions from 15 requirements, which included not equipping the aircraft with a cockpit voice recorder (CVR) and a second independent static pressure system for measuring speed and altitude.

On 15 April 2004, the Federal Office of Civil Aviation approved these applications from Ju-Air unconditionally. When JAR-OPS 1 was transferred to EU-OPS 1[34] in 2007 and EU-OPS 1 subsequently converted to EASA OPS[35] in 2014, these exemptions were carried over without review. As a result, the requirement to install a terrain awareness warning system was not taken into account.

Further information regarding aircraft instruments and equipment can be found in annex A1.6.

[33] On its accident flight, HB-HOT reached a maximum altitude of 2,833 m AMSL (see section 1.1.2) equivalent to a pressure altitude of 2670 m AMSL. As Ju-Air did not carry any supplemental oxygen in its Ju 52 aircraft, Ju-Air declared in its operations manual that the crews were not permitted to fly the Ju 52 aeroplanes at cabin altitudes above 10,000 ft (3,048 m) during normal operation (see annex A1.17).

[34] Council Regulation (EEC) No. 3922/91 of 16 December 1991 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation, amended by Regulation (EC) No. 1899/2006 of the European Parliament and of the Council of 12 December 2006 amending Council Regulation (EEC) No. 3922/91 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation.

[35] Commission Regulation (EU) No. 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No. 216/2008 of the European Parliament and of the Council.

1.17.1.9 Operations manual

The structure of parts A to D of the air operator's operations manual (OM) was based on that of a conventional airline. As Ju-Air only performed flights under visual flight rules, the usual sections which primarily concern instrument flights were omitted. The manual describes some of the procedures necessary for operation in detail. However, as a review of numerous flights and planning documents demonstrated, these specifications were merely formal and frequently not implemented by the flight crews during operations. It was, for example, common practice to not calculate the mass or centre of gravity, or to do so only partially. The operational flight plan was generally not filled out correctly and not used in accordance with the requirements.

The operations manual did not contain any information for flying in the mountains.

Further information on the contents of the operations manual can be found in several sections in annex A1.17.

1.17.1.10 Monitoring of flight operations

As the air operator did not have the means to conclusively assess its operations, such evaluation was carried out by the Swiss Transportation Safety Investigation Board after the accident. For this purpose, the STSB secured radar data from 216 flights carried out on Ju-Air Junkers type Ju 52/3m g4e aircraft between April 2018 and the day of the accident. These radar tracks were corrected in height for the pressure and temperature conditions prevailing at the time of the flight in question and then analysed with regard to the procedures used, particularly to those when flying in the mountains. Special attention was paid to the following aspects of flight tactics:

- Flight phases with no possibility of turning back or alternative flight path;
- Low-level flights over plateaus at 2,500 m AMSL and higher;
- Approaching and flying over ridges at almost 90 degrees to the ridge and close to the ground;
- Approaching the terrain vertically significantly below the recommended safety margin or the minimum required flight altitude prescribed for non-commercial VFR flights.

This made it possible to obtain a realistic overview of the operating principles and the procedures actually applied. It became apparent that in approximately one third (36.6 %) of the flights analysed, elementary principles of safe flight management in mountainous areas were significantly violated. 16.7 % of flights involved situations with a very high risk potential. Sixteen of the 27 Ju-Air pilots were trained Air Force pilots. Not all pilots were violating elementary safety rules; these violations mainly occurred among pilots who had been trained as Air Force pilots[36]. Comprehensive details on this investigation into flight operations can be found in annex A1.18.

1.17.2 Continuing airworthiness management organisation

The *Verein der Freunde der Schweizerischen Luftwaffe* (Association of the Friends of the Swiss Air Force or VFL), referred to as Ju-Air, was approved as a continuing

[36] The majority of these pilots completed their training with the Air Force during the Cold War. According to the Swiss Air Force, today's training programme for military pilots and the current air traffic control system of the Air Force cannot be compared to the conditions of that time and now conform with the international standards applicable today.

airworthiness management organisation (CAMO) in line with annex I (part M) of European Regulation 1321/2014. The Ju-Air members of staff required for the CAMO activities were the same people also employed by the Ju-Air and Naef Flugmotoren AG maintenance organisations.

Further information on the CAMO, in particular the structure of the relevant procedures and the qualifications of the staff involved, can be found in annex A1.17.

1.17.3 Maintenance organisations

The *Verein der Freunde der Schweizerischen Luftwaffe* (Association of the Friends of the Swiss Air Force or VFL), referred to as Ju-Air, was approved as a maintenance organisation as per annex II (part 145) of European Regulation 1321/2014[37], which allowed it to carry out maintenance on Ju 52/3m aircraft.

Maintenance, repairs and major overhauls of the engines were outsourced to Naef Flugmotoren AG, whose workshop was located in the same building as Ju-Air. Naef Flugmotoren AG had also been approved as a maintenance organisation according to annex II (part 145) of European Regulation 1321/2014.

Further information on the organisation of maintenance, in particular the structure of the relevant procedures and the qualifications of the staff involved, can be found in annex A1.17.

1.17.4 Supervisory authority

1.17.4.1 Organisation

The Federal Office of Civil Aviation (FOCA) is the national authority responsible for the supervision of civil aviation in Switzerland and for aviation development, provided these tasks are not performed by the supranational aviation authority, EASA. FOCA is part of the Federal Department of the Environment, Transport, Energy and Communications (DETEC) and is responsible for ensuring high safety standards in Swiss civil aviation and pursuing sustainable development.

During this safety investigation, the main focus was the influence of the ‘Safety Division – Aircraft’ and ‘Safety Division – Flight Operations’ on the accident.

Further details regarding FOCA’s responsibilities and its structure can be found in annex A1.17.

1.17.4.2 Inspection activities in the technical field

During five airworthiness inspections carried out on the Junkers Ju 52/3m g4e registered as HB-HOT since 2010, FOCA did not record any complaints or comments in the relevant documents.

During audits of the maintenance organisations, FOCA occasionally found deficits which it challenged and demanded that the organisation concerned rectify them. The maintenance organisations failed to comply with some of FOCA’s requirements, resulting in them again being criticised by FOCA during the next audit. Even then, some of these deficits were not rectified.

The continuing airworthiness management organisation (CAMO) was unable to perform the quality assurance processes it was intended to perform. While FOCA

[37] Commission Regulation (EC) 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.

challenged some items regarding procedures and personnel, the deficits regarding the lack of control mechanisms were not identified.

FOCA had been lacking expertise on piston engines for some time.

Details of FOCA's technical supervisory activities can be found in annex A1.17.

1.17.4.3 Operational approval

The air operator had an operations manual (OM) with parts A to D, as is usual for a commercial air operator. In this manual, the Federal Office of Civil Aviation had approved the procedures that required approval. These operating principles were based on the requirements of European Regulation 965/2012[38], which is also directly applicable in Switzerland.

There were different opinions within FOCA as to why derogation from the requirements of European Regulation 965/2012 was possible. For one, it was thought that these requirements would only apply to operations under instrument flight rules. The other view was that the regulations applicable to commercial operations did not adequately cover VFR operations of large and historic aircraft and that Switzerland was entitled to a certain degree of flexibility in applying the requirements. According to its own statements, FOCA had, however, failed to document these derogations in the correct form and to inform the European authorities accordingly. Ju-Air's documentation does not contain any formal permission to derogate from the rules in question. In this sense, FOCA tolerated Ju-Air's derogation from the minimum flight altitudes required for commercial air transport as well as from other operational requirements of European Regulation 965/2012.

Details on operational approval can be found in annex A1.17.

1.17.4.4 Operational supervision

FOCA's operational supervision included audits, inspection flights and ramp inspections.

In the six years prior to the accident flight, the Federal Office of Civil Aviation carried out a total of six unannounced ramp inspections of a Ju-Air Ju 52 aircraft on five days at aerodromes in Switzerland. During these inspections, FOCA staff checked the flight crew's licences and aircraft documents as well as the mass and centre of gravity calculations performed by the flight crew. As revealed by this investigation, the mass and centre of gravity calculations for these flights contained errors. An incorrect basic empty mass (BEM) was used in the flight plans, for example. This could easily have been identified by consulting the weight sheets contained in the aircraft flight manual on board the aircraft. During these ramp inspections, these errors regarding the mass and centre of gravity calculations were not challenged.

In addition to the audits, FOCA's operational inspectors also carried out flights with Ju-Air crews, usually participating in individual periodic proficiency checks scheduled by the air operator in spring. These flights were carried out without passengers on board and were not comparable to the routes used during commercial operations, as they usually took place in the vicinity of the airport and did not lead into the mountains. Only once in the ten years prior to the accident did an inspector from FOCA take part in a flight with passengers. This flight took place on 13 September 2016. Analysis of the corresponding data shows that, the safety margin of

[38] Commission Regulation (EU) No. 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No. 216/2008 of the European Parliament and of the Council.

at least 1,000 ft AGL (300 m AGL) was deviated from on several occasions during this flight. Furthermore, ridges were approached while climbing or at 90 degrees to the ridge. This choice of flight path clearly contradicts the guidelines for flights in the Alps drawn up by FOCA, as published under RAC 6-3 in the Swiss Aeronautical Information Publication (AIP) VFR guide (see section A1.17.6.2.2). The FOCA inspector on board the aircraft assessed the flight as flawless in every respect. The inspector also failed to criticise the clearly incorrect calculation of mass and centre of gravity.

In the years prior to the accident, the Federal Office of Civil Aviation was audited by the supranational supervisory authority, EASA. During this auditing process, EASA concluded, among other things, that FOCA's supervisory activities did not guarantee an in-depth verification of compliance by the supervised operators. In the context of the accident investigation concerning HB-HOT, similar shortcomings were observed with regard to the supervision of Ju-Air. It was not possible to determine that the intended measures (increase in the duration and number of audits and flight inspections) resulting from the audits proved effective for the supervision of Ju-Air and its maintenance organisations.

Further information on supervisory activities with regard to operations, and the FOCA audits in particular, can be found in annex A1.17.

1.18 Additional information

A selection of Ju-Air flights analysed by the STSB after the accident and information on this investigation into flight operations can be found in annex A1.18.

1.19 Useful or effective investigation techniques

The following investigation techniques proved to be particularly useful and effective during this investigation:

- Recovery, reading and evaluation of data from non-impact-resistant mobile phones and digital cameras belonging to the passengers on board the aircraft, some of which were severely damaged;
- Analysis of the sound characteristics of the engines to assess their speed and condition based on video recordings;
- Photogrammetric analysis of images and video recordings taken from inside the aircraft and by people on the ground to determine spatial positions, attitudes and chronologies.

Detailed information on the investigative methods used can be found in annex A1.19.

2 Analysis

2.1 Structure of the analysis

The first step taken in order to properly understand the processes during the accident flight is to consider the human factors for the flight crew and the significance of the technical factors, as well as to explain the weather conditions and operational factors. The second step is to explain the accident and the directly related causes. The third step is to evaluate the systemic aspects, i.e. the underlying reasons as to why it was possible for this accident to happen.

2.2 General context of the accident flight

2.2.1 Human factors

The careers, training and experience of pilots A and B make it clear beyond doubt that they were well-qualified and had the necessary expertise to perform the flight from Locarno to Dübendorf with the Junkers Ju 52/3m g4e aircraft registered as HB-HOT.

All of the evidence gathered during this investigation proves that pilots A and B were rested and in good mental and physical condition prior to the return flight to Dübendorf. The fact that the flight crew travelled to northern Switzerland in a light aircraft on 3 August 2018 and that pilot B performed several sightseeing flights from Dübendorf on the morning of 4 August 2018 with other Junkers Ju 52 aircraft operated by the air operator had no influence on the accident.

2.2.2 Technical factors

The extensive technical examinations have revealed that the Junkers Ju 52/3m g4e aircraft registered as HB-HOT had various technical restrictions. One of these was that none of the three installed BMW 132 A3 nine-cylinder radial engines were still able to reach the rpm specified by the manufacturer. It could also be proven that the aircraft was no longer capable of the flight performance specified in the operating instructions for the aircraft type. Numerous technical defects, such as corrosion damage, were also found during the investigation of HB-HOT. It was also established that various components had been inadequately maintained or replaced by reproduction parts that exhibited qualitative issues. In view of these numerous technical inadequacies, it can be concluded that, prior to the accident flight, the Junkers Ju 52/3m g4e aircraft registered as HB-HOT was not airworthy in either a physical or a formal sense. Nevertheless, the aircraft functioned in such a way that the identified technical defects did not have an effect on the accident. There is no indication that these defects influenced the actions and decisions of the flight crew. This is also proven by the fact that the crew had already flown the aircraft from Dübendorf to Locarno the day before without raising any complaints. Other flight crews did not make any corresponding complaints about HB-HOT in the weeks and months before the accident either. It is therefore possible to conclude that the flight crews had become accustomed to the limited flight characteristics and were unable to detect the remaining inadequacies. The improper mechanical condition of HB-HOT and its limited flight performance do, however, constitute factors to risk which should be eliminated in future for aircraft of the same type.

2.2.3 Weather conditions

The weather forecasts which the flight crew could consult before the flight showed no signs of unusual or particularly difficult weather conditions. The investigation proved that the weather encountered during the flight was largely in line with the forecasts. Pilot B had already flown from Dübendorf that morning and had experienced the weather conditions. Both pilots had already crossed the main ridge of the Alps in a light aircraft immediately before the accident flight. In view of this information and the flight crew's substantial experience, it can be concluded that the flight crew had sufficient knowledge of the weather conditions prevailing at the time. It must have been clear to the flight crew that it was easily possible to fly around areas affected by local showers or thunderstorms. The weather conditions were suitable for a VFR flight over the Alps and allowed various safe routes from Locarno to Dübendorf to be flown. In view of the forecasts and the actual weather conditions, it can be concluded that it was possible to turn back to Ticino at any time. The weather on the route did not present any surprises and was easy to assess. Furthermore, there is no doubt that the experienced, well-trained pilots were familiar with the phenomenon of a relatively high density altitude at high summer temperatures. Although, as explained above, the aircraft no longer performed as documented by the manufacturer, the temperatures prevailing on that day did not constitute a critical limitation for the planned flight.

2.2.4 Operational factors

The flight crew arrived at Locarno Aerodrome on 4 August 2018 approximately one and a half hours before departure to Dübendorf. This provided sufficient time for preparing the aircraft and flight planning. As part of the flight preparations, the mass and centre of gravity (balance) were to be calculated and recorded on the operational flight plan. The operational flight plans found after the accident (both for the flight from Dübendorf to Locarno on 3 August 2018 and for the accident flight) show that the flight crew's calculations were flawed and incomplete. Furthermore, no evidence was found of a calculation or even an estimation of the flight performance during take-off, cruise flight and landing. This investigation has revealed that Ju-Air's flight crews often failed to perform this type of pre-flight calculation, despite the fact that it was required according to the air operator's manual. It is therefore reasonable to assume that pilots A and B had also become accustomed to non-compliance with these operational requirements and that the flight preparations therefore remained incomplete. The supranational guidelines for take-off and cruise flight concerning take-off roll, rate of climb and obstacle clearance were not met during the accident flight.

For the accident under investigation, it could be proven that the aircraft was operated with a mass below its maximum take-off limit, both during the outward flight on 3 August 2018 and during the accident flight on 4 August 2018. On both flights, however, the aircraft's balance was behind the rearmost permissible centre of gravity specified by the manufacturer. It should be noted that if the mass and balance calculations had been performed correctly, using the documentation provided or Ju-Air's flight planning software, the flight crew would not have been able to identify that the centre of gravity was behind the permitted limit. The reason for this lay in inaccurate raw data and the flawed design of the flight planning software. These shortcomings represent a factor that systemically contributed to the accident.

2.3 Accident flight

2.3.1 Operational aspects

After taking off from Locarno on 4 August 2018, the Junkers Ju 52/3m g4e aircraft registered as HB-HOT flew over the basin of Lake Maggiore and the Blenio valley towards the Greina plateau. The flight was initially uneventful. The aircraft flew over the countryside preservation quiet zone in the Greina plateau – marked on aeronautical charts as a 'zone to be avoided' – at 120 to 300 m above ground, which suggests that the flight crew showed little consideration for this area. It should be noted that complaints from the general public had already been received in the years prior to the accident because Ju-Air aircraft had crossed wildlife reserves at low altitude. The Federal Office of Civil Aviation had subsequently demanded that the air operator implement suitable measures to raise awareness among and train its flight crews, though these obviously had no effect, at least not on pilots A and B.

A few minutes later, the aircraft crossed the Surselva region in the municipality of Ilanz on a north-easterly heading and made a relatively tight turn to the left. This manoeuvre took the aircraft over Ruschein (canton of Grisons), where a friend of the flight attendant (ISP) lived. The ISP had sent a text message to this friend using her mobile phone a few minutes earlier, saying that the Ju 52 would shortly be flying over Ruschein. It stands to reason that this noticeable change in heading, which could be seen from the ground, can be attributed to this.

During this phase, HB-HOT was climbing and, at 2,833 m AMSL above the Nagens region, attained the highest altitude recorded on its final flight.

It stands out that, shortly after passing the Berghaus Nagens lodge, the flight crew piloted the aircraft at a speed, which, for a long time, equated to a ground speed of only approximately 140 km/h. Taking into account the headwind during this phase, the aircraft was moving at a true airspeed of approximately 180 km/h. Thus, the airspeed during the approach to the basin south-west of Piz Segnas was approximately 44 % above the stall speed. As turbulence had already occurred during the flight prior this point and it was necessary to initiate a turn in order to cross the pass, associated with a higher stall speed, this safety margin was too small. In addition, even during this phase, the aircraft tended to fly quite low to the ground at just less than 200 m above the elevation of the Segnes pass, which the crew intended to cross. This, combined with the low speed, represented a risky starting point for the continuation of the flight.

This situation did not improve, despite the speed increasing by roughly 50 km/h up to a true airspeed of approximately 230 km/h for a short time, because this increase in speed was not due to an increase in power. Rather, this resulted from a slight descent of roughly 80 m, which reduced the aircraft's height above ground to approximately 115 m when compared to the Segnes pass. The pass represents the lowest point on the mountain range that borders the basin. Due to the narrowness of the pass, terrain elevations considerably higher than that of the pass must be factored into the choice of flight path in order to safely cross the corresponding ridge.

Upon increasing the speed of all three engines by about 40 rpm, the aircraft rose by approximately 25 m to 2,767 m AMSL, resulting in a height above ground of roughly 140 m when compared to the Segnes pass. At the same time, however, the true airspeed of HB-HOT decreased to 200 km/h and the prevailing headwind steadily eased.

The analysis of the power setting and rpm of the three engines shows that they could be controlled and that the aircraft reacted according to changes in power settings. Neither the maximum permissible engine speed nor the highest possible engine speeds to be expected in view of the proven technical restrictions were achieved. From this it can be concluded that despite the relatively high density altitude and the poor condition of the engines, there was still a reserve of power.

Evaluation of the aileron deflections and the reaction of the aircraft to these control inputs proves that it was possible to control the aircraft and that it reacted accordingly during this phase of the flight.

HB-HOT entered the basin south-west of Piz Segnas and from then on, the pilots navigated the aircraft on a north-north-easterly heading in approximately the middle of the valley. With this choice of flight path, the flight crew may have wanted to give the passengers a good view of the Martinsloch, a well-known geological feature and tourist attraction. Due to the aircraft’s low altitude and the narrow nature of the basin, it was no longer possible to turn back or to choose a flight path other than over the crest of the Segnes pass. It is one of the basic principles of flying in mountainous areas that there must always be the option of an alternative flight path or to turn back. Combined with the aircraft’s low altitude in relation to the pass the pilots intended to cross, the flight crew’s decision to dispense with these safety-related requirements created a very high-risk situation which did not permit any tolerance for further errors, faults or external influences. This type of piloting can be seen as a causal factor of the further course of the accident.

As the reconstruction of the flight path and the wind conditions show, the aircraft began to descend over several seconds while flying past the Tschingelhörner mountain peaks. This was due to downdraughts with a vertical speed of 2 to 5 m/s. Extensive meteorological investigation proved that downdraughts of this kind were present in this area of the basin. They do not represent an abnormal phenomenon in the mountains.

As video footage shows, when the aircraft was approximately level with the Martinsloch, the flight crew initiated a right turn during this descent and then made a left turn. The true airspeed was approximately 180 km/h and the difference between the aircraft’s pitch and flight path angles increased to approximately 15 degrees during the right turn.

During this phase, the power of the engines was slightly reduced, although the characteristics of the manner of control input suggests that the flight crew was in the process of synchronising the three engines. At the same time, the aircraft’s pitch attitude increased further and the descending flight path became increasingly steeper.

It is conceivable that due to their preoccupation with the engines and the view from the cockpit, which made it difficult to easily recognise the descent, the flight crew’s increase in pitch attitude was made subconsciously in order to compensate for this (see figure 21). Furthermore, the fact that the centre of gravity was beyond the rear limit facilitated the process and made the aircraft more unstable around its pitch axis, which represents a factor that directly contributed to the accident.

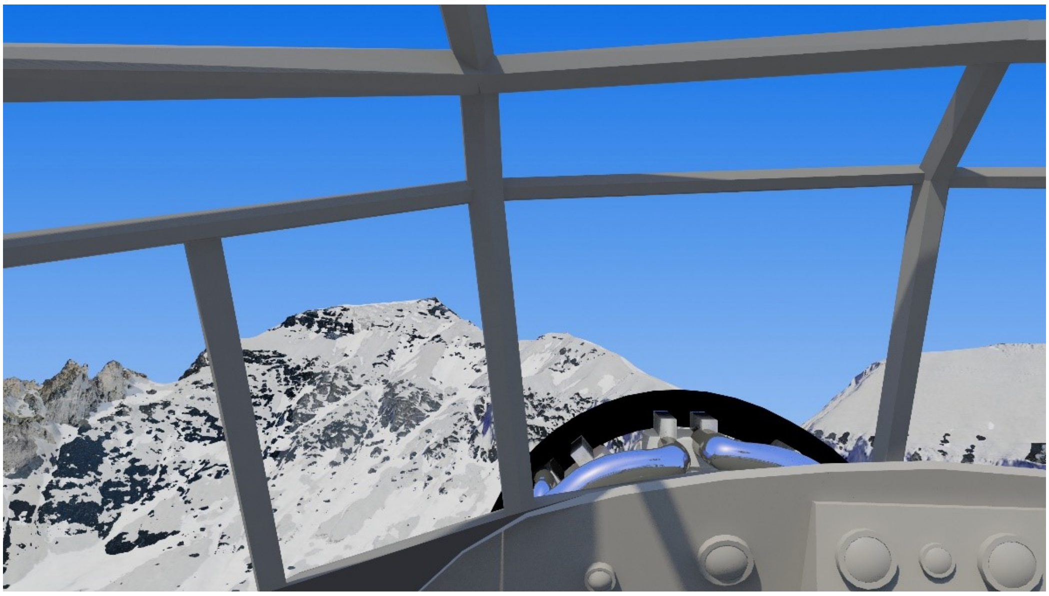

Figure 21: Reconstructed view from the position of the commander of HB-HOT at point F9. Piz Segnas can be seen in the line of sight. Shown using a simplified model of the aircraft and the three-dimensional terrain model. The absence of visible reference points made it difficult to detect the descent caused by the downdraught.

The aeroplane then assumed a rate of descent of approximately 6 m/s that subsequently increased further, which, based on the analysis of the flight attitude, speed and airflow conditions in the basin south-west of Piz Segnas, can no longer be attributed to a downdraught. Due to the high pitch attitude and the clearly downward flight path, it is also impossible that this descent was caused by the flight crew using the elevator control. Rather, it can be concluded that the aircraft was in a situation in which the airflow at the wing had at least partially stalled. It should be noted that a stall can occur regardless of the aircraft's speed if the critical angle of attack for the wing profile is exceeded.

From an aerodynamic point of view, the stall can be explained as follows: HB-HOT had been caused to enter a descent by an area of downdraught. The descent in the downdraught, which was partially compensated by increasing the pitch attitude, led to a flight attitude close to the maximum angle of attack. Given this flight attitude, the additional increase in the angle of attack caused when flying into an updraught was sufficient to lead the airflow to at least partially stall. This development would not have been expected had the downdraught continued or eased slowly. The air currents observed in the basin indicate that the aircraft was moving from an area of downdraught into an area of updraught. A change in the vertical component of the wind's vector from a downdraught with a speed of 2 to 5 m/s to an updraught with a speed of 0 to 3 m/s was sufficient to exceed the critical angle of attack (see figures 22 and 23). As both the measurements and the airflow calculation have shown, even larger shear values were easily possible. Correspondingly turbulent conditions in the mountains are not unusual and become a risk when flying close to the terrain.

Figure 22: Stationary flight in an area of downdraught. Black line: longitudinal axis of the aircraft; Black dashed line: horizontal plane; Green line: chord line; Yellow vector: movement for the aircraft in relation to the area of downdraught; Blue vector: downdraught vector; Red vector: flight path (i.e. the resulting vector of movement for the aircraft in space); Purple angle: pitch angle (angle between the horizontal plane and the aircraft's longitudinal axis); Red angle: flight path angle (angle between the horizontal plane and the flight path); Yellow angle: angle of attack (angle between the direction of airflow, which is the inverse of the vector of movement for the aircraft in relation to the area of downdraught, and the chord line).

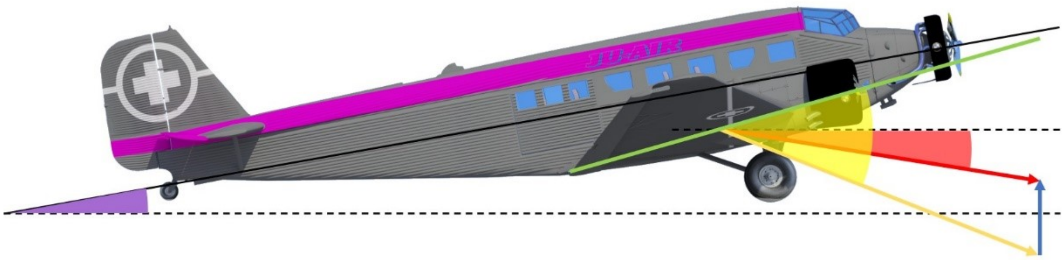

Figure 23: Entry into an area of updraught from an area of downdraught. The flight path vector (red) momentarily remains the same because of the inertia of the aircraft; Blue vector: updraught; Yellow vector: vector of movement for the aircraft in relation to the area of updraught. The angle of attack (yellow) increases considerably. Black line: longitudinal axis of the aircraft; Black dashed line: horizontal plane; Green line: chord line; Purple angle: pitch angle (angle between the horizontal plane and the aircraft's longitudinal axis); Red angle: flight path angle (angle between the horizontal plane and the flight path); Yellow angle: angle of attack (angle between the direction of airflow, which is the inverse of the vector of movement for the aircraft in relation to the area of updraught, and the chord line).

It is therefore also one of the fundamental principles of flying in mountainous areas that the airspeed, and thus the energy of the aircraft, must be increased during turbulent conditions and when in closer proximity to the terrain, so that wind shear does not cause a stall, even if it would usually only do so for a short time. It must be ensured that the aircraft is not overloaded by gusts or deflection of the control surfaces, so that the calculated manoeuvring speed lends itself to be the optimum speed. HB-HOT had a true airspeed of approximately 180 km/h during this phase (when it encountered wind shear) which was roughly 55 km/h or 44 % above the stall speed in the prevailing conditions. This level of speed reserve is too small for the turbulence that is common in the mountains.

As has been proven, the flight crew did not use the engines' available power reserves to consistently achieve an airspeed within the design manoeuvre speed range, which under the prevailing conditions was a true airspeed of 197 km/h. If the design manoeuvring speed cannot be achieved during horizontal flight, which is possible for aircraft with a relatively large mass-to-power ratio, this speed must be aimed for when descending. This in turn requires a sufficiently large altitude reserve to be created in advance. In any case, when flying in the mountains, great attention must be paid to ensuring a safe energy level for the aircraft.

In this investigated accident, the flight crew did not follow this important principle. This is shown, inter alia, by the fact that, at a time when the aircraft was already flying too low and too slowly in the basin, they further reduced the power of the three engines. The choice of a dangerously low airspeed with regard to the flight path is therefore a further causal factor of this accident.

Video footage further shows that during this situation, which resembled a deep stall, the angle of bank to the left increased steadily. Once the bank angle reached approximately 30 degrees, there was initially a small and then a significant corrective deflection of the left aileron downwards, which was intended to achieve a roll to the right, or rather to counter the roll. From this, it can be concluded that the flight crew intended to stabilise the left turn at a constant bank angle and had probably not really noticed the stall yet. At this time the aircraft was at an altitude of approximately 2,725 m AMSL and was therefore still at a height above ground of roughly 100 m compared to the Segnes pass.

However, the roll to the left did not slow down and the bank angle continued to increase. The ailerons were then brought into the neutral position and slightly deflected into a position for a left turn. At the same time the nose of the aircraft began to drop. This sequence of events can be explained as follows:

- During this phase the aircraft was proven to be in a situation that could no longer be controlled or in which it was impossible to prevent the roll motion to the left, at least momentarily.
- The uncontrolled rolling motion of the aircraft occurred because the airflow was stalling on the left wing (on the inside of the turn), at least to a greater extent than it was on the right wing. This resulted in an asymmetrical distribution of lift. The turbulence may also have generally had an asymmetrical effect. In the process, the right wing produced more lift than the left wing and allowed the aircraft to roll further to the left.
- Ju-Air's Junkers type Ju 52/3m g4e aircraft were known to roll towards the inside of the turn in the event of a stall during a turn, which leads the bank angle of the aircraft to further increase and subsequently decrease both the pitch attitude as well as the turn radius.
- The angle of attack must be reduced in order to stop the stall and bring the aircraft back under control. The way to achieve this is to reduce the deflection of the elevators and adjust the ailerons in the direction of the roll. Under no circumstances should an attempt be made to stop the roll by adjusting the ailerons in the opposite direction of the roll, as deflecting the aileron on the wing that is on the inside of the turn downwards only increases its angle of attack, making it more difficult for the airflow to reattach to the wing.
- In this investigated accident, the experienced pilots reacted appropriately and evidently tried to bring the aircraft back under control by adjusting the ailerons in the direction of the roll.

In principle, this initiated the process of bringing the aircraft back under control. It was, however, no longer possible to successfully perform this manoeuvre due to the aircraft's proximity to the terrain, as a corresponding simulation has shown.

The sequence of events in the lead up to the aircraft's collision with the ground in terms of flight mechanics can be explained as follows: As video footage recorded from inside HB-HOT shows, the aircraft was subject to low-frequency buffeting during its increasingly steeper flight path, which indicates that the airflow was stalling once again on the wing or horizontal stabiliser. The last photograph of the aircraft before impact shows that the wings were deflected upwards to a lesser degree than when in horizontal straight flight and that the elevators had been deflected upwards to approximately half of their full deflection. The rudder was deflected slightly to the right. At this time the aircraft was approximately 108 m above the ground. A little over two seconds later, it rolled a further 186 degrees to the left and hit the ground in a vertical flight attitude with an almost vertical flight path at a speed of approximately 200 km/h. These values also indicate that during the attempt to regain control at an airspeed of between 170 and 200 km/h, the critical angle of attack was exceeded again due to an accelerated stall. It also becomes clear that at the time when the last photograph of HB-HOT was taken, there was a pronounced uneven distribution of lift, which led to a roll rate of approximately 90 degrees per second in the final phase of the flight.

Both the analysis of the engine noise and the forensic examination of the throttle levers show that the full-throttle limiter was set to ‘on’ during the last phase of the flight. This means that the flight crew had not brought the engines up to the highest possible power.

2.3.2 Human aspects

The following compares the actions of the flight crew with the generally accepted principles of flying in mountainous areas.

It is clear from the sequence of events described above that the way in which the flight crew piloted the aircraft into the basin south-west of Piz Segnas demonstrated the following:

- Upon entering the basin, the choice of flight path, which ran approximately through the centre of the valley, made it impossible to turn back or to choose a flight path other than to fly over the Segnes pass.
- The low height above ground during the approach to the Segnes pass would inevitably have meant crossing the mountain range in close proximity to the ground, as the flight crew had not decided to climb early enough.

This choice of flight path was therefore in contradiction to the fundamental principles of flying in mountainous areas, as taught to every pilot as of part of their basic training. A central rule here is that, at any time, a pilot must have one or more exit routes for the duration of the entire flight in case a new, unexpected situation arises. In concrete terms, this means that there must always be sufficient manoeuvring space for a 180-degree turn or an alternative flight path if, for example, the aircraft is caught in a downdraught, experiences a technical problem, or suddenly encounters obstacles such as clouds or other aircraft, etc. Furthermore, it is crucial that there is sufficient distance between the aircraft and the terrain when flying in mountainous areas. Turbulence and rotors are particularly pronounced in areas below the crest of a ridge, which means that the associated risks can be reduced by maintaining a sufficient separation from the terrain. As is commonly known, maintaining the legally stipulated minimum altitude above uninhabited terrain (150 m above ground level) does not ensure adequate safety when flying in the mountains. To this end, the minimum altitude for the main routes over the Alps recommended on the aeronautical chart for Switzerland is 300 m above the elevation of the pass a pilot intends to fly over. Experience shows that even greater minimum altitudes may be necessary to fly safely in mountainous areas, depending on the local topography and the prevailing weather conditions.

The following examines the reasons as to why two very experienced, well-trained pilots flew the aircraft into the basin south-west of Piz Segnas in such a risky manner, thereby creating the conditions that enabled the accident to happen.

The investigation proved beyond doubt that both pilots were aware of the basic principles of flying in mountainous areas as described above. It is therefore impossible for this situation to have occurred due to ignorance. The investigation also ruled out the possibility that an incorrect altimeter reading could have deceived the pilots with regard to the true altitude of the aircraft upon entering the basin. Video recordings of the altimeter displays during the accident flight prove that the altimeters were set to a suitable reference barometric pressure. By comparing these readings with the actual altitude flown, determined using radar data and photogrammetric measurements, it can be concluded that the altimeters gave accurate readings based on this reference barometric pressure and that the actual altitude was, in fact, greater than that indicated by the altimeters due to the temperature change in the atmosphere. From the data available it can also be concluded that, when entering the basin at an actual altitude of 2,750 m AMSL, the crew was shown an altitude of approximately 2,650 m AMSL on the flight deck. As former Swiss Air Force pilots, the two pilots would have had extensive geographical knowledge and known the elevations of all major alpine passes, as these are taught intensively during the training to become military pilots. It can therefore be assumed that, even without using a map, the flight crew knew that the Segnes pass, which lay ahead of them, had an elevation of 2,625 m AMSL. This in turn suggests that the entry into the basin was the result of a conscious decision. It is, however, also conceivable that the crew did not pay attention to the altimeters and instead entered the basin purely on the basis of visual impressions, as is often the case when flying in mountainous areas.

This risky behaviour was ultimately the result of the pilots' flight training coupled with their development in Ju-Air's operational culture, which led them to become accustomed to this kind of flying. In the months and years prior to the accident flight, several safety-critical flights were documented in which pilots A and B, either individually or in some cases together, failed to comply with safety-related regulations and broke the rules:

- On several occasions during the flight from Dübendorf to Locarno on 3 August 2018, pilot B piloted the Junkers Ju 52/3m g4e aircraft registered as HB-HOT so close to the mountain flanks that it constituted a risk and flew below the stipulated minimum flight altitude.
- On 6 July 2018, pilot A acting as the pilot in command flew, together with pilot B acting as co-pilot, over Munich in the Junkers Ju 52/3m g4e aircraft registered as HB-HOT at an altitude considerably below the minimum required level.
- The analysed Ju-Air flights between April 2018 and the day of the accident prove that pilot A was involved as a crew member on at least six flights in which the aircraft was operated in a very high-risk manner. On four of these flights, he was working together with pilot B.
- The analysed Ju-Air flights between April 2018 and the day of the accident prove that pilot B was involved as a crew member on at least eight flights during which the aircraft was operated in a very high-risk manner. On four of these flights, he was working together with pilot A.
- On 6 July 2013, pilot B (as pilot in command), together with pilot A (as co-pilot), flew over the ridge of the Segnes pass in the sister Junkers Ju 52/3m g4e aircraft registered as HB-HOP in a very high-risk manner. He approached the ridge while climbing and without the option of a 180-degree turn, and the aircraft finally crossed the crest with a separation of just 30 m.

A common thread running through these events is the tendency of both crew members to regard rules for safe flight operations as not mandatory for themselves[39] or to take high risks. This behaviour is further substantiated by other examples, which can be seen in annex A1.5. In the same annex, other potential explanations for the observed actions are listed.

In summary, it should be noted that under the conditions prevailing on the day of the accident, it was easily possible to fly through the basin south-west of Piz Segnas at the appropriate altitude and reach the northern side of the Alps by crossing the Segnes pass. In addition to all of the investigations which have led to this conclusion, this is also illustrated by the fact that around one minute prior to the accident involving HB-HOT, a trainee pilot and their flight instructor on board a motor-powered Cessna C152 aeroplane were able to fly over the ridge of the Segnes pass from south to north. The crew had chosen a flight path that would have allowed for a 180-degree turn or an alternative flight path at any time. However, this aircraft was also piloted at an altitude above the ridge which did not comply with the rules for safe mountain flying as published in the Swiss Aeronautical Information Publication (AIP). The flight crew of the Junkers Ju 52/3m g4e involved in the accident was demonstrably accustomed to breaking the commonly accepted rules for safe flying and taking high risks, which led to the flying tactics described. This habit therefore constitutes a factor which directly contributed to the accident.

2.4 Systemic aspects

2.4.1 General

A full safety investigation should not focus solely on identifying the direct causes of, and factors contributing to, an accident. Particularly in view of making potential safety improvements, the analysis of systemic aspects usually provides the greatest need for action. This has also been demonstrated in this investigated accident, and has led to several safety recommendations and pieces of safety advice being issued.

2.4.2 Organisation and management of flight operations

2.4.2.1 Analysis of the flight crews' mountain flight tactics

Until the accident, the air operator had not evaluated or monitored its flight operations based on real flight data. Today, such flight data monitoring is frequently used in commercial flight operations to obtain a realistic picture of operations and thus detect operational deficits early on.

During the STSB investigation, the radar data of 216 of the more than 400 flights conducted by Ju-Air between April 2018 and the day of the accident were evaluated. In particular, the procedures adopted by the flight crews were analysed with regard to safe piloting while flying in mountainous areas. In view of the characteristics and mechanical condition of the Ju-Air aircraft, flight phases that did not offer the option of a 180-degree turn or alternative flight path for a relatively long period of time were classified as 'very high-risk'. When flying in mountainous areas, minimum flight altitudes alone are not a particularly suitable means of assessing dangerous situations. This is because the energy level and performance of an aircraft

[39] The 'Pilot's Handbook of Aeronautical Knowledge' published in 2016 by the American regulatory authority, the Federal Aviation Administration (FAA), describes such a dangerous attitude as follows: "*Anti-authority: This attitude is found in people who do not like anyone telling them what to do. In a sense, they are saying, 'No one can tell me what to do.' They may be resentful of having someone tell them what to do or may regard rules, regulations, and procedures as silly or unnecessary. However, it is always your prerogative to question authority if you feel it is in error.*"

must also be considered. It is for this reason that the evaluation of flights has consistently included an assessment of the overall situation.

During this evaluation of flights, numerous situations were identified in which Ju-Air aircraft were operated in mountainous areas at altitudes of less than 300 m above ground. Such situations can be recorded and analysed by a safety-conscious air operator to ensure low-risk flying in mountainous areas. During the assessment conducted as part of this investigation, however, these events were only evaluated statistically. In contrast, 44 situations identified over the course of 36 flights were examined in detail. In each of these cases, the likelihood of an accident was high because the flight crews took high risks.

The analysis of these situations in Ju-Air's flight operations shows that the chosen flight paths often did not allow for an exit route or 180-degree turn in the event of an updraught or downdraught, or a technical malfunction. The flight altitudes adopted would have offered little room for manoeuvre with such restrictions. It was also uncovered that flight crews often flew very close to rock faces and mountain flanks. The flight crews concerned systematically took risks that were easy to avoid and, in doing so, put people and property at risk. As there is no doubt that Ju-Air's experienced, well-qualified crews were familiar with the basic principles of flying in mountainous areas and with the general aviation legislation for VFR flights, such conduct must be classified as reckless violations in line with the just culture adopted by the air operator and the Federal Office of Civil Aviation.

By analysing the careers of the flight crews who, from the perspective of this safety investigation, had committed these violations, it became apparent that it was primarily the flight crews who trained as Air Force pilots that often did not adhere to the generally accepted principles of safe flying in mountainous areas.

The widespread habit of Ju-Air flight crews systematically failing to comply with recognised legal aviation rules or taking high risks also undoubtedly influenced pilots A and B. It is for this reason that the habit of breaking rules is considered a systemic contributory factor in the accident.

Several senior-management Ju-Air pilots repeatedly broke the rules and were involved in flights with a risky choice of flight path. Having said that, there is no indication that this high-risk manner of flying was actively promoted by those in charge at Ju-Air. However, due to a lack of control mechanisms, they were unable to detect the systematic violation of rules that were critical to safety. This is therefore also a systemic contributory factor in this accident.

2.4.2.2 Training and performance reviews

The training programme for obtaining the Junkers Ju 52 type rating was specifically analysed with regard to aspects relevant to the accident. During this training, the flight crews were familiarised with the behaviour of the aircraft type when approaching a stall and when stalling in slow straight flight. They were also trained in the necessary countermeasures to recover from a stall. This air work was performed on aircraft with relatively light loads and a forward centre of gravity, i.e. only the flight crew was on board. In order to preserve the aircraft, air work to experience stalling during a turn or on aircraft with normal loads was not carried out. Although this procedure may be understandable, it should be noted that the behaviour of an aircraft in the event of a stall is greatly dependent on its load. Furthermore, the behaviour of an aircraft when turning or in a situation involving increased speed and acceleration differs significantly from that in steady straight flight. Even if the fact that the flight crews were not familiarised with all critical situations regarding the behaviour of aircraft in the event of a stall did not demonstrably contribute to the accident under investigation, it is a factor to risk and should be improved upon.

The periodic proficiency checks to maintain the type rating and the line checks carried out by Ju-Air's training captains were also analysed with regard to pilots A and B, who were involved in the accident. It is striking that hardly any criticism or recommendations for improvement were ever recorded on the corresponding documents and that the pilot performances were always evaluated as 'standard' to 'high standard'. The radar data for pilot A's last line check on 7 April 2018 and that of pilot B on 12 May 2018, which were still available and could be analysed, revealed that these flights too were performed significantly below the safety altitudes as specified in the Aeronautical Information Publication (AIP) VFR guide. In addition, the pilots had disregarded essential principles for safe mountain flying. Nevertheless, the training captain, who also was a type rating instructor and examiner for Ju 52 aeroplanes, rated pilot A's flight as 'standard' to 'high standard' and did not criticise the errors made. The choice of flight path was explicitly described as "*appropriate*" and "*sensible*". Pilot B's performance was rated as 'high standard' and the choice of flight path was described as "*considerate*" and "*anticipatory*". This constitutes a missed opportunity to make pilots A and B aware of their non-compliance with safety rules, which might have had a positive influence on them. These cases also illustrate that line checks were carried out in a not very critical manner and without pointing out errors.

2.4.2.3 Safety management system

An analysis of the safety management system used by Ju-Air revealed that it formally included the usual aspects as are typical for a commercial air operator and that it had been approved in this form by the Federal Office of Civil Aviation.

However, considerable shortcomings were found in the implementation and application of the safety management system. It became apparent that considerable risks, such as specific challenges in VFR flight or the dangers of flying a commercial aircraft in mountainous areas, had never been raised and analysed. The supervisory authority has never requested such a risk assessment either. As a result, it was not possible to develop and apply remedial action to reduce these risks. Such action might have had an influence on this investigated accident.

As part of this investigation, around 150 safety-related incidents that occurred during Ju-Air's flight operations were analysed and assessed with regard to the way in which they were dealt with as part of the safety management system. This revealed, among other things, that at least nine serious incidents had not been reported to the competent safety investigation authorities between 2000 and the date of the accident. Furthermore, the supervisory authorities had not been notified about numerous other incidents. In many instances, the investigations into safety-related incidents conducted within Ju-Air were only rudimentary in nature and an investigation could not be opened by the state authorities actually responsible, as these authorities were unaware that the incidents had happened. As a result, it was not possible, or only possible to a very limited extent, to learn from these incidents and prevent similar situations from occurring in the future. It is therefore not surprising that similar incidents happened repeatedly. The unsatisfactory reporting culture and the deficient analysis of incidents systemically contributed to this investigated accident, because it can be assumed that safety would have been improved if the responsible persons and organisations had handled their reporting activities consistently.

In addition to the incidents which involved a high level of risk, it also stood out that the experienced, well-qualified flight crews often made mistakes in terms of basic flying skills. Airspace violations were, for example, often recorded even in the airspace around military airfields, which particularly the pilots who trained in the Air Force should have been familiar with. This type of error indicates a lack of knowledge of the valid rules or insufficient collaboration between flight crews (crew resource management – CRM). Even if this did not evidently contribute to the accident under investigation, it is a factor to risk and should be improved upon.

Ju-Air's internal control and audit system, which existed on paper and led to a great deal of formal effort, was not able to detect various irregularities at Ju-Air because it was not used appropriately. This includes in particular the operator's inadequate internal compliance monitoring to check that business activities conformed with self-defined processes and legal standards for achieving the level of safety required for commercial air transport, non-existent flight performance calculations and the various errors in the software for calculating mass and centre of gravity.

The overall impression was that a large part of the air operator's procedural requirements and, in particular, the safety management system had been established mainly for reasons of formality or due to legal requirements. It was not, however, possible to detect the consistent, safety-conscious application of these requirements. This can also be seen by the fact that the persons appointed as safety managers and compliance monitoring managers were willing and motivated, but lacked the necessary technical and methodological competence. In this context, it is striking that there are no legal specifications to ensure sufficient skills for these two roles in an air operator, which are so critical to safety. Although this did not demonstrably contribute to this investigated accident, it is a factor to risk and should be improved upon.

Ultimately, the safety management system and direct management of the responsible persons at the air operator was ineffective with regard to the risks which ultimately resulted in the accident. This failure must also be considered as a systemic contributory factor in this accident.

2.4.3 Organisation and performance of maintenance activities

2.4.3.1 Engines

BMW, who manufactured the BMW 132 A3 nine-cylinder radial engines installed on Ju-Air's Junkers Ju 52/3m g4e aircraft, stipulated that these engines require a major overhaul every 200 to 300 operating hours. After commencing civil operations, the air operator succeeded in obtaining permission from the Federal Office of Civil Aviation to gradually increase the operating time between two major overhauls to 1,500 hours. During this investigation, maintenance of the aircraft type, and in particular the maintenance of the engines, was examined in detail. During operation, the engines never achieved the operating times of 1,500 hours which had been approved by the Federal Office of Civil Aviation in deviation from the manufacturer's specifications. It was consistently necessary to repair the engines and, in particular, replace important components. This proves that the increase in operating time was not justified.

During the period under investigation (2008 to 2018), numerous engine faults occurred and one instance of engine failure during a flight was recorded. In 16 cases, it was necessary to shut down an engine during flight or run it at reduced power. There are similarities between these incidents and the operational incidents in that they were insufficiently analysed with regard to safety and improving safety.

It was established that the Junkers Ju 52/3m g4e registered as HB-HOT, which was involved in the accident, no longer achieved the originally demonstrated flight performance. The fact that the performance data of the aircraft had not been verified for a long time therefore represents a significant safety deficit, which should be addressed with a specific view to continued operation of such aircraft.

2.4.3.2 Spare parts management

As spare parts for the engines and airframe had not been available for some time, Ju-Air decided to have the required components manufactured based on pattern parts and to have other parts reconditioned. Some of the companies that performed such work were not certified to produce parts for use in aviation. The installation of such parts on an airworthy aircraft was not permitted. In other words, the use of such parts resulted in at least the formal loss of airworthiness for the aircraft concerned.

The relevant procedures were stipulated in 41 service bulletins between 1984 and 2001. In the absence of the original manufacturers, these were issued by Ju-Air. These service bulletins were submitted to FOCA, who approved them. It is striking that, with the exception of one bulletin concerning processes and subcontractors, these service bulletins had not been updated since 2002. Numerous other remanufactured components have, however, still been produced without being accompanied by a service bulletin. As a result, the review and approval process at the Federal Office of Civil Aviation was also omitted.

Overall, these inadequate processes and procedures resulted in Ju-Air’s Junkers Ju 52/3m g4e aircraft being in an unsatisfactory condition.

2.4.3.3 Quality assurance

The general condition of the aircraft and engines revealed numerous maintenance deficits, which indicate inappropriate processes and insufficient competence or quality awareness on the part of those responsible.

The interdependence of the various organisations and the limited number of people, who in most cases performed several roles at the same time, may also have made independent critical control of internal company processes more difficult.

Numerous incomplete or carelessly filled out documents were found in the maintenance records. This made it difficult to trace the maintenance work carried out as well as the modifications and repairs made to the aircraft.

Although none of these deficits and inadequacies in the organisation of maintenance demonstrably contributed to this investigated accident, they are factors to risk and should be improved in future.

2.4.4 Supervisory activities

2.4.4.1 Technical approval

As no manufacturer and no type certificate holder had existed since the air operator put the type Ju 52/3m g4e aircraft into service, there was no support for the aircraft’s continued airworthiness. At the time, the Federal Office of Civil Aviation classified Ju-Air’s Junkers Ju 52/3m g4e aircraft as ‘Standard’ category aircraft. FOCA was unable to provide a comprehensible explanation of the reason for this original classification. However, the fact remains that, at least according to the Swiss Ordinance on the Airworthiness of Aircraft (VLL), the type Ju 52/3m g4e aircraft should be classed as a ‘Special’ category aircraft and has therefore been incorrectly approved by the supervisory authority.

The Federal Office of Civil Aviation never questioned this classification, which was originally made in 1985, even though national and supranational regulations have evolved in the 33 years leading up to the accident. In particular, the transition to the joint aviation requirements (JAR) in the 1990s and the switch to the European operating rules (EASA-OPS/EU-OPS), which in both cases also affected Ju-Air with regard to the conduct of its commercial air transport operations, would have given cause to critically examine the existing situation.

As a consequence, the Federal Office of Civil Aviation was unaware that an essential basic requirement for commercial air transport operations had not been met.

2.4.4.2 Technical inspection activities

It is remarkable that airworthiness inspections performed by the Federal Office of Civil Aviation on HB-HOT (the aircraft involved in the accident) over several years did not reveal any defects. The FOCA inspectors had also found no reason for complaint with regard to overall maintenance since 2010. This can be explained by the fact that the inspectors only checked formal aspects and that the exchange of information between the specialist FOCA departments responsible for different areas within Ju-Air was minimal. The inspectors also lacked the specialist knowledge required to adequately understand these rather specific aircraft types and their characteristics. They were therefore dependent on people from the maintenance organisations, and had confidence in the expertise and professionalism of these people without critically assessing them.

The technical supervisory activities were largely formal and little consideration was given to the actual situation (this was also true for inspections). Furthermore, there was no recognition of or complaints made regarding the obvious and numerous shortcomings in the documentation and management of spare parts.

The auditing supervisory authority occasionally identified and challenged deficits within the continuing airworthiness management organisation and the maintenance companies. Some of these complaints were, however, not rectified by the relevant companies, which led FOCA to demand further improvements during the next audit. These identified deficits had not been corrected at the time of the accident.

As the improper mechanical condition of the Ju 52/3m g4e registered as HB-HOT had no demonstrable influence on the occurrence of the accident, the ineffectiveness of the technical supervision cannot be considered a causal factor. It is, however, a factor to risk which should be improved in future.

2.4.4.3 Operational approval

When analysing the application of the supranational requirements to the air operator’s approval for commercial air transport, it should first of all be noted that European Regulation 965/2012 applies to all commercial air transport, regardless of whether it is performed under instrument flight rules (IFR) or visual flight rules (VFR). FOCA tolerated that Ju-Air had been derogating from the minimum flight altitudes required for commercial air transport as well as from other standards. In this regard, there were different opinions within FOCA. Some officers were of the opinion that the requirements of European Regulation 965/2012 did not apply to these areas for operations under visual flight rules. Other FOCA officers, however, were convinced that the rules applied to any form of commercial air transport, including Ju-Air’s operations. At the same time, they took the view that Switzerland was permitted to grant exceptions. Nevertheless, FOCA had tacitly consented to these derogations without documenting them accordingly and notifying the European authorities.

The aim of the European rules and thereby also of the regulation in question is to ensure an appropriate level of safety for commercial air transport. In the present case, the exemptions accepted by FOCA resulted in Ju-Air's aircraft being operated with a level of safety that was significantly lower and did not correspond to that specified for commercial air transport.

An analysis of the air operator's operations manual (OM), based on the relevant legal bases, shows that it was prepared in an effort to meet the requirements of EASA and FOCA as best as it could. However, this extensive document is unconvincing from the point of view of safety, as it has been unable to identify and reduce the main risks of VFR operations, specifically those which were involved in the accident. Overall, it is evident that the chosen form of regulation and the associated supervision were not suitable for this type of operation. As a consequence, it merely led to a great deal of formal effort, which was ineffective with regard to the essential problems.

The requirements for commercial air transport operations were therefore ultimately not met. Had the supranational guidelines been observed, it would not have been possible for the accident flight to take-off and fly at the selected altitude and on the selected flight route. The fact that the flight took place nonetheless must be considered a systemic cause of the accident.

2.4.4.4 Operational supervision

As part of operational supervision, Ju-Air aircraft also underwent six unannounced ramp inspections carried out by FOCA in the years prior to the accident flight. As a standard procedure, the calculations of mass and centre of gravity should also be checked for their correctness during these inspections. To a certain extent, it is understandable that the calculation and programming errors in the flight planning programme used by Ju-Air were not detected as part of these inspections. It is, however, difficult to understand that none of the inspectors detected obvious errors, such as incorrect basic empty mass (BEM). An error of this kind should have been easy to detect. Even during the flight inspection on 13 September 2016, the FOCA inspector did not notice that the calculation used incorrect basic aircraft values for mass and arm. This is unlikely to be due to a lack of expertise as being able to perform such calculations correctly or to verify them is one of the basic skills of every pilot[40]. This demonstrates a less than critical approach to supervisory activities. In this case, this had a particularly dangerous effect as it did not help to prevent HB-HOT from having a risky centre of gravity during the accident flight, which qualifies as a systemically contributory factor.

Although FOCA inspectors usually conducted several proficiency checks on flights without passengers every year, they largely did so without flight inspections of actual flight operations. As a result, they had only a limited insight into the company's actual flight operations. On the occasion of one of these rare flight inspections, during which an inspector from the Federal Office of Civil Aviation supervised a flight with passengers on board and which took place in a mountainous area, the flight was performed significantly below the safety margin of at least 1,000 ft AGL (300 m AGL) on several instances. Furthermore, essential principles for safe mountain flying were disregarded. The choice of flight path clearly contradicted the guidelines for flights in the Alps drawn up by FOCA, as published under RAC 6-3 in the Swiss Aeronautical Information Publication (AIP) VFR guide (see section A1.17.6.2.2). The inspector, however, did not fault the flight in any way. This exemplifies either a lack of critical judgement or a lack of critical attitude on the part of the inspectors towards the flying skills of Ju-Air's experienced pilots, which led to obvious errors in flight operations not being rectified by the supervisory authority.

[40] FOCA's operational inspectors have a sound background as airline pilots.

An analysis of the operational inspections and audits carried out by the Federal Office of Civil Aviation at Ju-Air has shown that the main focus of the inspections was the formal existence of the procedures specified in the operations manual. In reality, however, the correct and safety-conscious implementation of these procedures was not examined effectively. The supervisory authority acted as if they were unaware of the, at times, serious violations committed by Ju-Air's flight crews, despite the fact that occasional reports to FOCA would have given cause for more in-depth investigations. The fact that the main risks to flight operations were not identified and that it was therefore not possible to take these into account in the design of operational supervision is likely to have had an aggravating effect. And, although the individual specialist departments within the authority engaged in an organisation-based exchange of information, communication between the technical inspectors was minimal, which meant that the regulatory authority was unable to obtain a true picture of Ju-Air's operations.

It should be noted that the audits of FOCA carried out by the supranational supervisory authority EASA in the years prior to the accident had revealed some of these shortcomings. These included insufficiently in-depth supervisory activities on the part of FOCA. At the time of the accident, however, these findings had not had any effect because they had apparently not led to any corrective action being taken by FOCA with regard to the supervision of Ju-Air and its maintenance organisations.

The fact that the supervisory authority was unable to identify the numerous operational shortcomings and risks, and was also unable to take corrective action in this respect, must be regarded as a systemic contributory factor in the accident.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The aircraft was certified for flying under visual flight rules (VFR).
- As no manufacturer or type certificate holder had existed since the air operator put the Ju 52/3m g4e aircraft with BMW 132 A3 engines into service, it was the air operator’s responsibility to ensure airworthiness in collaboration with the supervisory authority and without the support of a manufacturer.
- The certificate of airworthiness listed Ju-Air’s Junkers Ju 52/3m g4e aircraft in the ‘Normal’ subcategory of the ‘Standard’ airworthiness category.
- According to the Swiss Ordinance on Airworthiness (VLL) valid at the time of the accident, Ju-Air’s Junkers Ju 52/3m g4e aircraft should have been classified in the ‘Historical’ subcategory of the ‘Special’ category.
- The classification of Ju-Air’s Ju 52/3m g4e aircraft had not been reviewed since the air operator was established, even though the overall specifications have evolved over time.
- The air operator commissioned organisations, which did not hold the necessary certification to manufacture components for use in the aviation industry, to produce spares based on pattern parts, and then used these on the type Ju 52/3m g4e aircraft.
- A significant number of engine faults occurred in the ten years before the accident.
- The manufacturer originally intended that the HB-HOT engines would run for 200 to 300 hours until a major overhaul.
- Between 1985 and 2004, the air operator obtained approval from FOCA to extend the engine operating time to 1,500 hours before a major overhaul.
- HB-HOT’s engines sometimes required major repair work just a few operating hours after a general overhaul.
- In the two years before the accident, HB-HOT’s engines did not achieve the maximum rpm specified by the manufacturer during static testing.
- Several cases of pronounced vibrations caused by loose propeller blades occurred during flights between 2012 and 2018.
- HB-HOT was no longer able to achieve the flight performances originally published in the operating manual.
- Between 1984 and 2001, 41 service bulletins were issued for remanufactured components or parts to be reconditioned. Each of these bulletins was approved by the Federal Office of Civil Aviation.
- After 2002, the majority of service bulletins were no longer maintained, i.e. processes and subcontractors were no longer updated and submitted to the Federal Office of Civil Aviation for approval.
- Numerous other remanufactured components have, however, still been developed without being accompanied by a service bulletin. No approval was obtained from the Federal Office of Civil Aviation for these parts.
- In many instances, the quality of the remanufactured and reconditioned aircraft parts was poor.

- No complaints regarding HB-HOT were made during airworthiness inspections by FOCA between 2010 and 2018.
- There were shortcomings in documentation and in the management of spare parts.
- The generally inadequate record keeping was never challenged during inspections by FOCA.
- The consequence of persons simultaneously performing several roles at Ju-Air, as a maintenance organisation and CAMO, as well as Naef Flugmotoren AG was that the quality assurance processes were unable to develop sufficiently.
- FOCA repeatedly challenged various deficits in the maintenance organisations and the CAMO. Some of these complaints were not rectified.
- FOCA's supervisory activities identified and took issue with some deficiencies in infrastructure, work processes and the management of aircraft parts. However, most of these shortcomings had not been rectified by the maintenance organisations.
- The exchange of information among the employees of FOCA's 'Safety Division – Aircraft' department regarding the supervised organisations was insufficient. The respective inspectors carried out supervisory activities primarily within their relevant areas of expertise.
- There was no specific preparation of the audits and inspections taking the situation at Ju-Air into account. The audits were schematically and formally designed and prepared.
- FOCA had been lacking expertise on piston engines for some time.
- Considerable corrosion damage was found on structural parts of the wing and fuselage.
- A lower spar on the left outer wing showed evidence of fatigue fractures.
- The material, which is prone to intergranular corrosion, had insufficient or no surface protection at all.
- HB-HOT, the aircraft involved in the accident, was not airworthy in a physical or formal sense.
- There is no evidence that the technical defects found on HB-HOT and the inadequacies in maintenance were a contributory factor in this investigated accident.

3.1.2 Operational aspects

- The base and flight planning software for calculating the mass and centre of gravity exhibited deficits and errors.
- The flight crews who did not adhere to generally accepted principles for safe flying in mountainous areas when operating the type Ju 52/3m g4e aircraft were often those who had trained as Air Force pilots. In particular, they systematically and significantly flew below safe altitudes and violated the minimum separation from obstacles.
- The air operator had not analysed the significant operational risks that led to the accident; nor had such a risk assessment or suitable remedial measures ever been requested by the supervisory authority.

- During this investigation, the air operator's management and monitoring of flight operations were identified as ineffective with regard to the known risks and the violation of rules.
- Ju-Air's Ju 52/3m g4e aircraft were not operated properly because neither the licensing and regulatory authority nor the air operator adequately took into account the basic requirements for commercial air transport operations.
- Experienced flight crews who often made mistakes regarding basic flying skills (airspace violations, non-compliance with basic rules) during flight operations showed deficits in terms of operation-specific training and collaboration (crew resource management – CRM).
- Performance reviews were conducted by those responsible in a manner which lacked critical rigour and ignored errors.

3.1.3 Flight crew

- Both pilots possessed the necessary licences for the flights.
- There is no indication that the pilots experienced any health problems during the accident flight.
- At the time of the accident, both pilots possessed vast overall flight experience and their training on the accident type was sound and up to date.
- The flying careers of the two pilots are very similar. The aeronautical skills of both pilots were assessed as good to very good throughout their careers.
- The behaviour of both pilots shows that they regarded some rules for safe flight operations as not mandatory for themselves and were willing to take high risks.

3.1.4 Accident flight

- The crew's knowledge of the weather conditions with regard to the accident flight was sufficient. The calculations for mass and centre of gravity were not carried out correctly. The performance calculations for take-off, cruise flight and landing were missing.
- All of the aircraft's controls were in working order for the entire flight; it was possible to adjust the engines and they provided power.
- The flight crew chose a very high-risk flight path, which, due to the low height above ground and the lack of space to turn back, did not allow any exit routes or room for correction in the event of errors, malfunctions or weather effects.
- The flight crew piloted the aircraft at a speed that was too low for the chosen flight path and was therefore dangerous.
- Flying into weather conditions usual for high mountain terrain in summer with inadequate safety margins led to at least a temporary loss of control of the aircraft.
- During the attempt to regain control of the aircraft, an accelerated stall occurred which led to an almost vertical impact.
- At the time of the accident, the mass of the aircraft involved in the accident was within the limits specified in the aircraft flight manual. The centre of gravity was beyond the rear limit.
- At the time of the impact, the full-throttle limiter was set to 'on', which shows that the engines were not running at the highest possible speed.
- The ELBA emergency location transmitter was triggered.

3.1.5 General conditions

- The weather conditions were suitable for a VFR flight over the Alps.
- The weather developed in line with the forecasts, with shower and thunderstorm activity on the chosen route being somewhat lower than predicted by the forecast.
- Meteorological developments were easy to observe and, due to the weather in the canton of Ticino and in the Rhine valley, it was possible to turn back or change route at any time.
- The crew was aware of the hazards posed by density altitude and the chance of thunderstorms; they had no effect on the course of the flight under investigation.
- There were several alternatives, should the clouds and precipitation on the alpine ridge have hindered the flight over the Alps.
- When the Alps were crossed, precipitation was limited to a few light showers that were easy to avoid.
- The turbulence in the lee of the Segnes pass was not unusual for an afternoon of increasing northerly wind and included significant areas of updraught and downdraught, which posed a hazard for a flight in close proximity to the terrain.
- The majority of the air operator's procedures, and in particular its safety management system, were only formal in nature and were not properly applied.
- The air operator, maintenance organisations and the supervisory authority used personnel who either did not identify the risks or did not take effective measures to reduce them.
- The majority of incidents as well as several serious incidents were not reported to the competent authorities. As a result, it was not possible for any appropriate lessons to be learnt or consequences to be drawn from such occurrences.
- The regulatory and supervisory activities were not adapted to this type of operation.
- FOCA's activities relating to regulation, approval and supervision were to a large extent ineffective with regard to the risks, incidents and violations identified during the investigation.
- The supranational supervision of the Swiss supervisory authority showed that FOCA's activities did not adequately ensure an in-depth verification of compliance by the aviation companies.

3.2 Causes

> In order to achieve its objective of prevention, a safety investigation authority shall express its opinion on risks and hazards that have been identified during the investigated incident and which should be avoided in the future. In this sense, the terms and formulations used below are to be understood exclusively from the perspective of prevention. The identification of causes and contributory factors does not, therefore, in any way imply assignment of blame or the determination of administrative, civil or criminal liability.

3.2.1 Direct cause

The accident is attributable to the fact that after losing control of the aircraft there was insufficient space to regain control, thus the aircraft collided with the terrain.

The investigation identified the following direct causal factors of the accident:

- The flight crew piloted the aircraft in a very high-risk manner by navigating it into a narrow valley at low altitude and with no possibility of an alternative flight path.
- The flight crew chose a dangerously low airspeed as regard to the flight path.

Both factors meant that the turbulence which was to be expected in such circumstances was able to lead not only to a short-term stall with loss of control but also to an unrectifiable situation.

3.2.2 Directly contributory factors

The investigation identified the following factors as directly contributing to the accident:

- The flight crew was accustomed to not complying with recognised rules for safe flight operations and taking high risks.
- The aircraft involved in the accident was operated with a centre of gravity position that was beyond the rear limit. This situation facilitated the loss of control.

3.2.3 Systemic cause

The investigation identified the following systemic cause of the accident:

- The requirements for operating the aircraft in commercial air transport operations with regard to the legal basis applicable at the time of the accident were not met.

3.2.4 Systemically contributory factors

The investigation identified the following factors as systemically contributing to the accident:

- Due to the air operator’s inadequate working equipment, it was not possible to calculate the accurate mass and centre of gravity of its Ju 52 aircraft.
- In particular, the air operator’s flight crews who were trained as Air Force pilots seemed to be accustomed to systematically failing to comply with generally recognised aviation rules and to taking high risks when flying Ju 52 aircraft.
- The air operator failed to identify or prevent both the deficits and risks which occurred during operations and the frequent violation of rules by its flight crews.
- Numerous incidents, including several serious incidents, were not reported to the competent bodies and authorities. This meant that they were unable to take measures to improve safety.

- The supervisory authority failed to some extent to identify the numerous operational shortcomings and risks or to take effective, corrective action.

3.2.5 Other risks

The investigation identified the following factors to risk, which had no or no demonstrable effect on the occurrence of the accident, but which should nevertheless be eliminated in order to improve aviation safety:

- The aircraft was in poor technical condition.
- The aircraft was no longer able to achieve the originally demonstrated flight performance.
- The maintenance of the air operator’s aircraft was not organised in a manner that was conducive to the objective.
- The training of flight crews with regard to the specific requirements for flight operations and crew resource management was inadequate.
- The flight crews had not been familiarised with all critical situations regarding the behaviour of the aircraft in the event of a stall.
- The supervisory authority failed to identify numerous technical shortcomings or to take corrective action.
- The expertise of the individuals employed by the air operator, maintenance companies and the supervisory authority was in parts insufficient.

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

4.1 Safety recommendations

> In accordance with international[41] and national[42] legal bases, all safety recommendations are addressed to the supervisory authority of the competent state. In Switzerland, this is the Federal Office of Civil Aviation (FOCA) or the supranational European Union Aviation Safety Agency (EASA). The competent supervisory authority must decide on the extent to which these recommendations are to be implemented. Nonetheless, any agency, organisation and individual is invited to strive to improve aviation safety in the spirit of the safety recommendations expressed.
>
> 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.

The Swiss Transportation Safety Investigation Board drew up an interim report on the accident which is the subject of the investigation. This interim report was published on 20 November 2018. In this interim report, the STSB issued safety recommendation no. 548 and safety advice no. 25. In the context of the final report, the STSB is issuing safety recommendation nos 561 to 567 and safety advice nos 32 to 37.

4.1.1 Inspecting corrosion damage and defects in system components

4.1.1.1 Safety deficit

Considerable corrosion damage was found on the spars, hinges, wing fittings and in the area of the cabin floor panel on the wreckage of HB-HOT. Two of the three engines were equipped with remanufactured cam discs which exhibited defects.

Due to the sister aircraft, HB-HOP and HB-HOS, having the same year of manufacture, type of operation and operating hours, it must be expected that they have similar defects.

4.1.1.2 Safety recommendation no. 548

The Federal Office of Civil Aviation (FOCA), in collaboration with the air operator, should take appropriate measures to ensure that the sister aircraft, HB-HOP and HB-HOS, are inspected for corrosion damage and defects in system components.

4.1.2 Laying the foundations for effective, risk-based supervision

4.1.2.1 Safety deficit

The safety investigation has revealed that the implementation of legal requirements by both the supervisory authority and the air operator for operations with historic aircraft was primarily formal in nature. Many of the processes described in the manuals represented the operational requirements to a limited extent only. In particular, only partial provisions had been made for the relevant risks of visual flight rules operations involving annex II aircraft, as specified in European Regula-

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[41] Annex 13 of the International Civil Aviation Organization (ICAO) and article 17 of Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC.

[42] Article 48 of the Swiss Ordinance on the Safety Investigation of Transport Incidents (OSITI) of 17 December 2014, as at 1 February 2015 (OSITI, SR 742.161).

tion 216/2008 (equivalent to today's annex I aircraft, as specified in European Regulation 2018/1139). Overall, regulation proved to be complex and not well adapted to the actual needs of flight operations. Regardless of the organisational form, the level of safety required for air operations involving passengers should be guaranteed. A consultation on possible safety recommendations has shown that a solution needs to be sought at national level. As the legislative process is likely to take some time, a two-step approach is recommended.

4.1.2.2 Safety recommendation no. 561

The Federal Office of Civil Aviation should ensure that rules are adapted to air operations with passengers on aircraft referred to in annex I of European Regulation 2018/1139 and that these effectively address the risks specific to such operations.

4.1.2.3 Safety recommendation no. 562

Until safety recommendation no. 561 has been implemented, the Federal Office of Civil Aviation should ensure that the risks specific to the particular flight operations involving passengers on annex I aircraft, as defined in European Regulation 2018/1139, are identified and effectively reduced with an effort suited to the complexity and scale of the respective operation.

4.1.3 Issuing exemptions

4.1.3.1 Safety deficit

The safety investigation has revealed that at the time it was commissioned for use in civil aviation, the aircraft was categorised in accordance with legal requirements which have changed over time. As a result, the type classification was no longer correct at the time of the accident. Based on the original classification of the type, various requirements for approval were declared inapplicable by way of exemption. These decisions were not reviewed even in the case of major legislative amendments.

4.1.3.2 Safety recommendation no. 563

When granting exemptions for annex I aircraft, as specified in European Regulation 2018/1139, the Federal Office of Civil Aviation should take into account the risks specific to their relevant operation and periodically review the exemptions.

4.1.4 Monitoring operation of historic aircraft

4.1.4.1 Safety deficit

The safety investigation demonstrated that on numerous occasions, the flight crews violated rules and took high risks during the operation of historic aircraft. This high-risk behaviour was detected by neither the air operator nor the supervisory authority due to a lack of effective management, monitoring and oversight. Numerous other safety-related incidents were neither detected by the operator nor the regulatory body, and, where they had been detected, were not addressed in a manner that enhanced safety.

4.1.4.2 Safety recommendation no. 564

The Federal Office of Civil Aviation, together with organisations which operate historic aircraft primarily for the transport of passengers, should define effective risk-based management and supervisory measures which are capable of identifying and correcting the specific problems with this type of operation at an early stage.

4.1.5 Improving the organisation of supervisory activities

4.1.5.1 Safety deficit

The safety investigation demonstrated that the audits and inspections performed by the Federal Office of Civil Aviation were not capable of providing a realistic overview of the actual operations or actual processes conducted by the air operator and in the maintenance companies. Supervision was largely formal and ineffective, particularly as there was a lack of critical attitude within the authority and because the exchange of information between the technical inspectors was inadequate.

4.1.5.2 Safety recommendation no. 565

The Federal Office of Civil Aviation should improve its organisation of audits and inspections in such a way as to improve the exchange of information within the authority, as well as to enable both critical analysis of the organisation concerned and the identification of relevant problem areas more effectively.

4.1.6 Improving the level of expertise of the supervisory authority

4.1.6.1 Safety deficit

The safety investigation revealed that the staff of the Federal Office of Civil Aviation were often unable to identify the safety-related problems during audits and inspections of the air operator and the maintenance organisations. With regards to supervision of technical aspects, a lack of technical and methodological expertise in such historic aircraft played a major role in this. This led to a certain dependence on the know-how of the staff employed by the maintenance organisations under supervision. With regards to supervision in the field of operations, the inspectors no doubt had the expertise, they acted however insufficiently critical towards the air operator’s pilots. As a result, the activities of these companies were not effectively supervised.

4.1.6.2 Safety recommendation no. 566

The Federal Office of Civil Aviation should acquire the necessary technical and methodological expertise for the supervision of historic aircraft or make it available from an independent party. Furthermore, it should ensure that supervision is exercised in an effective manner.

4.1.7 Determining performance data for overhauled aircraft

4.1.7.1 Safety deficit

The safety investigation demonstrated that certain aspects of the aircraft’s performance and operating data were no longer accurate or were missing. It was, for example, no longer possible to achieve the documented performance for cruise flight, there was a lack of information on manoeuvring speed, and the performance after an engine failure was insufficiently documented.

4.1.7.2 Safety recommendation no. 567

The Federal Office of Civil Aviation should require the air operator to determine key performance data of its Ju 52/3m g4e aircraft following a major overhaul, and adapt the corresponding documents accordingly prior to the aircraft type being released for service.

4.2 Safety advice

> The STSB may publish general relevant information in the form of safety advice[43] if a safety recommendation in accordance with Regulation (EU) No. 996/2010 does not appear to be appropriate, is not formally possible, or if the less prescriptive form of safety advice is likely to have a greater effect.

4.2.1 Reviewing and improving maintenance procedures

4.2.1.1 Safety deficit

Several shortcomings were identified during examination of the maintenance work. This included in particular the documentation for performing major modifications and the management of spare parts. Such deficiencies represent a risk.

4.2.1.2 Safety advice no. 25

The air operator and maintenance organisations should – together with the continuing airworthiness management organisation (CAMO) – review and improve their existing processes to ensure the traceability of maintenance work and unambiguous spare parts management.

4.2.2 Retraining flight crews

4.2.2.1 Safety deficit

The safety investigation demonstrated that the flight crews exhibited a tendency towards systemic reckless violation of generally recognised aviation rules. Furthermore, air operator Ju-Air's pilots were found to have insufficient up-to-date knowledge of basic flying principles such as the structure of airspace, flight preparations, calculation of the mass and centre of gravity, and knowledge of aviation regulations.

4.2.2.2 Safety advice no. 32

The air operator should provide retraining for its flight crews with specific regard to discipline, compliance with rules and in particular safe flying practices in mountainous areas and the application of the basic principles of flying.

4.2.3 Improving crew resource management

4.2.3.1 Safety deficit

The safety investigation revealed that even flight crews with extensive experience frequently made basic errors such as airspace violations. Despite the fact that aircraft were often flown by two experienced pilots with captain's rank, these mistakes were not avoided. Performance reviews were occasionally accepted without critical rigour and obvious mistakes were not identified or addressed with regards to corrective action to be taken. Such behaviour is evidence of considerable deficits in collaboration, especially among experienced crew members of equal rank.

4.2.3.2 Safety advice no. 33

The air operator should optimise collaboration among its flight crews (crew resource management) to meet the specific requirements of its operations (VFR flights, flights in mountainous areas, extensive experience, equal rank, etc.).

[43] Article 56 of the Swiss Ordinance on the Safety Investigation of Transport Incidents (OSITI) of 17 December 2014, as at 1 February 2015 (OSITI, SR 742.161)

4.2.4 Improvement of management measures in flight operations

4.2.4.1 Safety deficit

The safety investigation revealed that flight crews at the air operator were often irresponsible in the way they dealt with the freedoms provided by the general operational framework conditions. Even experienced crew members who had worked at large airlines for long periods demonstrated this risky form of behaviour and violated basic safety rules. The companies for which they had previously worked all had effective management and monitoring measures in place which would have immediately revealed any deviation from the required quality of work. Ju-Air, in contrast lacked the means and tools to detect these safety issues. It can be concluded that flight crews with a long history of safety-conscious environments can become undisciplined if effective management and monitoring measures are not in place.

4.2.4.2 Safety advice no. 34

The air operator should develop and implement management and monitoring measures to detect and ensure compliance with basic safety principles and legal requirements.

4.2.5 Improving the safety management system

4.2.5.1 Safety deficit

The safety investigation revealed numerous quality issues in the maintenance of the aircraft operated by Ju-Air. Likewise, several examples proved that reports concerning safety-related incidents were not forwarded or processed in a manner that improved safety. This prevented or at least substantially reduced what could have been learnt from such incidents. Although the air operator formally had a safety management system in place, it was ineffective to a large extent.

4.2.5.2 Safety advice no. 35

The air operator should improve its internal processes, specifically those in relation to quality assurance and risk management, in order to allow the timely identification and targeted resolution of safety issues.

4.2.6 Performing incident and risk assessments

4.2.6.1 Safety deficit

The safety investigation demonstrated that the air operator never analysed significant risks encountered during flight operations. As a result, operations regularly took place in such a way that a minor malfunction could have caused an accident. The accident under investigation is typical of this, not least because a frequently applied, high-risk procedure coupled with a natural, every-day framework condition had a fatal effect.

4.2.6.2 Safety advice no. 36

The air operator should perform the missing incident and risk assessments and ensure that in the event of engine failure and when flying in mountainous areas, appropriate flight planning and route selection will allow for all flights to be completed safely without fail.

4.2.7 Improving training for critical flight conditions

4.2.7.1 Safety deficit

The safety investigation demonstrated that the air operator's flight crews had no experience of how the Junkers type Ju 52/3m g4e behaves in critical flight conditions under a normal passenger load.

4.2.7.2 Safety advice no. 37

The air operator should document critical flight conditions for realistic operational situations. Crews should be made as familiar as possible with critical flight conditions.

4.3 Measures taken since the accident

On 16 August 2018, the Federal Office of Civil Aviation decreed that the air operator must equip its aircraft with a logger in order to monitor and evaluate its flight operations. In addition, except for during take-off and landing, FOCA imposed increased minimum flight altitudes of 1,000 ft AGL above uninhabited areas and 2,000 ft AGL above inhabited areas. Furthermore, FOCA stipulated passengers must remain in their seats with their seat belts fastened throughout the entire flight. For its flight and cabin crews, Ju-Air was instructed to conduct a refresher course on standard operating procedures and crew resource management.

On 16 November 2018, FOCA issued a ruling withdrawing the certificates of airworthiness for HB-HOT's sister aircraft, HB-HOP and HB-HOS.

In September 2019, the Swiss Transportation Safety Investigation Board informed the relevant managers of the air operator, the maintenance organisations and the Federal Office of Civil Aviation to the fullest extent about the investigation results available up to that point and the safety deficits identified. This was done with the intention of providing these organisations with the necessary information as early as possible, in order to enable them to take effective measures to improve safety by the time the final report is published.

In its statement dated 29 July 2020, FOCA reported that it had taken the following measures to improve aviation safety. They are listed here by the STSB without comment:

"During the first quarter of 2019, three part-145 audits were carried out at Ju-Air, which led to the suspension of the part-145 certificate. This was followed by an inspection which revealed that Ju-Air continued to carry out maintenance work despite the withdrawal of its part-145 certificate. This led to a fine which was imposed on 15 October 2019.

Between 3 and 5 April 2019, a periodic audit was carried out at Naef Flugmotoren AG, which ended with the withdrawal of its part-145 engine approval (rating B2) and the privileges for subcontracting, effective from 11 April 2019. In preparation for this audit, files were inspected at the STSB on 13 and 14 March 2019.

Ju-Air voluntarily returned its part-M/G CAMO certificate on 15 May 2019.

On 11 June 2019, the new Junkers Flugzeugwerke company applied for part-145 certification for Ju 52 aeroplanes. This process is not yet completed.

On 7 May 2020, Naef voluntarily returned its part-145 approval.

On 24 June 2020, Ju-Air voluntarily returned the suspended part-145 approval.

Within FOCA, various internal activities have been launched.

On 25 and 26 March 2019, the STOB[44] & STOZ[45] departments conducted a 2-day 'Lessons Learnt' workshop based on the STSB's preliminary report and further measures were defined.

This was followed by a 2-day refresher course with the STOZ and STOB departments on audit technique and tactics, held on 23 and 24 September 2019. This included practical workshops and a session on lessons learnt.

In addition, a project was set up at FOCA to address and cater for ageing aircraft. A risk assessment has been carried out in this regard, which will also be included in the planned amendment to the law.

FOCA has supplemented and refined its processes for assessing the risks of flight operations. This is to ensure that supervisory planning covers particular risks that are not sufficiently addressed by the rules and regulations. This in-depth risk assessment has been adopted since 2019.

As operations have been suspended for a prolonged period of time [...]*, there is currently no immediate need for further operational measures against Ju-Air."*

Apart from FOCA, no other stakeholder reported measures taken since the accident.

This final report was approved by the Swiss Transportation Safety Investigation Board (article 10(h) of the Ordinance on the Safety Investigation of Transport Incidents of 17 December 2014).

Bern, 22 December 2020 Swiss Transportation Safety Investigation Board

44 *Sektion Technische Organisation Bern* (department 'Technical Organisations Bern')

45 *Sektion Technische Organisation Zürich* (department 'Technical Organisations Zurich')

A	Aeroplane
AAIB	Air Accidents Investigation Branch of the United Kingdom. Also referring to the English name of the BFU (*Büro für Flugunfalluntersuchungen*), i.e. the STSB as it was known formerly (Aircraft Accident Investigation Bureau)
ACM	Accountable manager
ACR	Aerobatics
AD	Airworthiness directive
AFM	Aircraft flight manual
AG	*Aktiengesellschaft*, public limited company
AGL	Above ground level
AIP	Swiss Aeronautical Information Publication, contains information for safe flight operations that is valid indefinitely
AIRMET	AIRMET and SIGMET are standardised warnings about hazardous weather elements. AIRMET focuses on VFR flights in the lower air space; SIGMET on IFR operations in the upper air space. See https://www.skybrary.aero/index.php/AIRMET For Switzerland (in French, Italian and German only) see https://www.meteosuisse.admin.ch/content/dam/meteoswiss/fr/service-und-publikationen/publikationen/doc/MCH_Flugwetter_2019_F_Web.pdf
Albedo	Percentage of backscattered solar radiation from the surface See UK MetOffice Glossary https://digital.nmla.metoffice.gov.uk/digitalFile_92185bd2-3849-4bfb-8196-cb7a941489c7/ or https://www.metoffice.gov.uk/weather/learn-about/weather/atmosphere/albedo
AMC	Acceptable means of compliance
AMP	Aircraft maintenance programme
AMSL	Above mean sea level
AOC	Air operator certificate
Aqua	One of the polar orbiter satellites, which observe the Earth from an altitude of about 700 km and thus provide medium-resolution images. This, however, can occur only once or twice a day for a specific location. https://aqua.nasa.gov/
ARC	Airworthiness review certificate
ARO	Authority requirements for air operations
Assimilation	Important step for the selection and preparation of data used in forecast models See https://www.metoffice.gov.uk/services/data/business-data/glossary
ATC	Air traffic control
ATPL(A)	Airline transport pilot licence aeroplane
ATS	Air traffic services
BA	Bank attitude
BAMF	*Bundesamt für Militärflugplätze*, Federal Office for Military Aerodromes
BAZL	*Bundesamt für Zivilluftfahrt*, Federal Office of Civil Aviation (FOCA)
BEA	*Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile*, the French safety investigation authority
BEM	Basic empty mass
BFU	*Büro für Flugunfalluntersuchungen*, former German name of the Swiss Transportation Safety Investigation Board (STSB), Aircraft Accident Investigation Bureau of Switzerland

BR	Propeller blade rate
CAME	Continuing airworthiness management exposition, manual for managing an aircraft's continued airworthiness
CAMO	Continuing airworthiness management organisation
CASA	*Construcciones Aeronáuticas Sociedad Anónima*, former Spanish aircraft manufacturer
CAT	Commercial air transport
CB	A cumulonimbus is a high reaching cumulus with an anvil-shaped top, usually generating a thunderstorm. High reaching cumuli without anvil are called TCUs (towering cumuli). In flying, TCUs and CBs often get mixed up. See https://cloudatlas.wmo.int/en/home.html or https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/clouds/low-level-clouds/cumulonimbus and https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/clouds
CEST	Central European summer time (UTC plus two hours)
CFD	Computational fluid dynamics: a branch of science that, with the help of computers, produces simulations of different fluids' flow (gases and liquids) behaviour
CG	Centre of gravity
CMD	Commander
CMM	Compliance monitoring manager
CofA	Certificate of airworthiness
COSMO	Consortium for Small-scale Modeling https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/warning-and-forecasting-systems/cosmo-forecasting-system.html
CR	Cylinder rate
CRM	Crew resource management
CSR	Crank shaft rate
CT	Computed tomography, an imaging procedure used in radiology; objects can be viewed three-dimensionally on a computer
CTR	Control zone
Cumulus, Cumuli	The technical term for cauliflower-shaped heap clouds, which are formed by isolated rising air parcels. Cooling during the ascent causes previously invisible water vapour to condense. A cumulus with a flat base (lower limit) is still active; a decaying one with an undefined base is no longer fed by updraughts. See also https://cloudatlas.wmo.int/en/home.html or https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/clouds/low-level-clouds/cumulus and https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/clouds
CVR	Cockpit voice recorder
Diurnal variation	A fluctuation of, for example, temperature or atmospheric pressure that occurs over the course of a diurnal rhythm
Density altitude	The altitude relative to the ICAO standard atmosphere at which the air density would be equal to that at the location under consideration. Instead of mentioning the explicit air density, the altitude at which this density would normally occur in the standard atmosphere is stated.
DME	Distance measuring equipment, a transponder-based measuring system for the slant range distance from a beacon

EASA	European Union Aviation Safety Agency, formerly the European Aviation Safety Agency (prior to September 2018)
EASA-OPS	Colloquial term for the rules laid down in European Regulation 965/2012
EC	European Community
EDTG	ICAO code for Bremgarten Airport (Germany)
EEC	European Economic Community
ELBA	Emergency locator beacon aircraft, an emergency transmitter carried on an aircraft
ESD	Electrostatic discharge
ETE	Estimated time elapsed
ETO	Estimated time overhead
EU	European Union
EUMETSAT	International organisation for the operation of European weather satellites https://www.eumetsat.int
EU-OPS	Colloquial term for the rules laid down in European Regulation 3922/91, amended by European Regulation 859/2008
FDM	Flight data monitoring
FDR	Flight data recorder
FI	Flight instructor
FIS-LW	Air Force command and information system
FL	Flight level
FOCA	Federal Office of Civil Aviation, *Bundesamt für Zivilluftfahrt (BAZL)*
FOQA	Flight operations quality assurance, a system where flights and their parameters such as position, altitude, speed, bank attitude, etc. are recorded, analysed and compared against a standard benchmark; a common synonym for flight data monitoring (FDM) in American English
FOR	Zurich Forensic Science Institute
FPA	Flight path angle: the angle between the tangent to the flight path and the horizontal plane in the geodetic coordinate system
ft AMSL	Feet above mean sea level
ft/min	Feet per minute, a unit of measurement for vertical speed
GAFOR	General aviation forecast for the weather conditions prevailing along the main VFR flight routes in Switzerland
GEN	General requirements
GIN	*Gemeinsame Informationsplattform Naturgefahren*, Common Information Platform for Natural Hazards https://www.natural-hazards.ch/home/about-us/federal-agencies-with-responsibility-for-natural-hazards.html
GM	Guidance material
GND	Ground
GoPro	A type of robust and weatherproof small action camera used for video recording
GPS	Global Positioning System, a satellite-based navigation system
GS	Ground speed, speed of the aircraft in relation to the ground over which it is flying, i.e. in relation to the geodetic coordinate system
Gust, gusts	Gusts, also referred to as turbulence, are deviations from the average wind speed, which can have both positive and negative values. Information on

	gusts in aviation weather reports (code G), however, denote the wind speed in wind peaks (positive gusts).
Heap cloud	See cumulus
Histogram	A bar chart that shows the relative or absolute number of classed values
Hotspot	An identified high-risk flight situation
hPa	Hectopascal (100 Pa), the internationally standardised unit of pressure; 1 hPa corresponds to 1 millibar (mbar), a unit that is also still widely used
Hz	Hertz, the unit of measurement for frequency, expressing the number of oscillations per second
IAS	Indicated airspeed
ICAO	International Civil Aviation Organization
IDE	Instruments, data, equipment
IFR	Instrument flight rules
IMC	Instrument meteorological conditions
Interpolation	The insertion of an intermediate value calculated between two supporting values (e.g. from a table); this can be either a simple linear interpolation or based on an algorithm adapted to the data set
ISA	International standard atmosphere according to the ICAO
Isotherm	Lines of equal temperature on a corresponding diagram
Isothermal layer	A layer of air in which the temperature does not change with altitude; an isothermal layer is a stable layer (see neutral stratification)
ISP	In-flight service personnel, flight attendant
JAA	Joint Aviation Authorities
JAR-OPS 1	Joint aviation requirements for operations
JFM	Junkers Flugzeug- und Motorenwerke AG
Joint	The Ju 52/3m g4e is designed as an all-metal aircraft featuring a truss-construction airframe. The spars are connected to each other with cross bracings and struts. The connection points are called joints.
JU-OFP	Ju-Air’s flight planning software
kt	A unit of speed commonly used in aviation; 1 kt = 1 nautical mile per hour = 1.852 km/h = 0.5144 m/s
Lee	The side sheltered from the direction of the air current; concerning wind, lee in relation to a northerly wind is located on the southern side of the crest (see windward)
LES	Large eddy simulation, a simulation similar to CFD; see also PALM
Lidar	Laser detection and ranging – a measuring system that emits laser pulses and evaluates the backscattered light from the atmosphere, in this case with regard to the Doppler effect; in this investigation, it was used for the three-dimensional measurement of wind above the site; https://www.zxlidars.com/wind-lidars/zx-300/
LSMD	ICAO code for Dübendorf Air Base
LSMM	ICAO code for Meiringen Air Base
LSZA	ICAO code for Lugano Airport
LSZC	ICAO code for Buochs Airport
LSZH	ICAO code for Zurich Airport
LSZL	ICAO code for Locarno Aerodrome
LSZT	ICAO code for Lommis Airfield

LTA	*Lufttüchtigkeitsanweisung*, airworthiness directive issued by a supervisory authority
m AMSL	Height (altitude for flights or elevation for terrain) in metres above mean sea level
m/M	*Meter über Meer*, German for metres above mean sea level
m/s	Speed in metres per second; 1 m/s = 3.6 km/h = 1.944 kt or approximately 1 m/s ≅ 2 kt
MAB	Mass and balance
MAR	March
MEM	Management evaluation meeting
METAR	Meteorological aviation routine weather report is a coded message, reporting the present weather conditions on airports. See https://www.skybrary.aero/index.php/Meteorological_Terminal_Air_Report_(METAR) For Switzerland (in French, Italian and German only) see: https://www.meteosuisse.admin.ch/content/dam/meteoswiss/fr/service-und-publikationen/publikationen/doc/MCH_Flugwetter_2019_F_Web.pdf
MeteoSwiss	Abbreviation for the Federal Office of Meteorology and Climatology https://www.meteoswiss.admin.ch/home.html?tab=overview
mm/h	Millimetres per hour: a measure of the intensity of precipitation as rain, snow, sleet, soft hail, etc., which also corresponds to one litre per square metre per hour; this indication of intensity can also be applied to precipitation with a duration of less than one hour
MME	Maintenance management exposition, manual for managing an aircraft's maintenance
Mode S	Secondary radar, radar data from a transponder with mode S functionality
MOE	Maintenance organisation exposition, manual for a maintenance organisation
MOPSC	Maximum operational passenger seating configuration
MPA	Motor-powered aircraft
MRT	Multi-radar tracking
MS	Abbreviation for the Dassault Mirage III S fighter aircraft
Neutral stratification	The vertical temperature distribution (temperature profile, ambient temperature profile) of a rising or sinking air parcel determines whether it continues to rise or fall unhindered (neutral), accelerates (unstable), or is slowed down (stable). Neutral stratification with a temperature decrease of 1°C per 100 m of altitude is always achieved when non-condensing ('dry') air is mixed vertically, which is typical for sunny days below clouds. If condensation (cumuli) occurs in a neutrally stratified atmosphere, it continues to grow until a stable layer with a temperature decrease of less than approx. 0.5°C per 100 m prevents it. The exact values depend on humidity and altitude, which are represented on diagrams or in calculation models.
NLR	*Koninklijk Nederlands Lucht- en Ruimtevaartcentrum,* Royal Netherlands Aerospace Centre
NPCA	Nominated person continuing airworthiness
NPFO	Nominated person flight operations
NPGO	Nominated person ground operations
OFP	Operational flight plan
OM	Operations manual

OM A	Part A of the operations manual
OM B	Part B of the operations manual
OMM	Operation management manual
OP	Operating procedures
OPS	Operations, prefix for EU-OPS rules
OR	Occurrence report, operations report or operational report
ORO	Organisation requirements for air operations
PA	Pitch attitude
PA	Public address, announcement of information to passengers using the on-board communication system
PALM	The parallelized large-eddy simulation model https://palm.muk.uni-hannover.de/trac
PAX, Pax	Passenger, passengers
PF	Pilot flying
PIL	Pending items list
PM	Pilot monitoring, pilot not flying, assisting pilot
POL	Aircraft performance and operating limitations
Pressure gradient	Pressure difference per mostly horizontal distance
PS	*Pferdestärke*, metric horsepower, a historical unit of power; 1 PS corresponds to 0.736 kW
QFE	Atmospheric pressure at the location under consideration
QFF	The atmospheric pressure measured at a location (at a certain altitude) or determined in a model (QFE), which has been converted to the theoretical pressure at sea level, taking into account the local temperature, to allow ground weather maps to be drawn
QNH	Atmospheric pressure reduced to sea level, calculated using values for ICAO standard atmosphere. Like the QFF, this is a purely theoretical value. Because no actual ambient temperature is taken into account, the QNH is even further away from reality than the QFF, depending on the season. The primary use of the QNH is in internationally standardised handling of altitude measurement for medium- and low-level air traffic (e.g. in the vicinity of airports) based on pressure measurement.
RAC	Rules of the Air and Air Traffic Service, chapter within the Swiss Aeronautical Information Publication (see also AIP)
Radar	Radio detection and ranging, a measuring system that emits radio waves that are scattered by objects. In meteorology, it is used to record the distribution of precipitation in a radius of about 100 km and more at different altitudes. Details for Switzerland can be found at https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/atmosphere/weather-radar-network.html
REGA	*Schweizerische Rettungsflugwacht*, Swiss air rescue service
rpm	Revolutions per minute, unit of measurement
SACA	Safety assessment of community aircraft
SAFA	Safety assessment of foreign aircraft
Safety altitude	A deliberate choice of words referring to the flight altitude necessary for safe piloting. Depending on the situation, this may be the legal minimum required flight altitude or another safe distance from the ground in mountainous areas. Experience shows that, depending on the combination of

	topography and weather conditions, even greater minimum altitudes are required for safe mountain flying.
SAG	Safety action group
SANA	Safety assessment of national aircraft
SB	Service bulletin
SD card	Secure digital memory card, a digital storage medium
SEP	Single engine piston
SERA	Standardised European rules of the air
SIGMET	See AIRMET and https://www.skybrary.aero/index.php/SIGMET
SLS	*Schweizerische Luftverkehrsschule*, Swiss Aviation School
SM	Safety manager
SMS	Safety management system
SOP	Standard operating procedures
SPI	Safety performance indicator
SRB	Safety review board
SSID	Supplemental structural inspection document
ST	The *Sicherheit Flugtechnik* (Flight Safety) division of the Federal Office of Civil Aviation (FOCA)
Stable stratification	See neutral stratification
STEH	The *Entwicklung und Herstellung* (Design and Production) department of the Federal Office of Civil Aviation (FOCA)
STLZ	The *Lufttüchtigkeit Flugmaterial Zürich* (Aircraft Airworthiness Zurich) department of the Federal Office of Civil Aviation (FOCA)
STOB	The *Technische Organisation Bern* (Technical Organisations Bern) department of the Federal Office of Civil Aviation (FOCA)
STOZ	The *Technische Organisation Zürich* (Technical Organisations Zurich) department of the Federal Office of Civil Aviation (FOCA)
SUST	*Schweizerische Sicherheitsuntersuchungsstelle*, Swiss Transportation Safety Investigation Board (STSB), formerly the *Schweizerische Unfalluntersuchungsstelle*, Swiss Accident Investigation Board
SWC	Significant weather chart, a weather chart with various characteristics that represent the most important weather elements for the respective users
TAF	Terminal aerodrome forecasts are standardised coded messages, describing the expected weather for airports during the next 9 or 30 hours (short or long, resp.). See https://www.skybrary.aero/index.php/Weather_Forecast#Weather_Forecast. For Switzerland (in French, Italian and German only) see: https://www.meteosuisse.admin.ch/content/dam/meteoswiss/fr/service-und-publikationen/publikationen/doc/MCH_Flugwetter_2019_F_Web.pdf
TAS	True airspeed, the true airspeed relative to the surrounding air
TAWS	Terrain awareness and warning system
TC	Type certificate
TCU	Towering cumulus, cumulus congestus clouds without an anvil-shaped top (see CB)
TE	Abbreviation for the Northrop Tiger F-5E fighter aircraft
TERRA	An Earth observing satellite (see Aqua), https://terra.nasa.gov/
TM	*Technische Mitteilung*, technical communication

TMA	Terminal area
TOM	Take-off mass
TORA	Take-off run available, available distance for take-off roll
TOW	Take-off weight
TR	Type rating
Transponder	An on-board device (part of the avionics) that is triggered by air traffic control radar signals and automatically sends a response. This makes the aircraft identifiable for air traffic control, and also allows other data to be transmitted.
TRE	Type rating examiner
TRI	Type rating instructor
TSB	Transportation Safety Board of Canada
TT	True track, navigational heading, actual path of the aircraft
UeG	*Überwachungsgeschwader*, Swiss surveillance unit
UTC	Universal time coordinated
UVEK	*Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation*, Federal Department of the Environment, Transport, Energy and Communications (DETEC)
VF Flab	*Verein der Freunde der Fliegerabwehrtruppen*, association of the friends of the air defence corps
VFL	*Verein der Freunde der Schweizerischen Luftwaffe*, Association of the Friends of the Swiss Air Force
VFMF	*Verein der Freunde des Museums der Schweizerischen Fliegertruppen*, association of the friends of the Swiss air corps museum
VFR	Visual flight rules
VfV	*Verantwortlicher für Flugvorbereitung*, person responsible for flight preparation
VLL	*Verordnung des UVEK über die Lufttüchtigkeit von Luftfahrzeugen*, DETEC Ordinance on the Airworthiness of Aircraft
VOR	VHF omnidirectional radio range, ultra-short-wave rotating beacon
VSZV	*Verordnung über die Sicherheitsuntersuchung von Zwischenfällen im Verkehrswesen*, Ordinance on the Safety Investigation of Transport Incidents (OSITI)
WGS	World geodetic system
Wind shear	A change in wind speed or wind direction. This is usually understood to mean the change in horizontal wind with a change in altitude. However, a change in vertical wind or in horizontal wind over a horizontal distance is also a wind shear. In flying, anything that changes the flow of air around an aircraft without the pilot having initiated control manoeuvres can be called wind shear.
Windward	The side facing into the direction of the air current; concerning wind, windward in relation to a northerly wind is located on the northern side of the crest (see lee)
ZFH	*Zürcher Fachhochschule*, Zurich University
ZHAW	*Zürcher Hochschule für Angewandte Wissenschaften*, Zurich University of Applied Sciences, is a university that has been offering a course in aviation and operating a centre for aviation in Winterthur since 2006