Contents

A1. Factual information

A1.16 Tests and research results

A1.16.1 Simulation of the flight path and possible options

Using a simulation, it was investigated as to whether it would have been possible for the flight crew to manoeuvre the aircraft safely out of the valley shortly before the accident. The photogrammetrically determined point F13 was taken as the key point for the simulation and as the last position on the reconstructed flight path of HB-HOT. Before this point, the flight crew initiated a right turn and then steered the aircraft into a left turn to navigate it over the ridge of the Segnes pass. After point F13, roll to the left increased steadily and did not decrease even when there was significant aileron deflection to the right.

The aim of the simulation was not only to examine the flight path options from this key point onwards, but also to approximate the flight path and flight attitude of HB - HOT as closely to the reconstructed conditions before point F13 as possible, in order to verify the assumptions for the simulation (see figure 1).

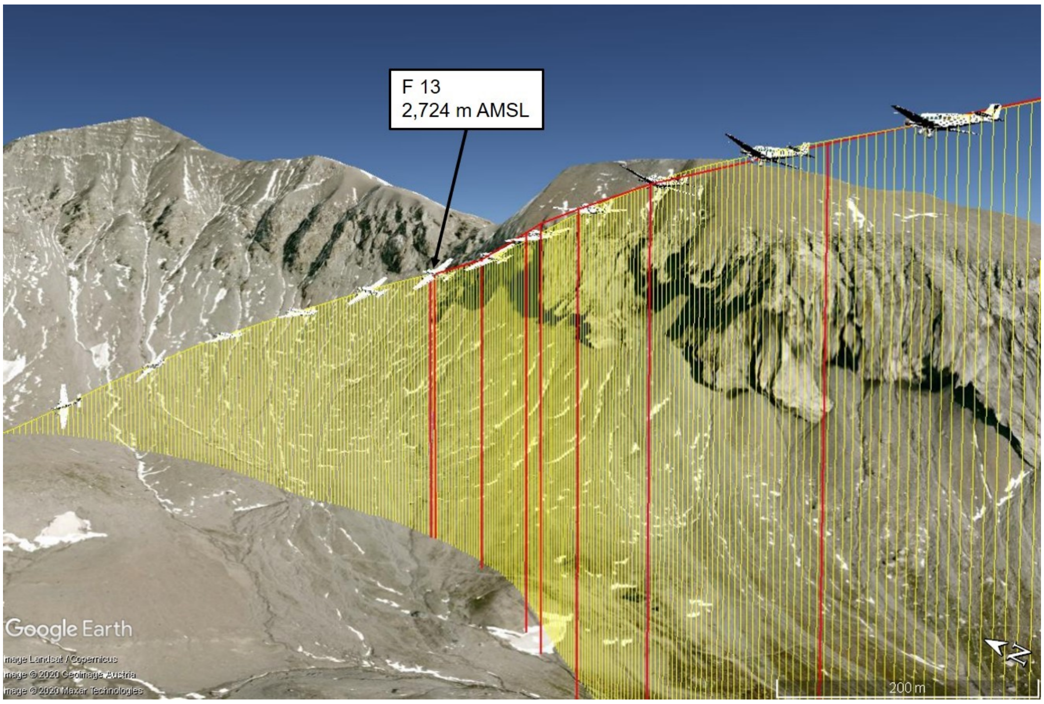

Figure 1: Simulated flight path (yellow) and reconstructed flight path of HB-HOT (red) from 4 August 2018 leading up to the photogrammetrically determined position F13; shown on Google Earth. The enlarged (2:1) three-dimensional models are shown on the basis of simulation results at position F13 and at two-second intervals before and after that point.

The movement of a generic aircraft through a wind field can be approximately simulated using simplified assumptions without having to reproduce all details as required in a full flight simulator. As the flight characteristics of the Ju 52/3m g4e, registered as HB-HOT, are not known in full detail, approximations had to be made. These are primarily based upon the aircraft flight manual and basic physical aerodynamic principles. The most important results are not directly dependent on exact knowledge of, for example, the lift over drag polar curve, but only on correctly selected ratios and the corresponding engine power. These assumptions could be corroborated and adjusted using the precisely known flight path and flight attitude from approximately two minutes before the accident, and idealised flights.

After the above-mentioned aircraft parameters had been determined as best as possible through iteration, it was possible to adjust the wind field based on the assumptions from the meteorological COSMO model (see annex A1.7), which is to be understood as follows. When the simulated path and speed in a flight phase correspond to the photogrammetrically reconstructed points, but the angle of pitch attitude is too small compared to this reconstruction, the pitch can be adjusted by increasing the downdraught. The same applies to crosswind and its effect on the aircraft's heading. This resulted in a refined wind field with similar characteristics to the wind field from the PALM meteorological flow model (see annex A1.7): a decrease of headwind and downdraughts towards the north. This refinement is not significant, meaning the analysis is not based on it. Nevertheless, it illustrates that flight path simulation can correctly take into account details in the wind field.

It should be noted that the investigation did not examine the aircraft's behaviour in stall, as this would not have been acceptable using these simplified assumptions and due to missing information. The simulations carried out permitted, however, to provide an answer to the question as to whether, under optimal conditions, the aircraft's envelope would have still allowed for a flight over the pass or for the aircraft to turn around after passing point F13.

Findings from the simulations:

- After several iterations, the simulated flight path and attitudes up to the arrival at F13 corresponded to a large extent with the photogrammetric reconstruction. A conscious decision was subsequently made not to continue this iterative process as the residual uncertainty that would remain as a matter of principle was not relevant for the conclusion.
- The selected wind field adjustments are within the determined possibilities (see annex A1.7). They even confirm the tendency that headwinds and crosswinds abated in the north-eastern part of the basin.
- For the aircraft to exceed its maximum angle of attack and lose altitude with at least a partial loss of lift before F13 – despite an indicated airspeed (IAS) that is significantly above stall speed – can be conclusively explained by an updraught.
- Based on realistic assumptions, none of the simulation variants showed a course of flight after F13 that would have allowed the aircraft to safely continue over the pass or turn around.
- However, had the area of downdraught continued to exist, a flight over the pass would still have been possible, i.e. the simulation confirms the conclusion that it was not the obviously existing area of downdraught that triggered the fatal course, but a quite plausible updraught in the north-eastern part of the basin.

In order to obtain even more accurate simulation results, an identical Ju 52/3m g4e aeroplane would have to undergo an extensive test-flight programme, the results of which would enable a full flight simulator to be programmed by a specialised team. However, given that the STSB's simulations take into account all of the important environmental parameters and fundamental aircraft characteristics, it can be surmised that the results produced by a full flight simulator up to the loss of control would not be radically different.

A1.16.2 Metallurgical background information

A1.16.2.1 General

The structure of the Ju 52/3m g4e aircraft, consisting of the wing, fuselage and empennage as well as parts of the controls, is of mixed construction. The components are mainly manufactured of aluminium and steel. The steel components are mainly welded constructions fabricated in sheet metal. Most of the structure is made of the high-strength aluminium alloy Duralumin. The components are riveted together, using both Duralumin and steel rivets. The sheets for the panelling and profiles are plated on both sides using thin, more corrosion-resistant aluminium alloy[1]. When the aircraft was made, the corrosion-prone components were given a protective coating.

A1.16.2.2 Properties of Duralumin

Duralumin (also known as Dural) is an alloy of aluminium (Al) with copper (Cu) and magnesium (Mg) that was developed at the beginning of the 20th century. This alloy is high in strength and features good plastic elongation values, and – at the time – was used mainly in the construction of aircraft. Its favourable mechanical properties are achieved by solution heat treatment and subsequent natural ageing[2]. The corrosion resistance properties of Duralumin are generally limited.

Prolonged exposure to temperatures above 80 °C can make Duralumin more prone to corrosion, whilst thermal stress above 120 °C drastically increases the material's susceptibility to corrosion; this is referred to as a thermal ageing process.

A1.16.2.3 Applied examination methods

The chemical composition of the investigated parts was determined by optical emission spectroscopy (OES), energy-dispersive X-ray spectroscopy (EDX) and other methods.

The material condition was determined by metallographic microsection analysis. This allows conclusions to be drawn about material properties and the manufacturing process.

Fracture surfaces and cracks were examined using microfractographic analysis under a scanning electron microscope (SEM). Based on the fracture characteristics, the cause of the crack or fracture can be determined.

The mechanical material properties were determined using hardness measurements according to the Brinell or Vickers methods. These test methods do not provide information about the elastic and plastic properties of the material. To determine further mechanical material properties, complex tests such as the static tensile test and impact test, as well as fatigue tests would have to be carried out.

A1.16.3 Metallurgical examinations

A1.16.3.1 Fuselage

Parts of the cabin floor, stringer sections and structural parts from the aft section of the fuselage were examined. According to the OES analysis, the majority of the examined parts consist of an AlCuMg alloy and correspond chemically and materially to the aircraft manufacturer's specification. Individual parts are made of steel and were riveted to parts made of Duralumin. Sheets were found with plating on both sides (see figure 2).

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[1] Plating is the process of applying a thin layer of a metal with different properties to a base metal, usually by rolling. In this case, a thin layer of a more corrosion-resistant aluminium alloy was rolled onto the AlCuMg sheet.

[2] Ageing (natural/artificial): A thermal process used to improve the mechanical properties of a material.

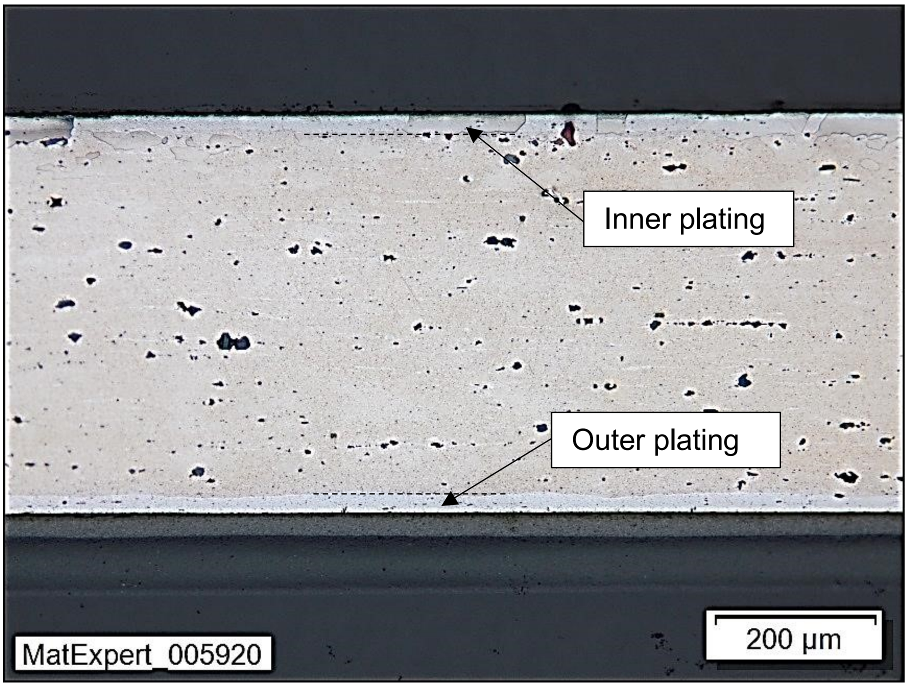


Figure 2: Microsection of sheet with inner and outer plating.

A1.16.3.2 Wing

A1.16.3.2.1 General

The self-supporting wing consists of the centre wing, which is firmly structurally connected to the fuselage, and the two outer wings.

Following visual inspection, the subsequent parts of the wing were subjected to material tests:

Designation in the report	Manufacturer's position numbers
Lower spar section L1	Spar I, left, with joint 89 (mirror image of joint 32, right)
Lower spar section L2u	Spar II, left
Lower spar section 1Ru	Spar I, right, with joint 32
Upper spar section A	Spar I, right, with joints 15, 16 and 116
Upper spar section B	Spar I, left, with joint 85 (mirror image of joint 15, right)
Lower spar section C	Spar I, bottom right, with joint 31 and the fixing for attaching to the centre wing

The joint numbering is based on the Junkers Ju 52/3m aircraft parts list H (see figure 3).

Joints 15 and 32 of the right-hand outer wing and joints 85 and 89 of the left-hand outer wing are part of ribs I. Joints 16 and 116 are part of rib Ia of the right-hand outer wing. The left or right engine respectively is mounted between those two ribs (rib I and rib Ia).

The lower spar section C comes from the area where the right-hand outer wing is bolted to the centre wing.

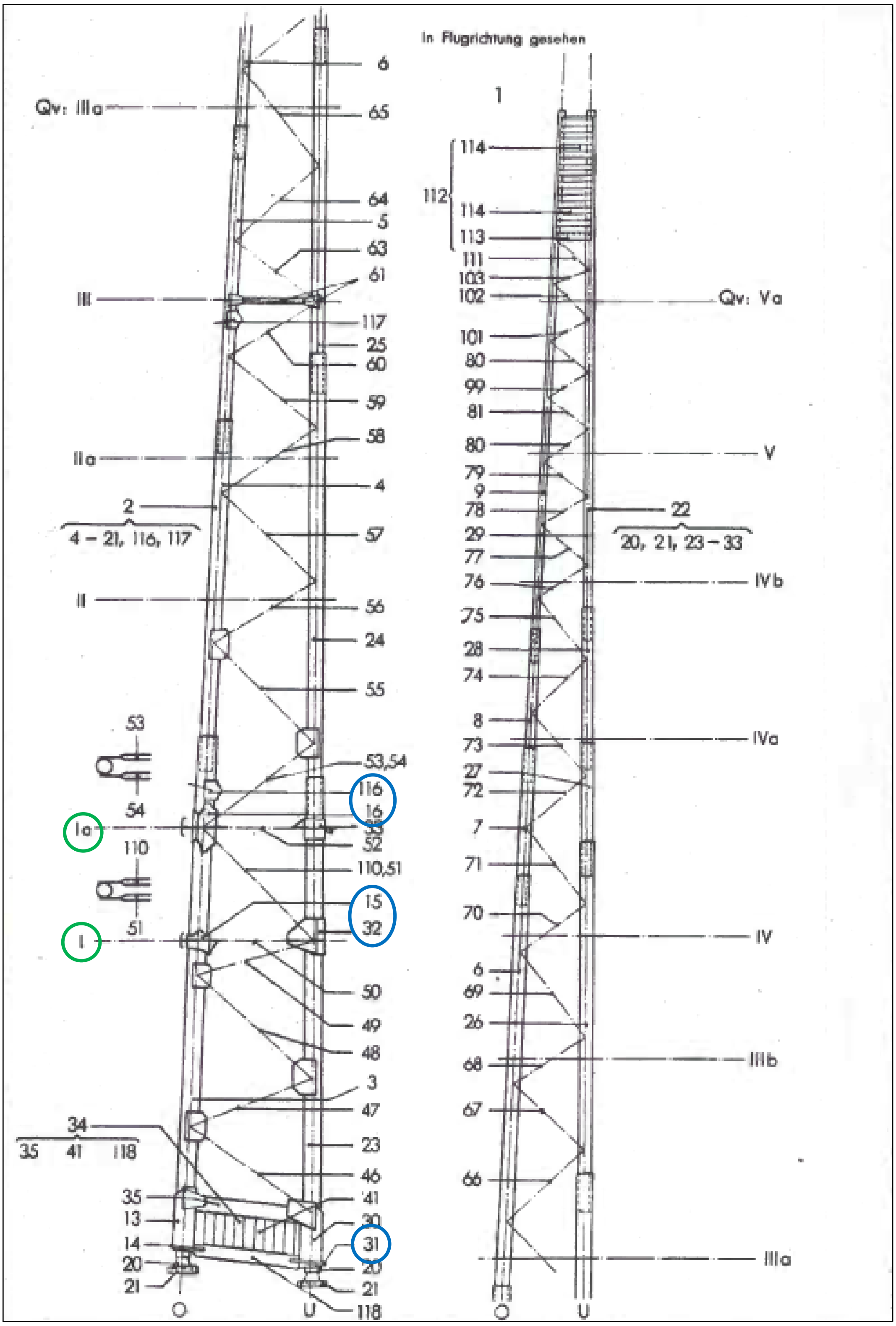


Figure 3: Spar I of the right-hand outer wing – the blue encircled position numbers indicate the examined parts, the green encircled positions I and Ia indicate the ribs. Source: Junkers Ju 52/3m aircraft parts list H.

A1.16.3.2.2 Wing spars

According to the aircraft manufacturer's specifications, the wing's spar tubes are made of the naturally aged wrought aluminium alloy Duralumin Du44 (AlCuMg). When naturally aged, the corrosion resistance of this alloy is very limited due to the presence of the copper used in it. When artificially aged, the alloy is extremely susceptible to corrosion and becomes mechanically brittle.

According to chemical analysis, the material used in the six spar tube sections examined corresponds to Du44.

The hardness of the spar tube sections was measured in microsections according to the Vickers method. The measurements ascertained are usual for the investigated material and correspond to a hardened AlCuMg alloy.

The alloy as it is present in the analysed parts is not in line with the current state of technology.

After removing joint 89 (see figure 4), severe corrosion and cracks were found in the contact area between the joint and the spar tube. This would not have been visible without dismantling the joint or the panelling. After cutting open the spar tube, no damage was visible on the inside (see figure 5). This shows that a borescope inspection cannot detect such damage and is therefore unsuitable (see annex A1.6).

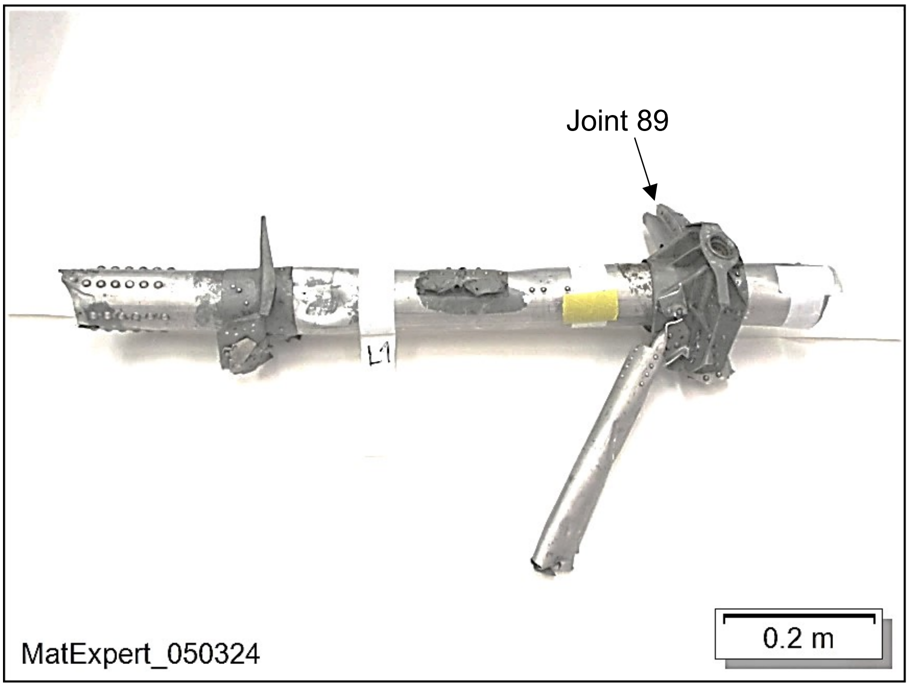


Figure 4: Lower spar section L1 of the left outer wing.

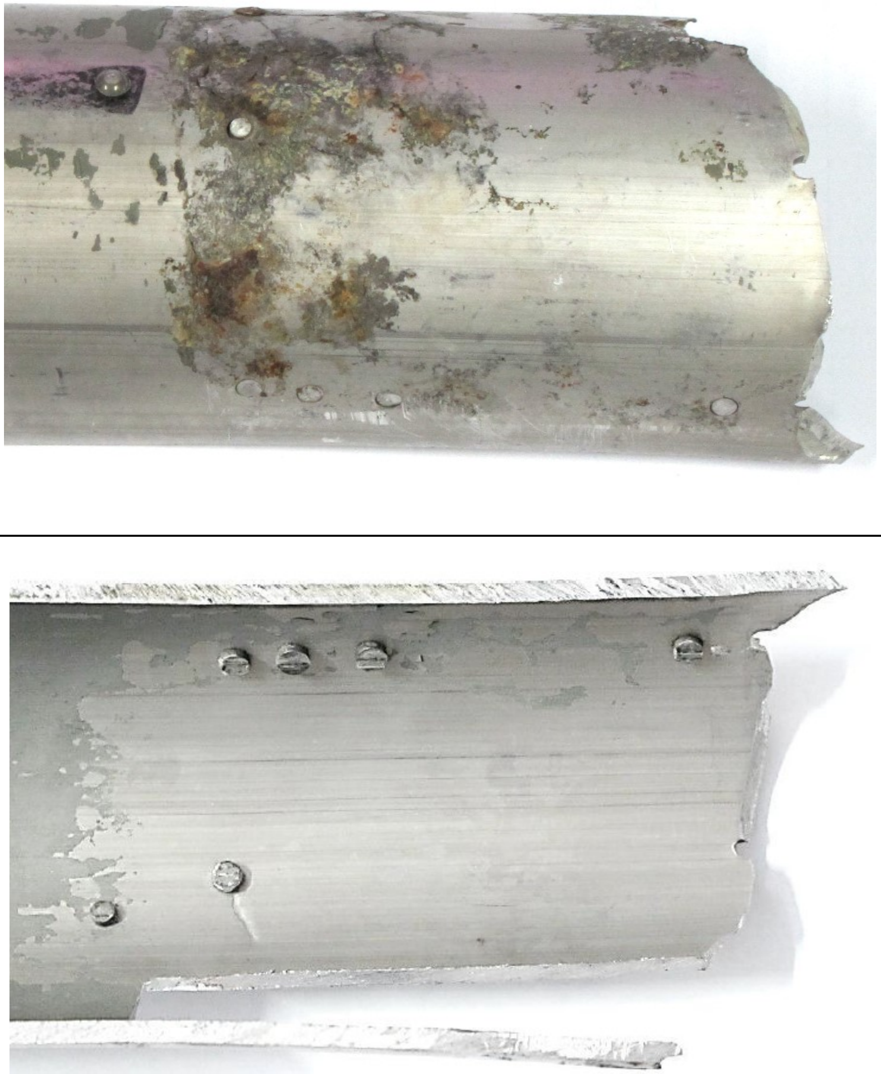


Figure 5: Cut open lower spar section L1 – the outer surface with corrosion and cracks, the inner surface with no signs of corrosion.

Spar section L1 (see figure 4) exhibited grain boundary precipitations (see figure 6). These precipitates were formed either by artificial ageing after solution heat treatment or by a secondary, longer exposure to a temperature of more than 120 °C. This makes the material in question susceptible to intergranular corrosion. Intergranular corrosion can develop along the detected grain boundary precipitates.

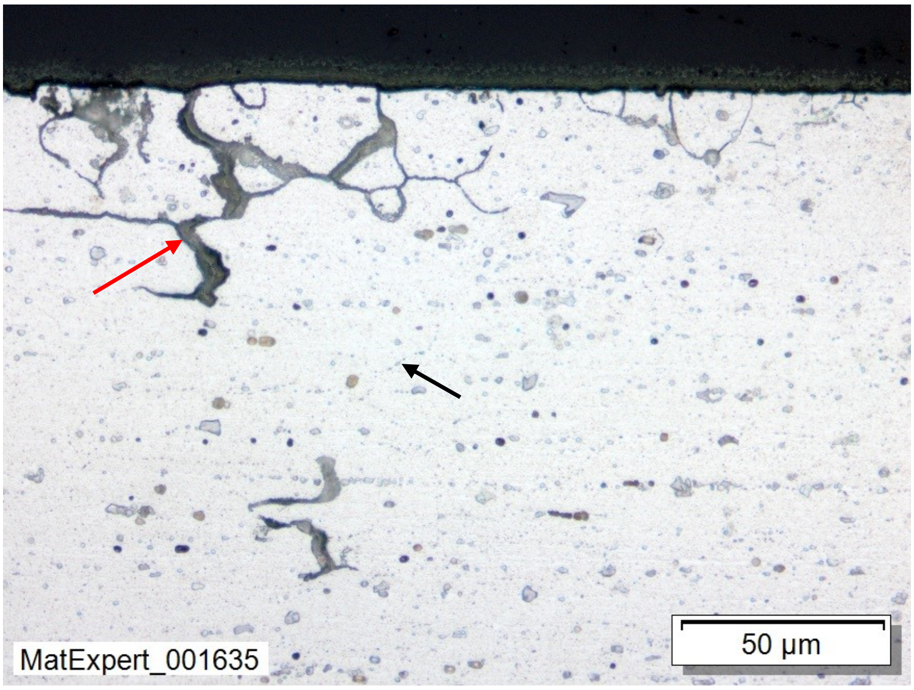


Figure 6: Microsection of spar section L1 – intergranular corrosion attack (red arrow) and grain boundary precipitation (black arrow).

Similar to artificial ageing, thermal stress changes the original microstructure of the naturally aged alloy and has a very negative effect on corrosion resistance.

On further investigation, joint 89 was gently removed from the lower spar section L1, and joints 15 and 16 were removed from the upper spar section A.

The spar tube below joint 89 was broken (see figure 7). The analysis of this fracture surface using SEM showed a ductile spontaneous fracture and a fatigue fracture with typical striations (see figure 8). The fatigue fracture accounted for approximately 10 % of the total fracture surface. Extensive corrosion damage and further cracks were uncovered in the contact area between joint 89 and the spar tube. This corrosion was intergranular corrosion resulting in a loss of wall thickness (see figures 9 and 10). One of the cracks was exposed and fractographically analysed (see figure 11). This crack was an intergranular fracture with striations, i.e. a fatigue crack (see figures 12 and 13).

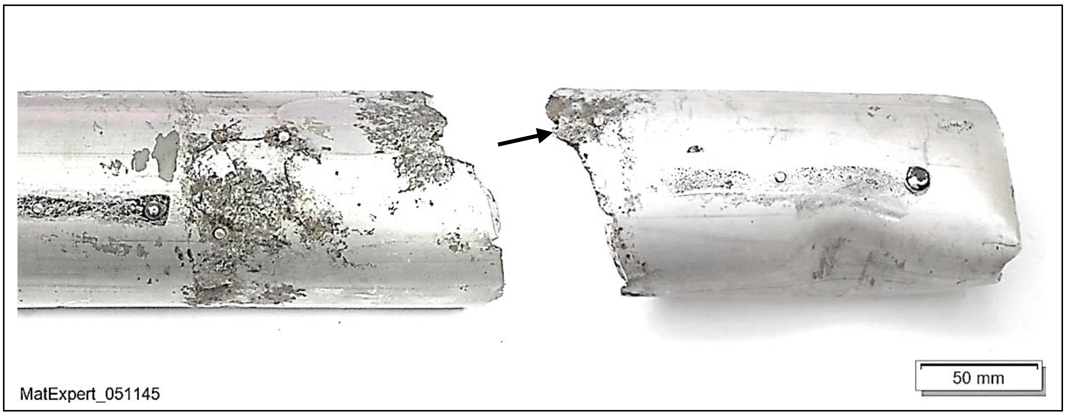


Figure 7: Overview of the broken spar section; approximately 10 % of the fracture surface (arrow) is accounted for by fatigue fracture.

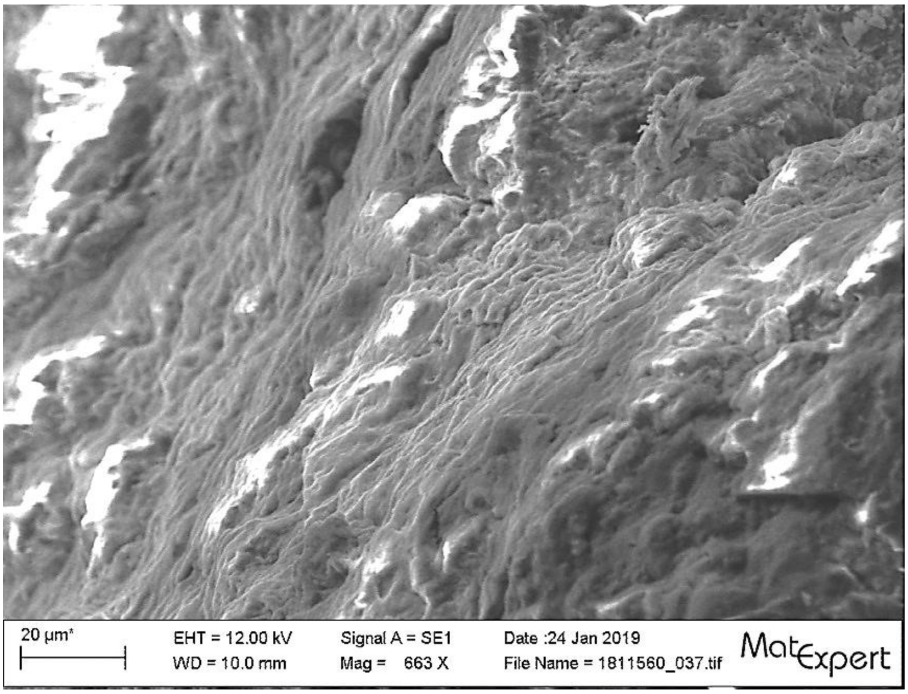


Figure 8: Fatigue fracture with typical striations.

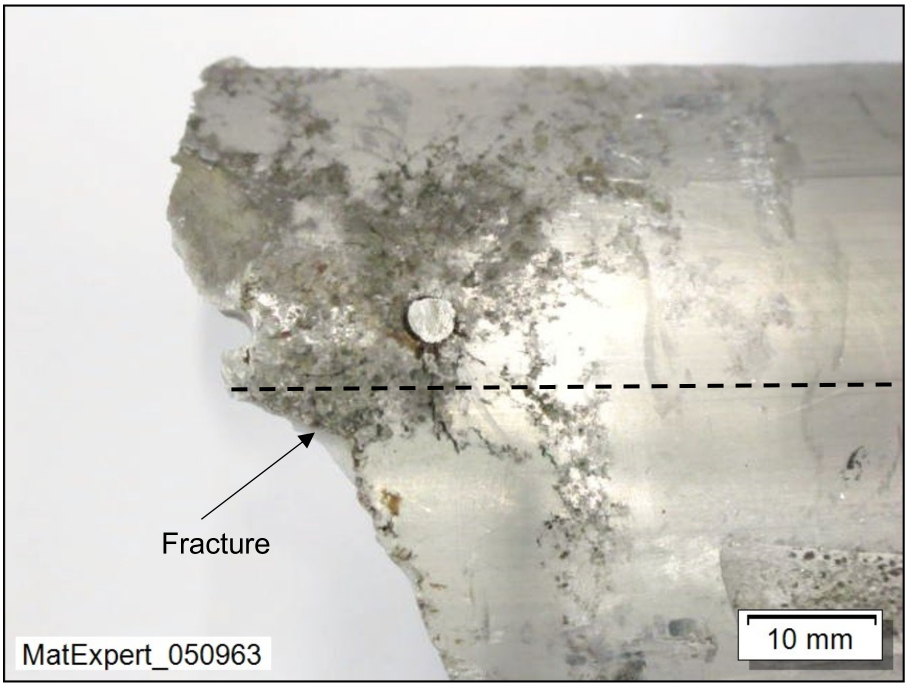


Figure 9: Point of corrosion with broken rivet. The black, dashed line indicates the position of the microsection.

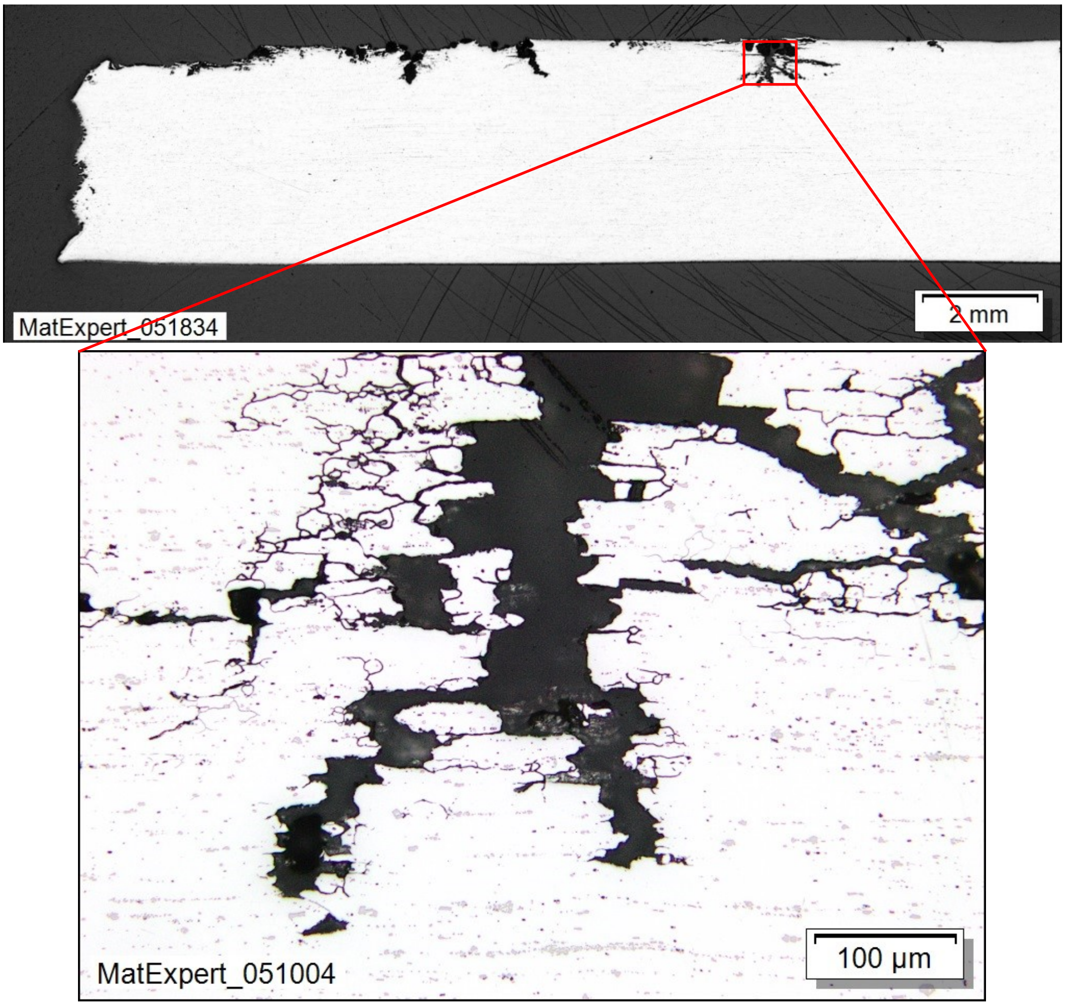


Figure 10: Wall thickness loss due to corrosion and intergranular corrosion.

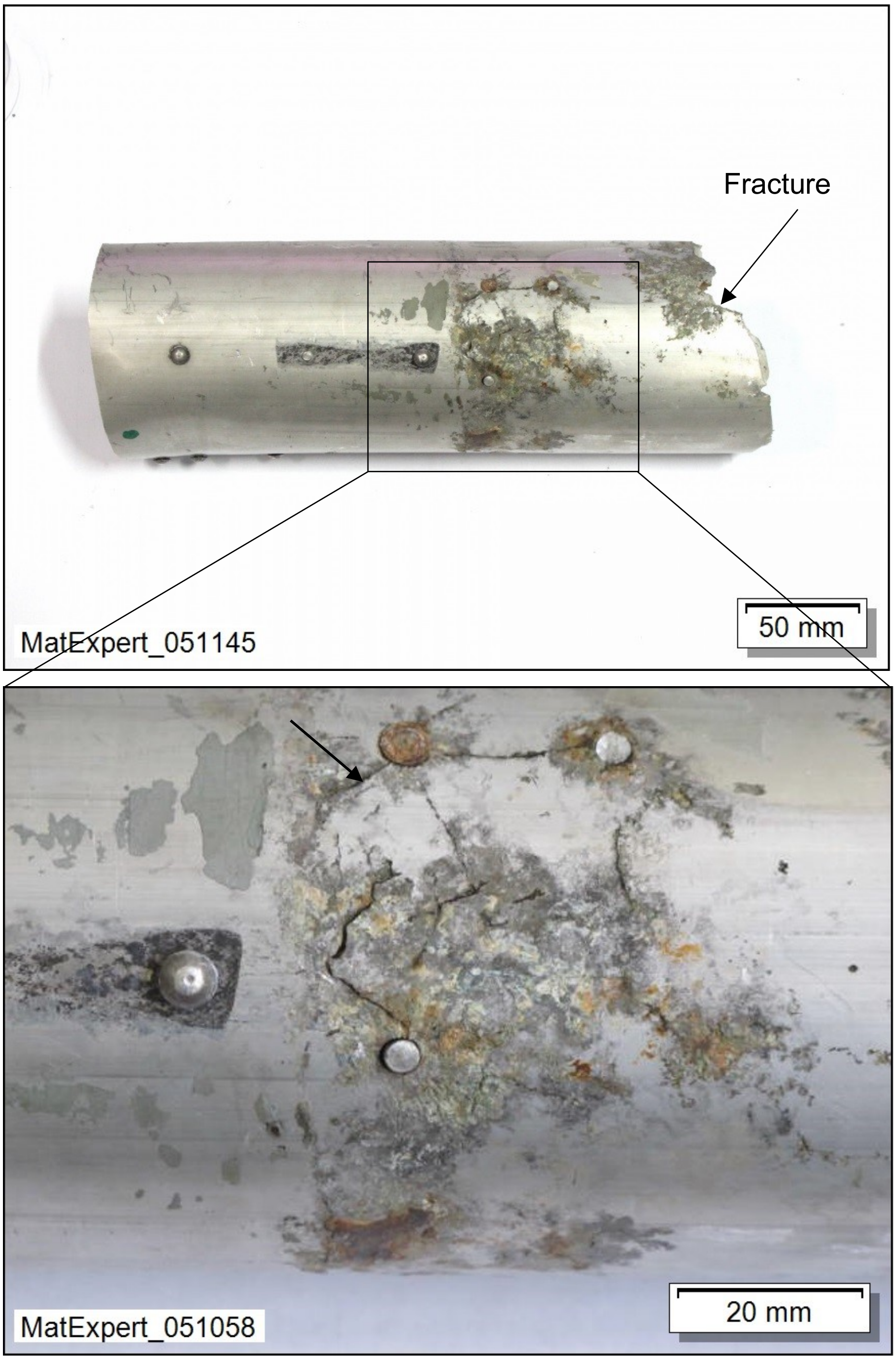


Figure 11: Exposed crack (arrow) under joint 89 on the lower spar section L1.

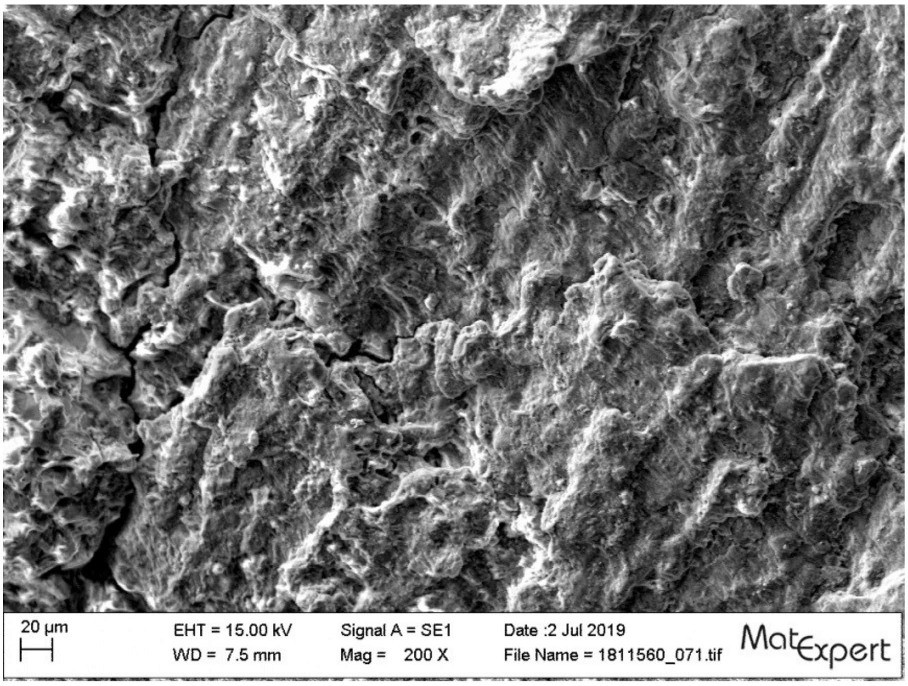


Figure 12: Close-up – crack surface in the exposed crack with fatigue fracture and intergranular cracks.

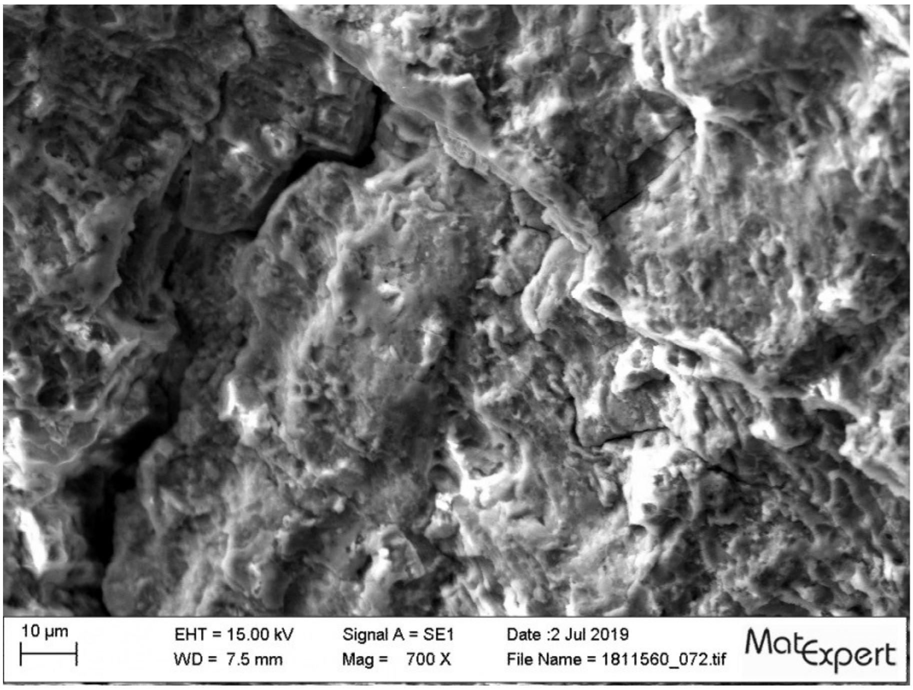


Figure 13: Magnified version of figure 12.

In the area where the panelling was riveted to the spars, damage similar to chafing can be seen (see figure 14). This type of wear attests that the panelling was no longer firmly attached to the spar and that the surface was severely damaged by the panelling's movement and by penetrating liquid (see figure 15). Besides general loss of material, intergranular cracks were also discovered (see figure 16). These cracks were mainly found near the rivet holes, and they can initiate fatigue cracks (see figure 17).

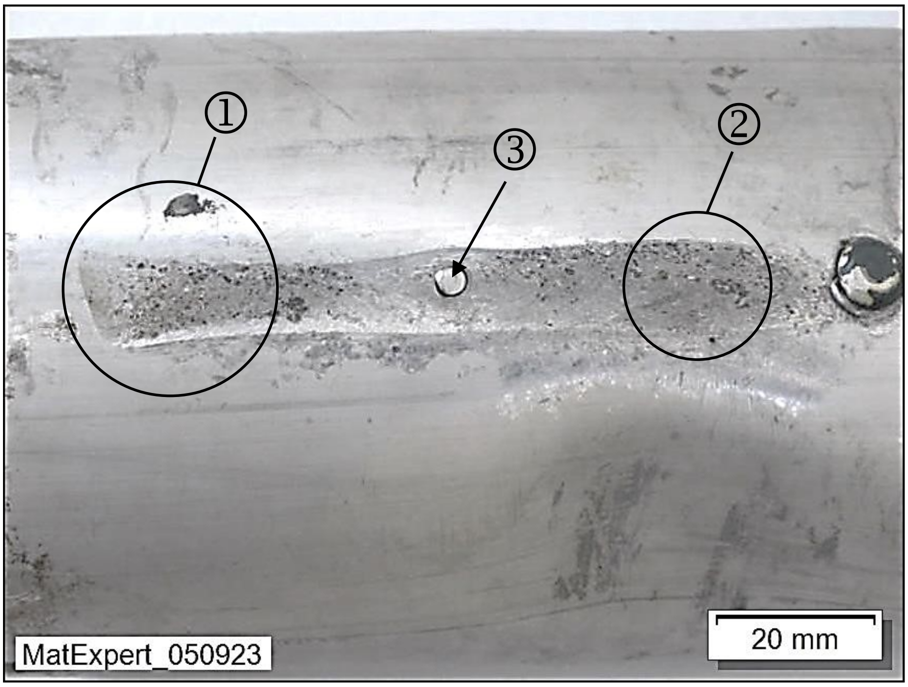


Figure 14: Wear on the lower spar L1 – number (1) see figure 15, number (2) see figure 16, number (3) see figure 17.

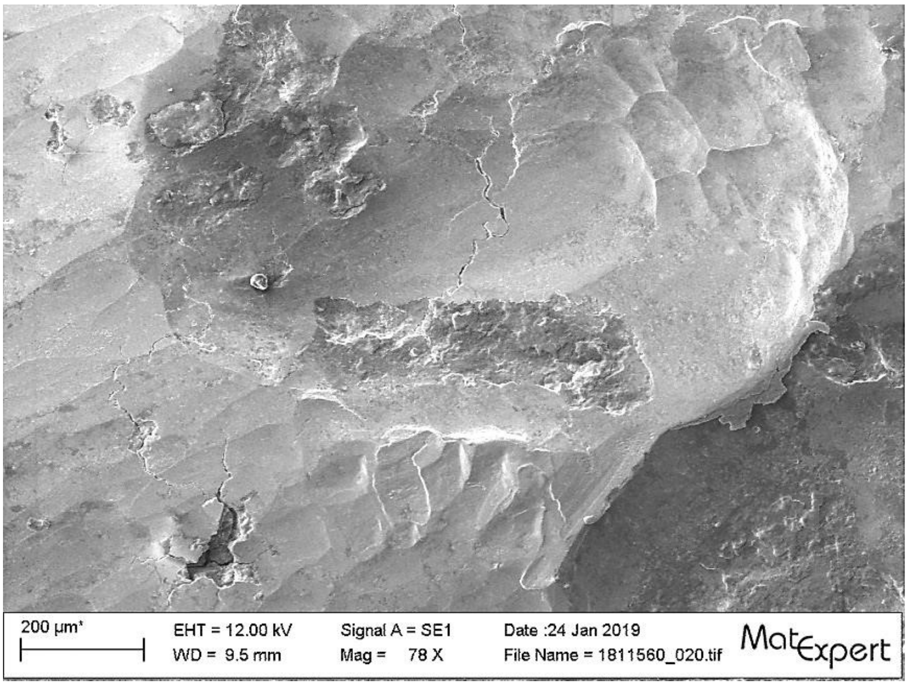


Figure 15: Impact wear on lower spar L1 (close-up of number (1) in figure 14).

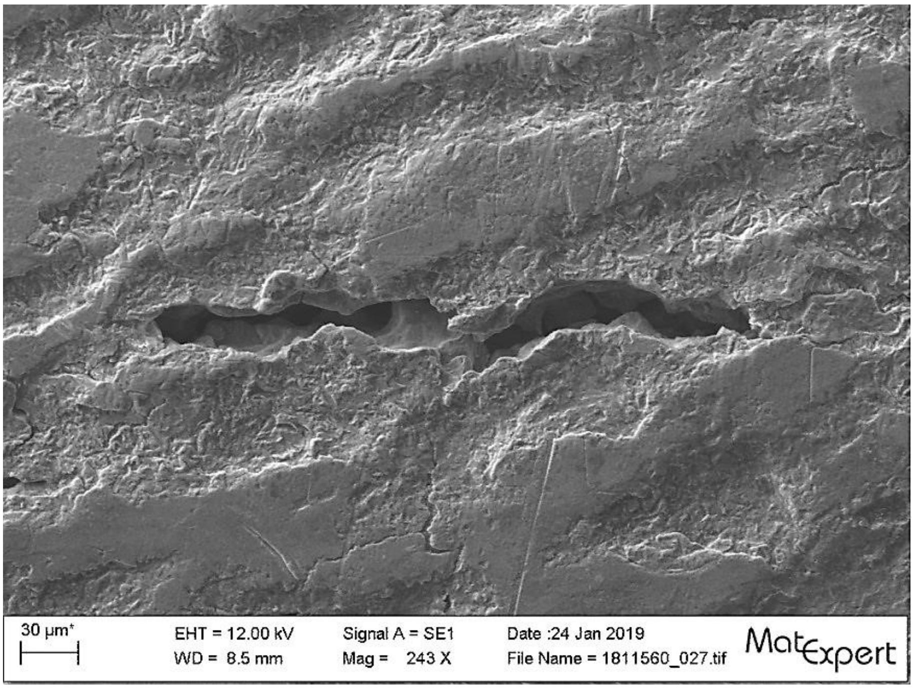


Figure 16: Incipient crack and wear due to erosion and cavitation (close-up of number (2) in figure 14).

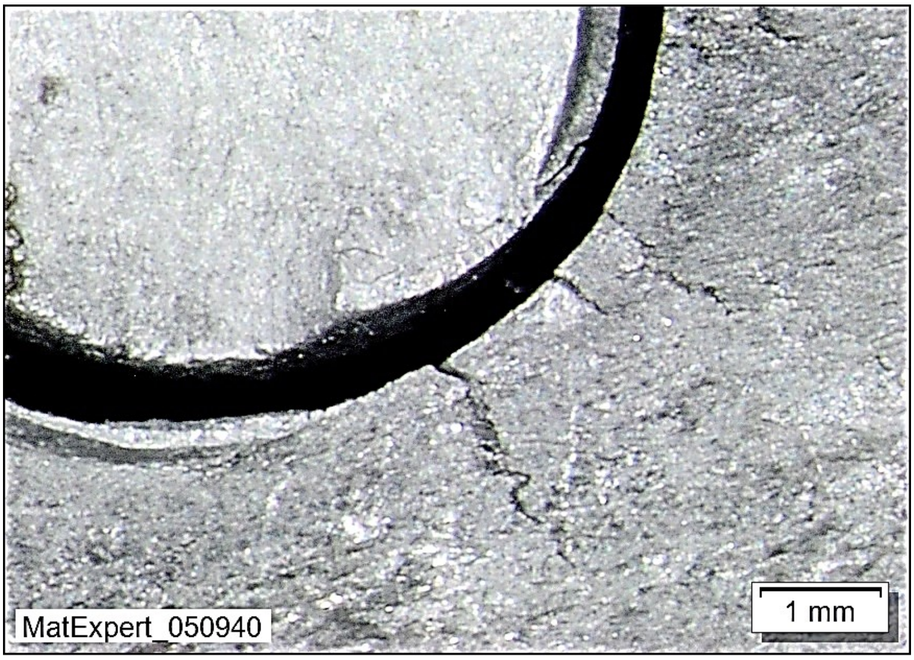


Figure 17: Intergranular incipient cracks at the rivet hole, crack lengths of up to 5 mm (close-up of number (3) in figure 14).

Upper spar section A showed a similar condition as lower spar section L1 at both joints. There are also several intergranular cracks, old rivet fractures and wear caused by the panelling.

The lower spar section 1Ru (see figure 18), cut from spar I near the right engine, exhibits pitting (see figure 19). This is the typical type of corrosion for a naturally aged structure. This type of corrosion also leads, among other things, to a localised loss of wall thickness. Wear caused by the panelling is also present on this spar section.

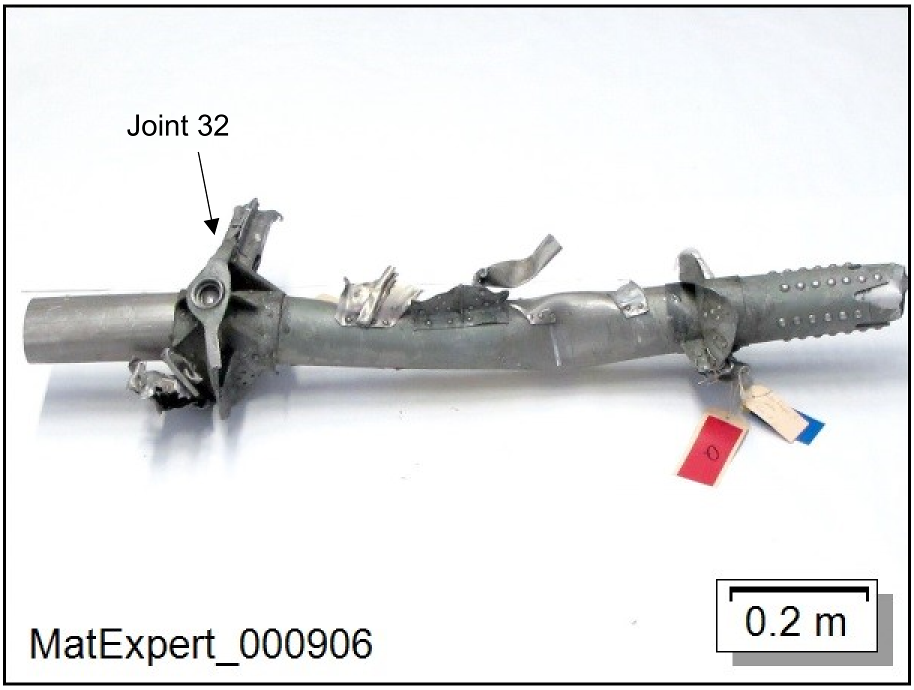


Figure 18: Lower spar section 1Ru.

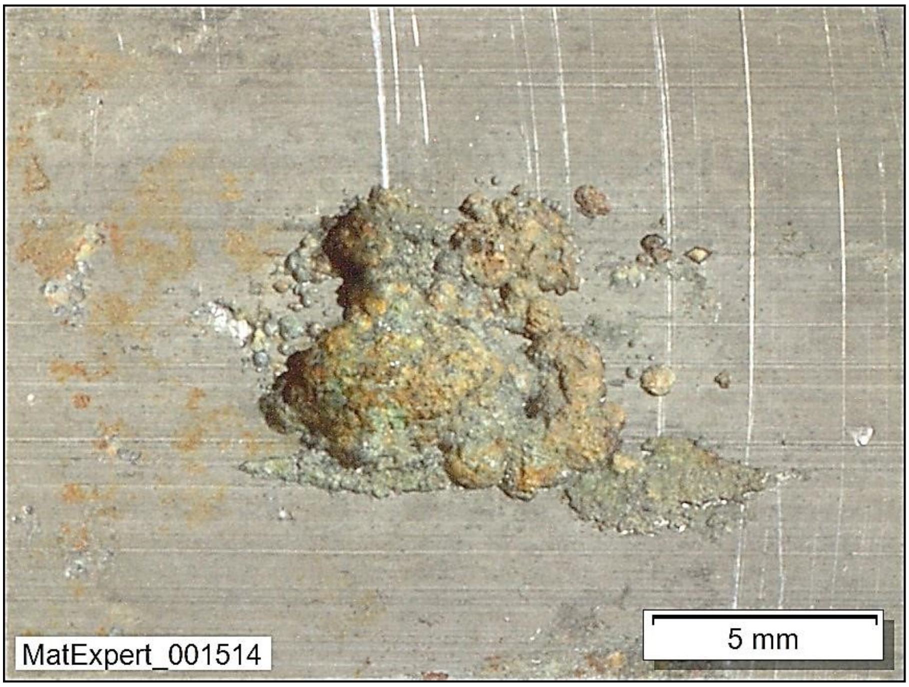


Figure 19: Close-up – pitting on the lower spar section 1Ru.

All of the spar sections analysed and the joints only exhibited remnants of anti-corrosion paint. The corrosion protection was therefore insufficient.

A1.16.3.2.3 Joints and rivets

Joint 89 mounted on the lower spar section L1 was twisted and displaced on the spar tube as a result of the accident. The joint is a welded steel construction. The inner tubing of joint 89, which was in direct contact with the lower spar, was made of a heat-treatable alloy steel. The inner tubing was un-heat-treated.

The inner tubing of the analysed joint exhibited corrosion with surface corrosion around the rivets (see figure 20).

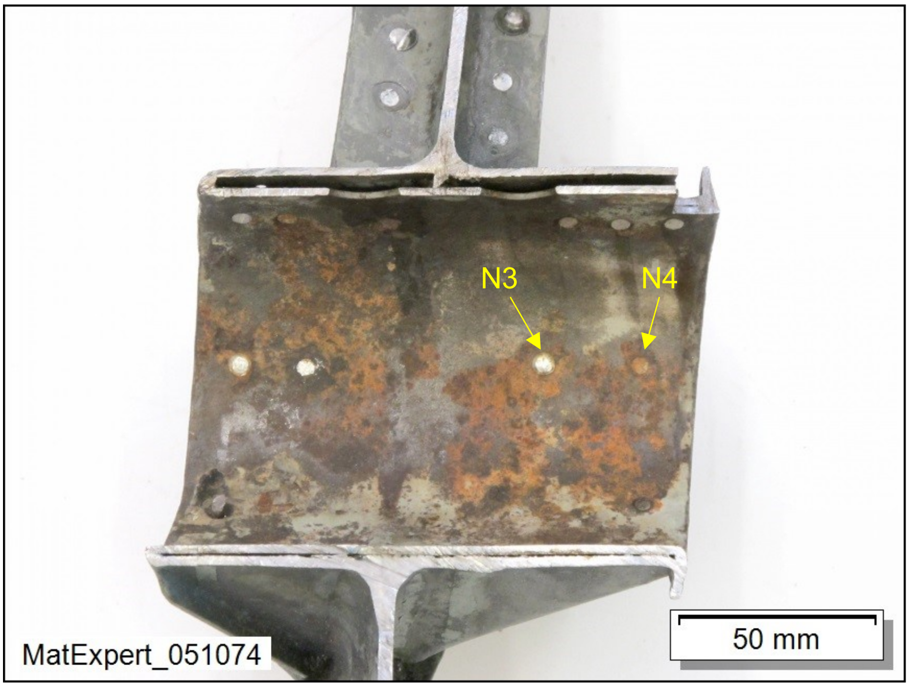


Figure 20: Cut open joint 89 with rivets N3 and N4.

Rivet fractures were discovered which clearly occurred before the accident (see figure 21). They can be easily distinguished from the shear fractures caused by the accident.

Figure 21: Close-up – broken rivet N4 with severe corrosion.

The fracture surfaces and the contact areas between the rivets and the joint and spar tube respectively were analysed. The rivets were examined metallographically as well as macro- and microfractographically.

The rivets consist of a wrought aluminium alloy (AlCuMg), which is very similar to the spar material.

Pitting and surface corrosion can be identified in the contact area between the rivets and both the joint and spar tube (see figure 22).

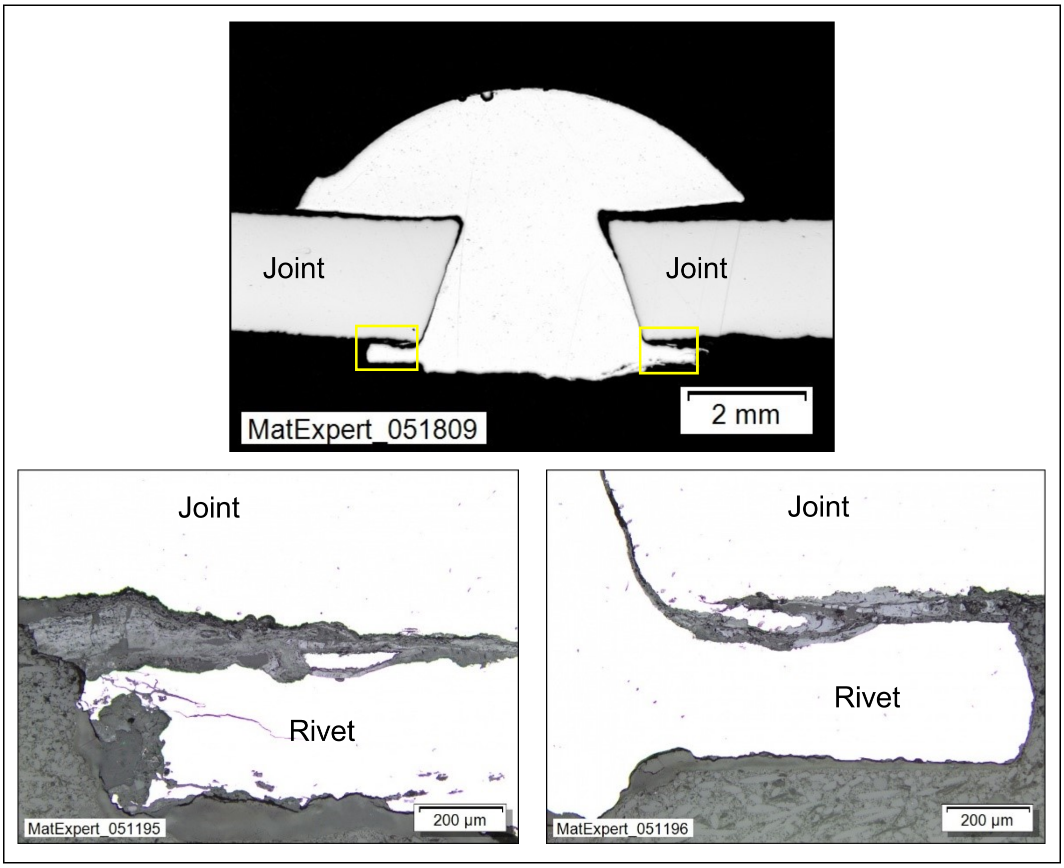


Figure 22: Cross section of rivet N3 – pitting and surface corrosion of sheet steel and aluminium rivets.

Fractures were found in the rivets which clearly occurred before the accident (see figures 23 to 25). Furthermore, intergranular corrosion was discovered (see figure 26). Fatigue and intergranular fractures were also discovered in some rivets. They can be easily distinguished from the shear fractures caused by the collision.

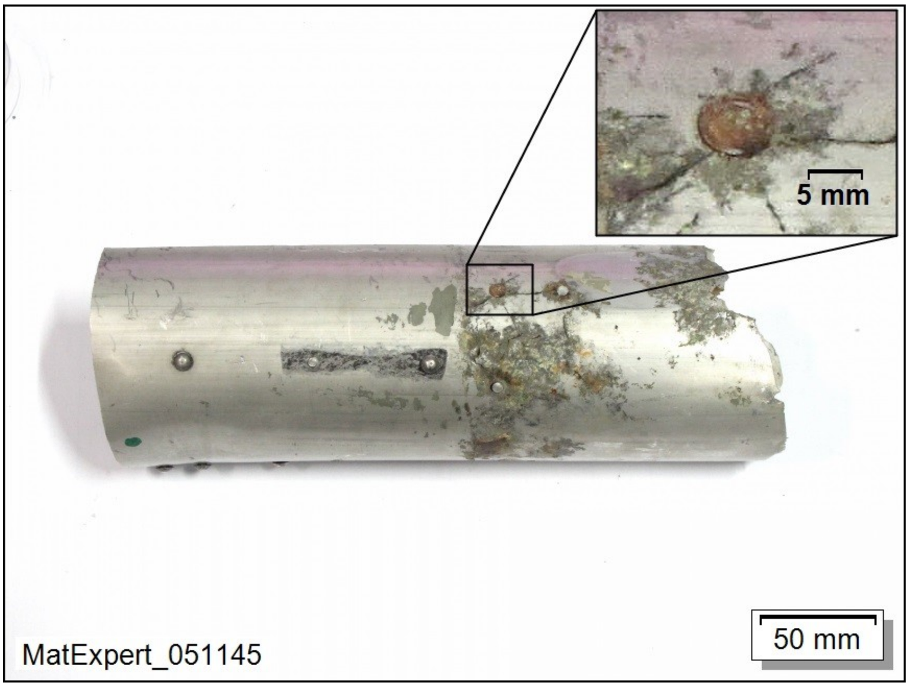


Figure 23: Spar section L1, after removing joint 89, with rivet N5.

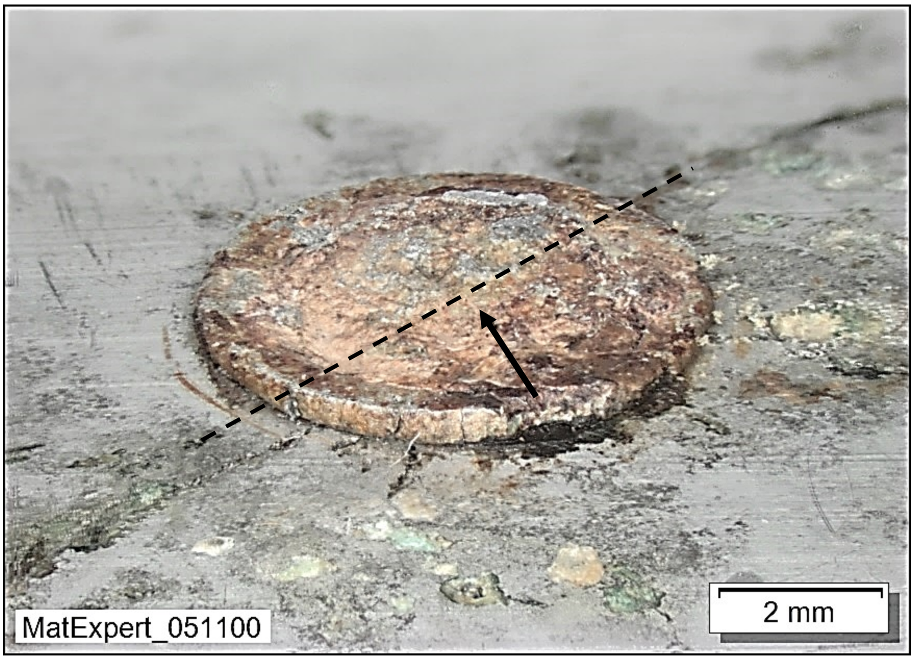


Figure 24: Severely corroded rivet N5. The black dashed line indicates the position of the microsection and the arrow indicates the direction the microsection surface was viewed from.

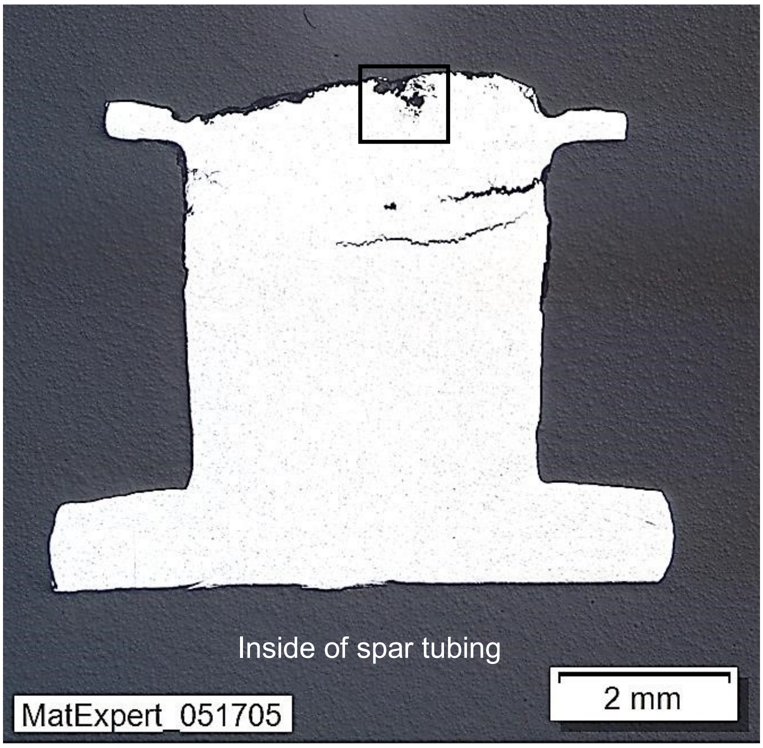


Figure 25: Cross section of broken rivet N5 with intergranular corrosion.

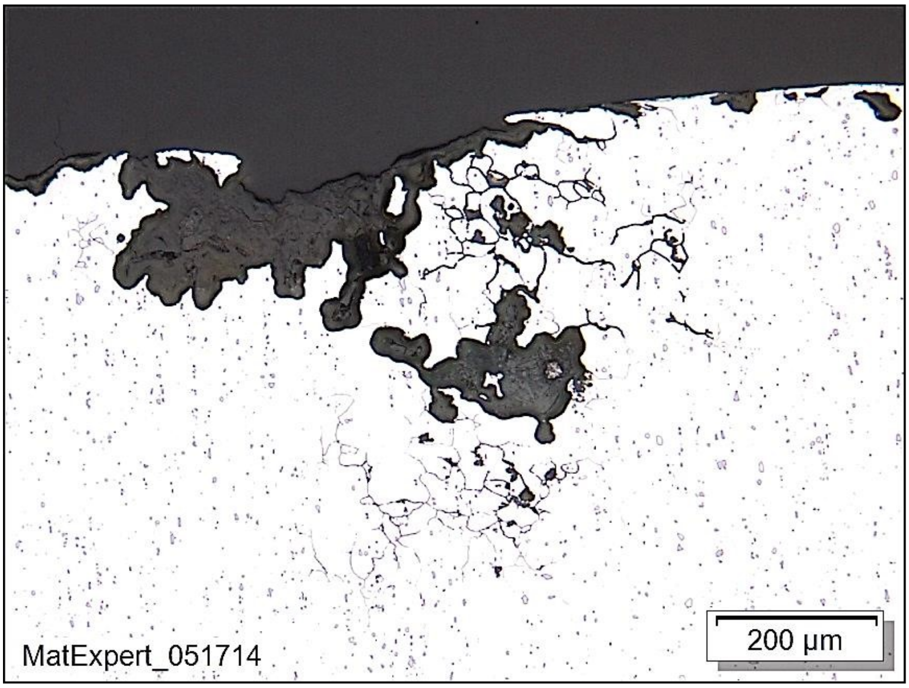


Figure 26: Close-up – intergranular corrosion on rivet N5.

Examination of spar section A (see figure 27) shows a similar condition for the joints as those on spar section L1. In the contact areas between the joints and the spar tube, severe corrosion and cracks, old rivet fractures, impact wear, erosion and cavitation were also found on the surface of the aluminium spar tube (see figures 28 to 32).

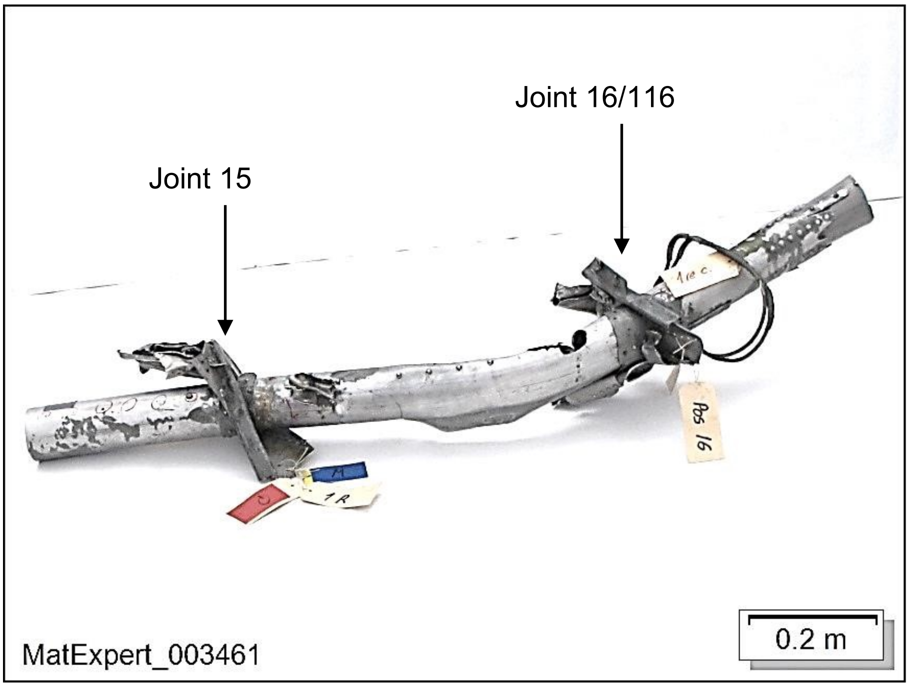


Figure 27: Spar section A.

Figure 28: Area around joint 15 – brittle cracking, partially intergranular.

Figure 29: Area around joint 15 – brittle cracking, partially intergranular.

Figure 30: Area around joint 15 – crack-like surface condition.

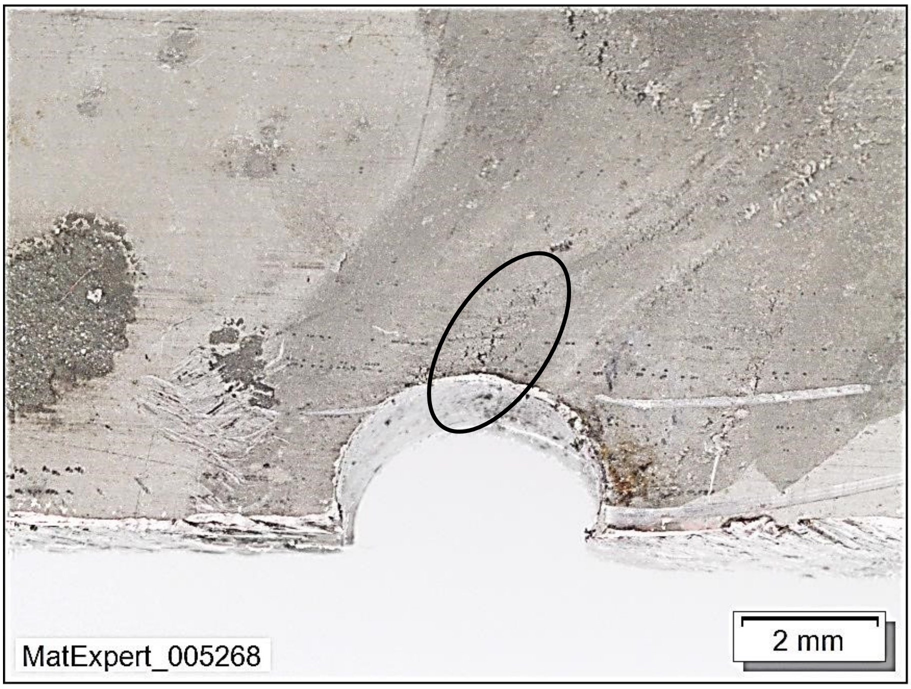


Figure 31: Close-up of figure 30 – start of a crack at the rivet hole (circled).

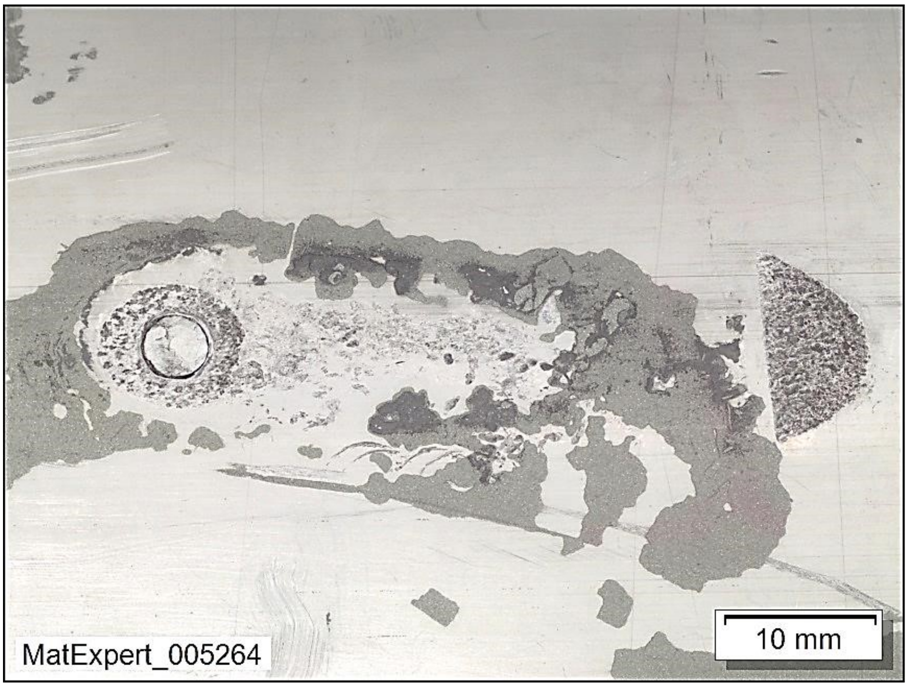


Figure 32: Area around joint 16/116 – pre-existing broken rivet and impact wear, erosion and cavitation on the spar tube.

A1.16.3.2.4 Panelling

The examined piece of sheet metal came from HB-HOT's wing panelling. The sheet thickness was 0.80 mm including an inner plating of 0.029 mm and an outer plating of 0.027 mm.

The sheet was made of a wrought aluminium alloy (AlCuMg). The core hardness was measured in microsection and was 123 HV1[3]. This corresponds to a hardened material. The plating, consisting of a material with a lower copper content, was applied to improve the level of protection from corrosion. There were areas of flaking anti-corrosion paint on both the inside and outside of the panelling.

A1.16.3.3 Engine mount

A1.16.3.3.1 Material analysis

The material used for the engine mount of the left and the centre engines has a low magnesium content, 0.44 % and 0.39 % respectively, and does not chemically correspond to the specified Duralumin Du42. The material structure of these two engine mounts is similar to cast aluminium and exhibits many intermetallic inclusions. Components with such a microstructure carry a high risk of fracturing. It is probable that the two engine mounts already exhibited these unfavourable material properties when new.

The right engine mount is made of an alloy that is chemically similar to the other two engine mounts, but has a magnesium content of 1.45 %. The structure is homogeneous and has good material properties. The machine-manufactured right engine mount was probably made of a rolled plate and therefore has a superior grain structure. The right engine mount was not broken, but plastically deformed.

A1.16.3.3.2 Fracture analysis

A fracture surface from the centre engine mount (see figure 33) was microfractographically analysed using SEM (see figure 34). The fracture was identified as a brittle, spontaneous fracture exhibiting a mixed fracture pattern of honeycomb, quasi-cleavage and intergranular fractures across a wide area (see figure 35). The intermetallic phases are clearly visible in the fracture pattern and are partially surrounded by roundish cavities. The localised 'terracing', which is a defect, is striking (see figure 36). On the fracture surface, a localised fatigue fracture-like formation can be seen (see figure 37).

[3] Hardness test: Indentation of the material according to the Vickers test method.

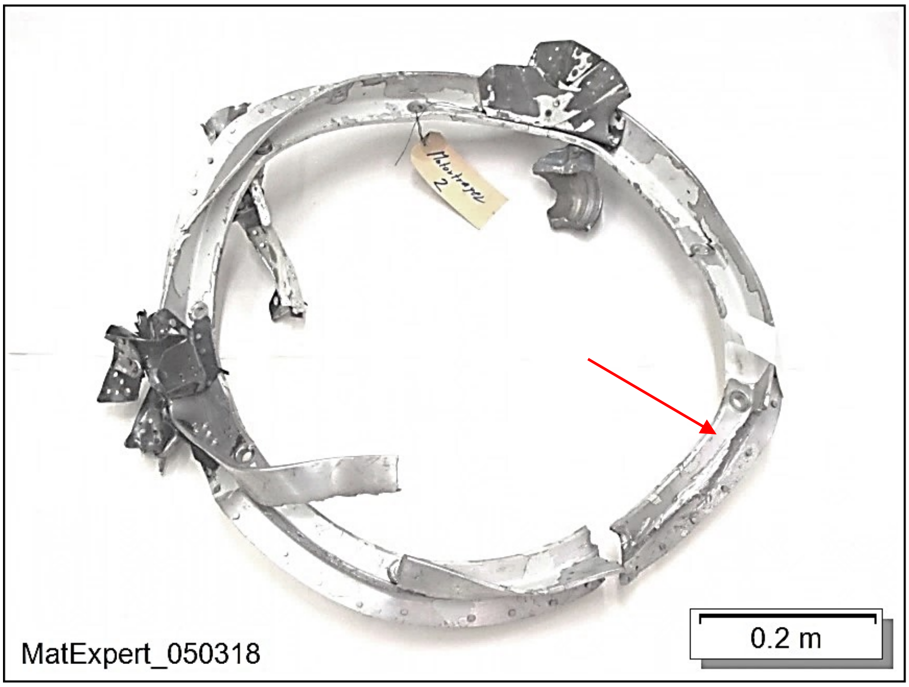


Figure 33: Severely deformed and broken centre engine mount. A part of the fracture surface on the engine mount (red arrow) was analysed.

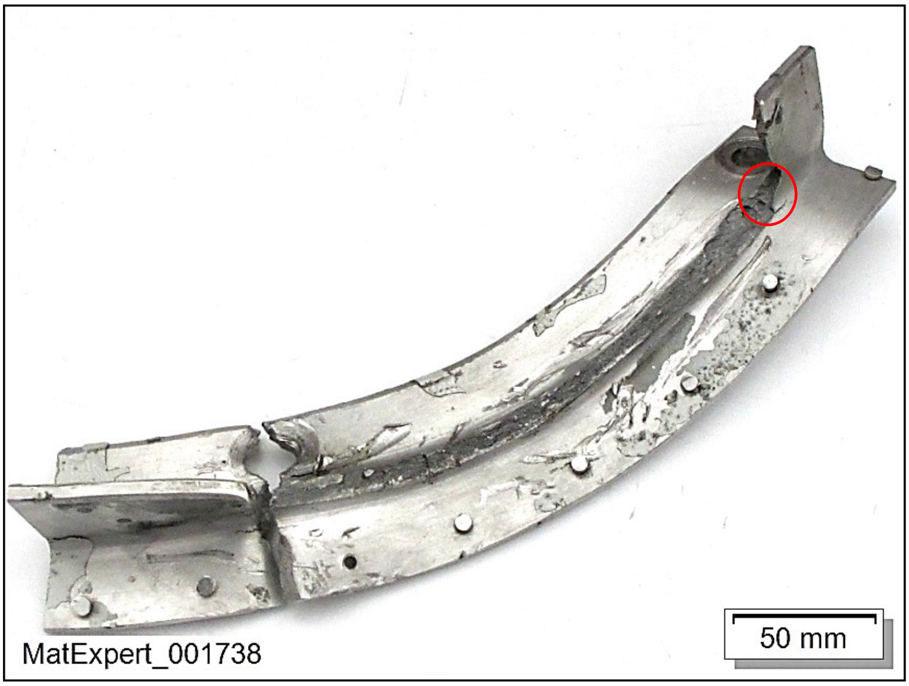


Figure 34: Location of the analysed fracture surface (red circle).

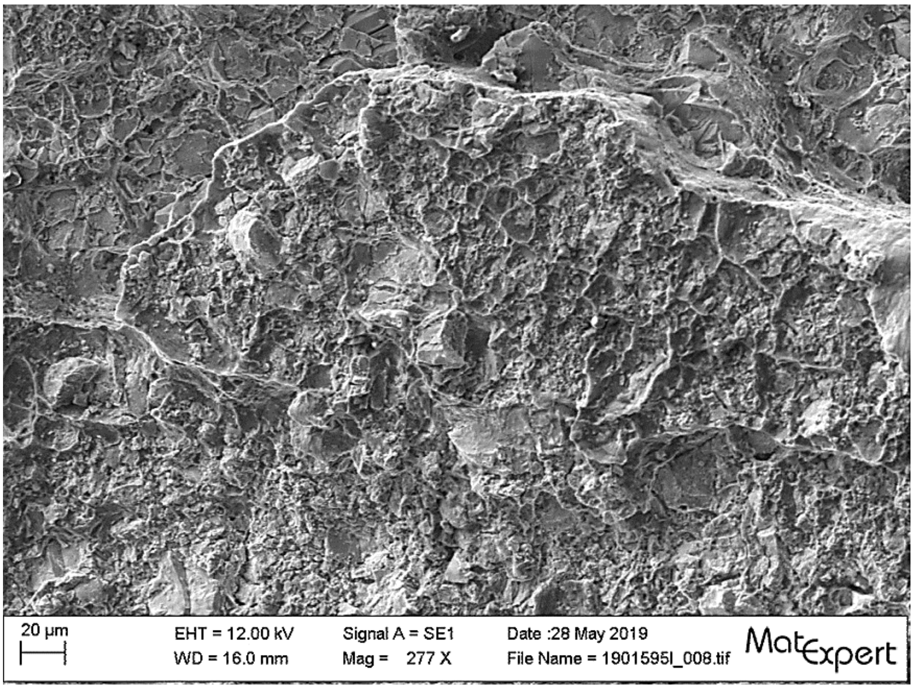


Figure 35: Mixed fracture featuring honeycomb and quasi-cleavage fractures.

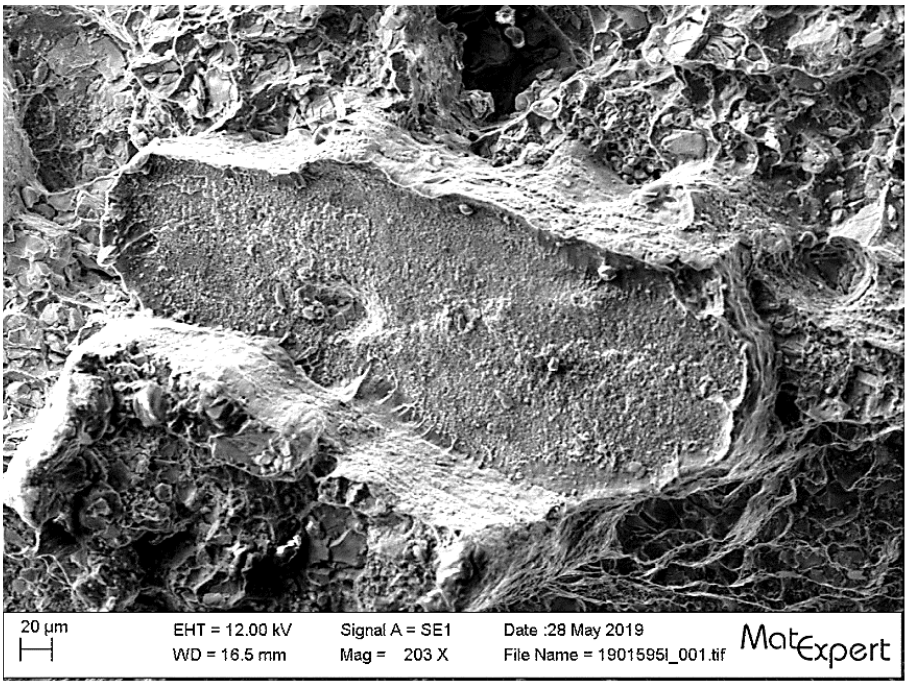


Figure 36: Defect in the form of a terrace, with oxide skin.

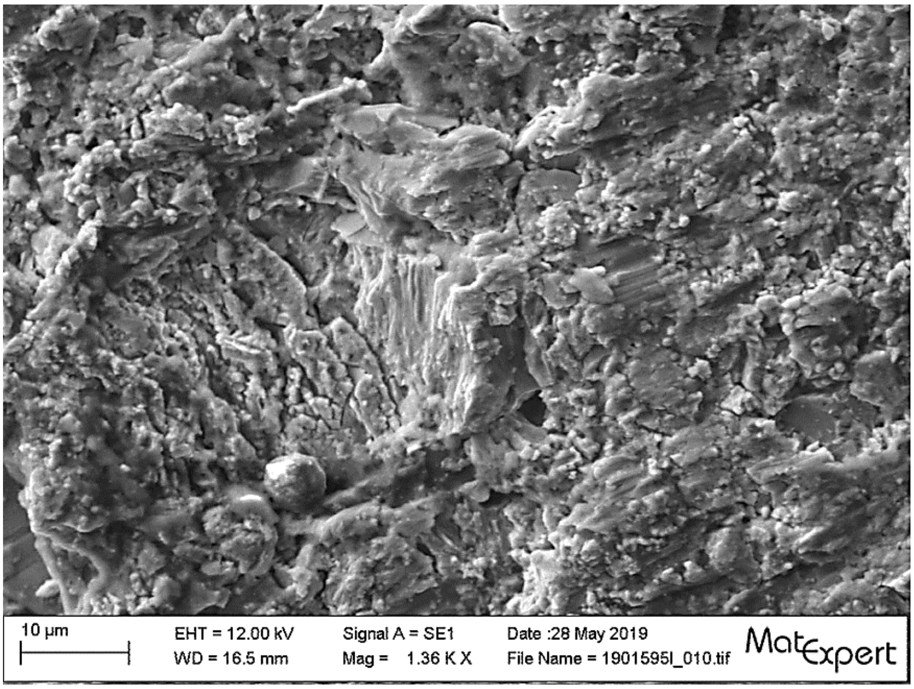


Figure 37: Fine, fatigue crack-like secondary cracks.

A1.16.3.3.3 Surface analysis

The surfaces of the three engine mounts were significantly different.

The centre engine mount is assumed to have been shot-peened. In addition, many small cracks can be seen on the surface (see figures 38 to 42). It is not possible to determine when these cracks were formed. The crack depth was not measured.

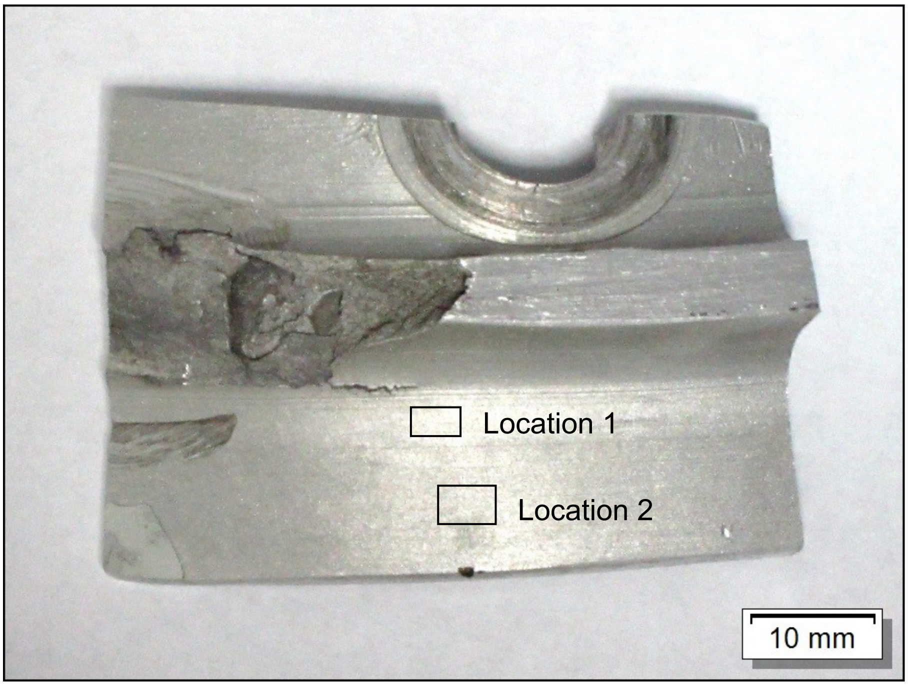


Figure 38: Segment of the centre engine mount – locations of the examined surfaces.

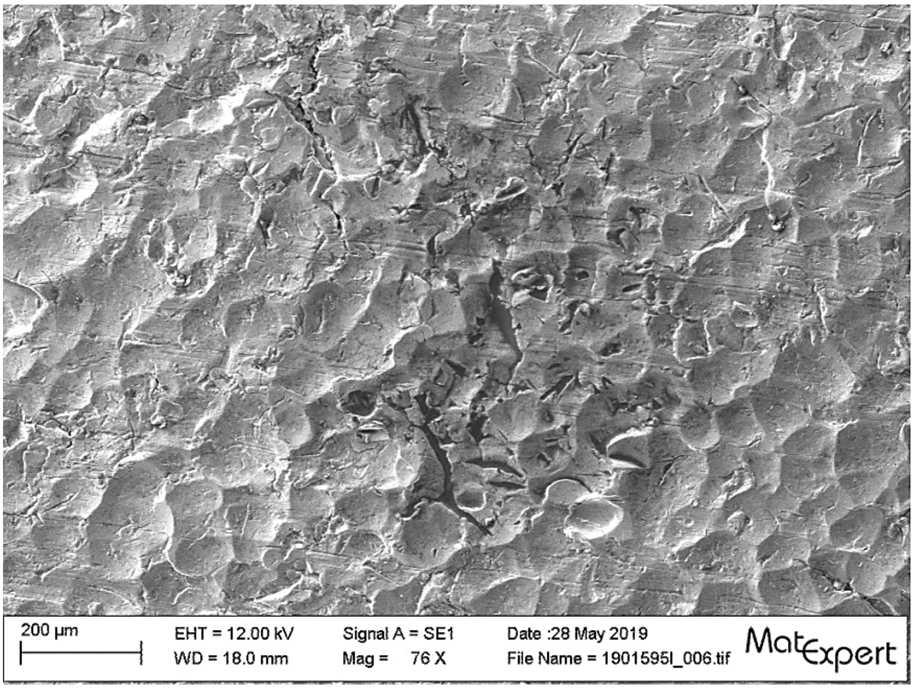


Figure 39: Close-up of location 1 – shot-peened surface with cracks.

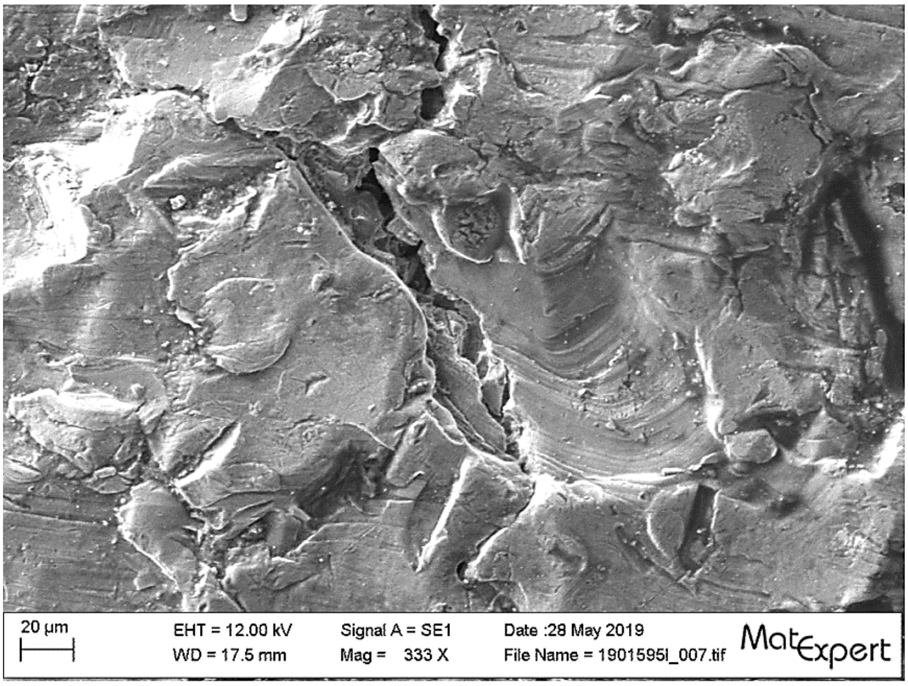


Figure 40: Magnified version of figure 39.

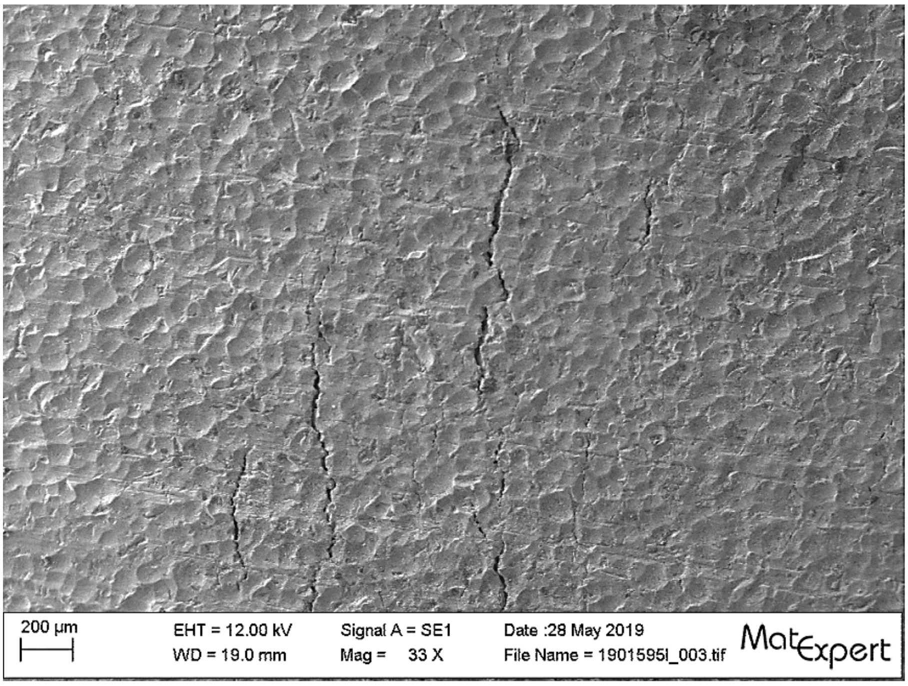


Figure 41: Centre engine mount, location 2 – shot-peened surface with cracks.

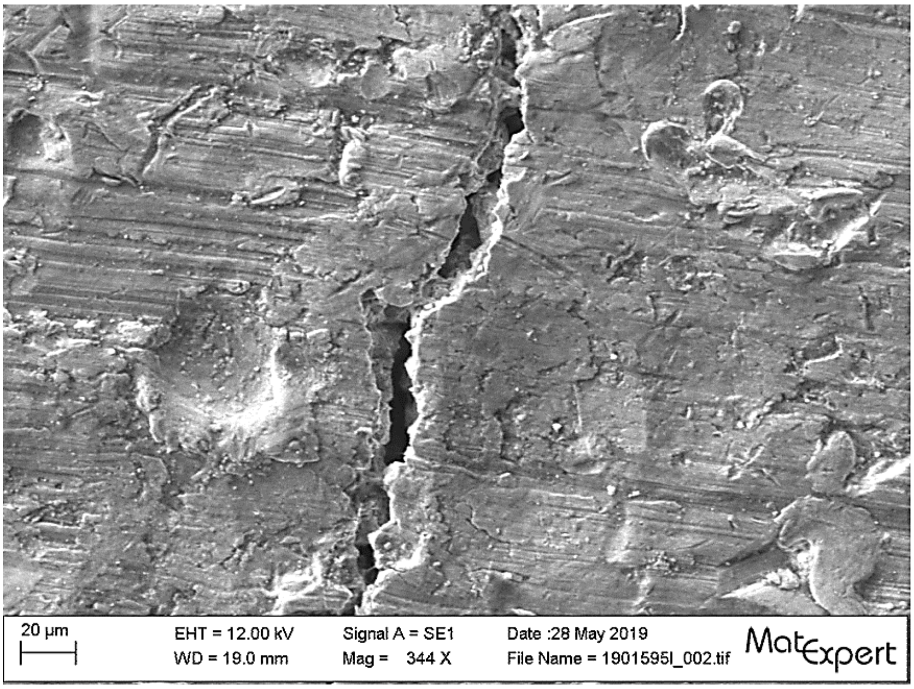


Figure 42: Magnified version of figure 41.

The distinct marks found on the surface of the right engine mount indicate that it was machined (see figure 43). No signs of shot peening and no surface cracks were found.

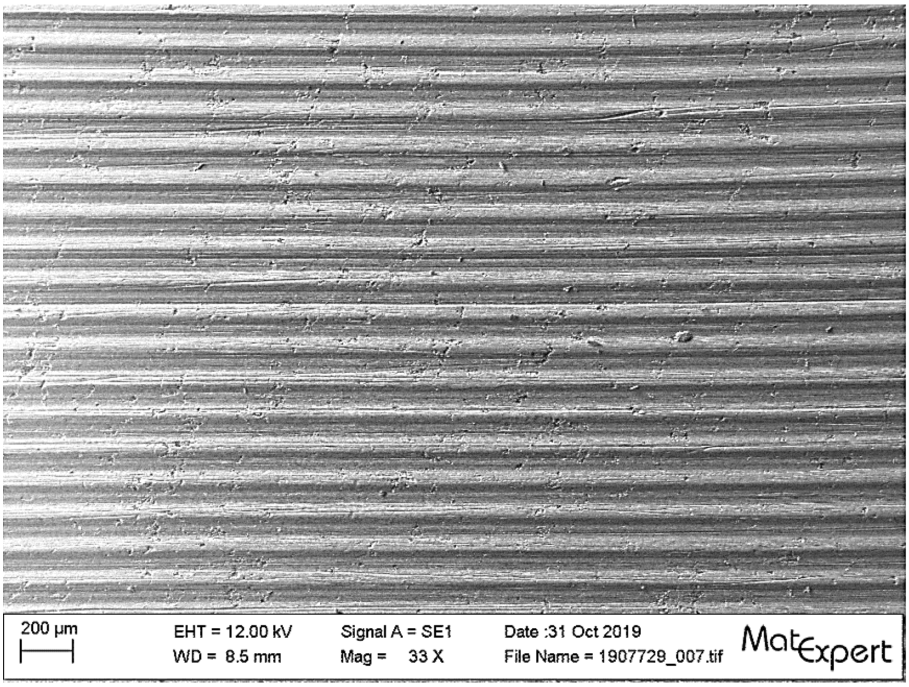


Figure 43: Right engine mount – existing, distinct machining marks (from turned surface).

There were no signs of shot peening on the left engine mount. Microscopic examination of the surface did not discover any microcracks. Based on the determined microstructure, it is conceivable that there are microcracks. However, a more elaborate examination method would be required to prove this.

A1.16.3.4 Engine components

A1.16.3.4.1 Cylinders

One cylinder from each of the three engines was metallurgically examined in the laboratory. The three cylinder barrels were sectioned and the structure of the cylinder wall was analysed. This revealed that all three cylinders were coated on the inside. The base material of the cylinder barrels, the type and thickness of the coatings and the Vickers hardness values were determined. One cylinder head was also analysed to determine the material used.

The examined cylinder from the left engine as well as that from the centre engine has been hard-chrome plated (see figure 44). The thickness of this plated surface is 0.121 and 0.123 mm respectively. It features peeling and has cracks covering the surface like a net, which can be seen with the naked eye. The cracks detected are typical for these kinds of coating and are a result of the process used. The chrome plating is extremely hard, the measured value HV0.3 is between 775 and 820.

The cylinder barrel is made of a medium-strength alloy steel. The HV10 hardness value measured for the cylinder material was 230 and 260 respectively. Before the centre engine's cylinder was chrome-plated, the cylinder's inner diameter was 156.12 mm.

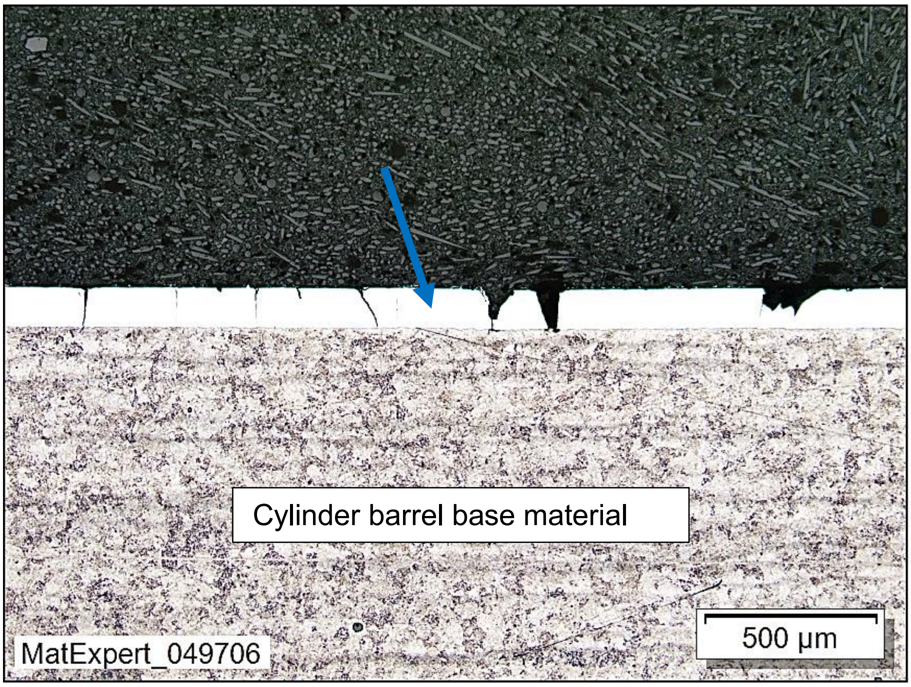


Figure 44: Microsection of the cylinder wall (left engine, cylinder 5) including hard-chrome plating (blue arrow), network of cracks and peeling.

The cylinder from the right engine was plated with a thermal sprayed coating consisting of two different materials (see figure 45). The surface of this plating was porous, cracked and partially discoloured red (see figures 46 and 71).

What is known as a bond coat was found on the substrate, which had been covered by a top coat that featured approximately the same level of thickness as the bond coat. The measured thickness of the bond coat was 0.135 mm and that of the top coat 0.165 mm. The hardness measurement HV0.3 of the bond coat was 160 and that of the top coat 340.

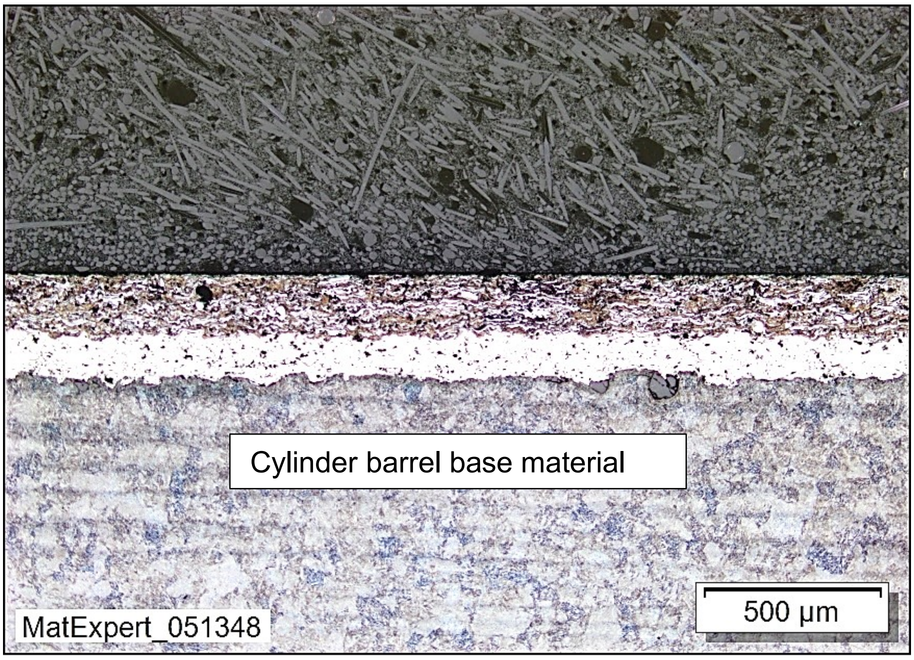


Figure 45: Microsection with two-layer spray coating (right engine, cylinder 1).

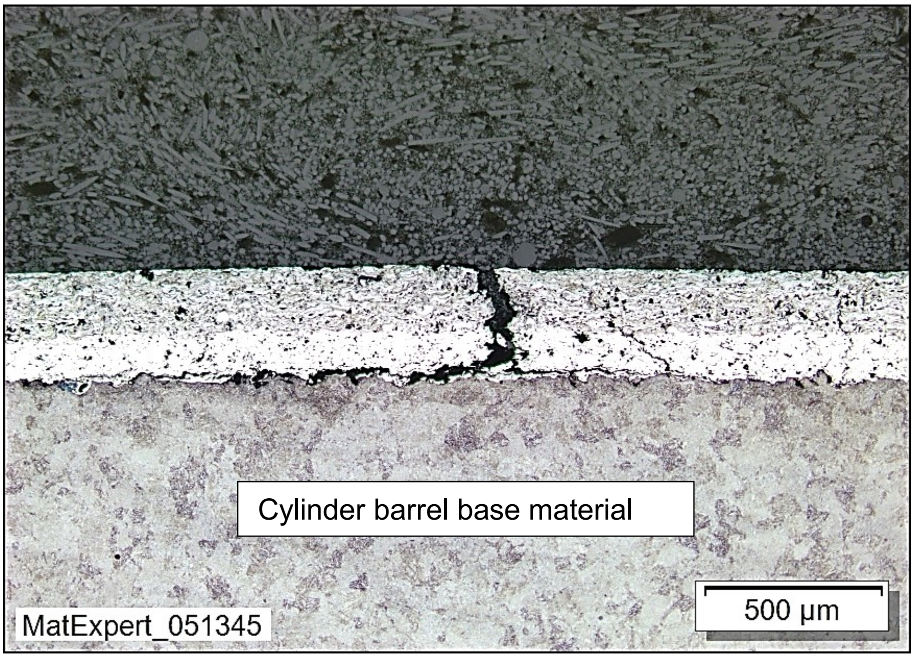


Figure 46: Crack in bond and top coat.

Prior to coating, the cylinder was honed to a diameter of 156.44 mm and the surface was abraded (see figure 47). Honing the cylinder to this diameter is not permitted according to the 1939 operating instructions supplied by the manufacturer of the BMW 132 A3 aircraft engine.

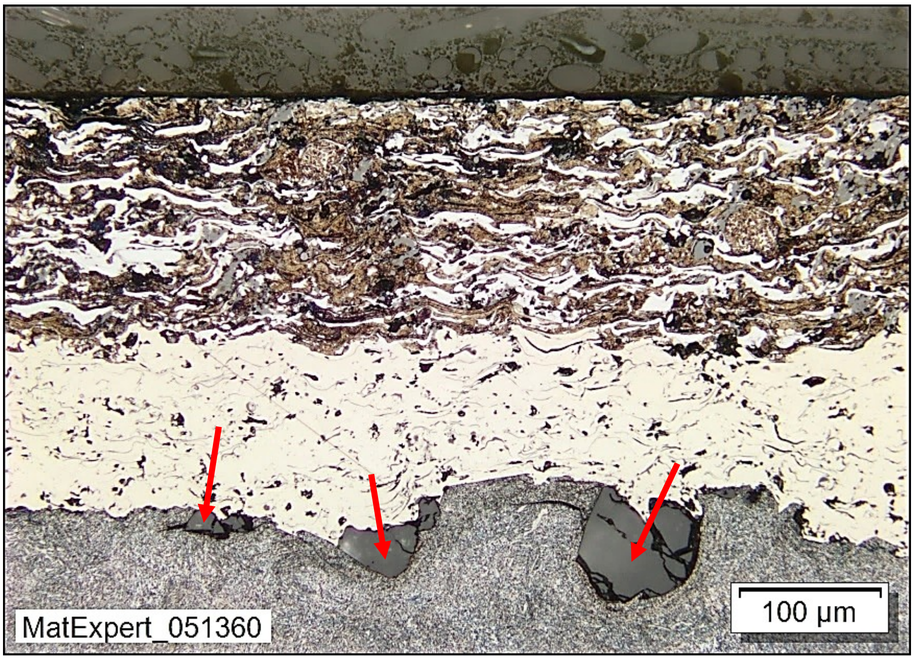


Figure 47: Microsection of the spray coatings with typical abrasive residues on the surface of the base material (red arrows).

The applied spray coatings were analysed for their chemical elements through micro-area analysis using EDX. The analysis was carried out on microsections.

The analytical values of the top coat correspond to a mixture of a low-alloy carbon steel and molybdenum (Mo). Boron (B) was also detected. The analysis of the bond coat indicated an alloy of nickel (Ni) with aluminium (Al) and iron (Fe) i.e. an NiAlFe alloy.

The hardness of the base material for the cylinder from the right engine, measured according to HV10, was 225.

All examined cylinder barrel base materials correspond chemically to the requirements of the engine manufacturer.

The microstructures of all of the cylinder barrels have phase components (ferrite) which do not meet optimum tempering requirements. It is possible that these microstructures were created by long-term thermal stress.

The material used for the cylinder head complies with the specifications of the engine manufacturer. Casting defects in the form of shrinkage cavities are evident (see figure 48). The microstructure can be judged as typical for the alloy in question, but is more consistent with a brittle state.

Compared to modern materials, the alloy has a simple structure. The materials used to manufacture cylinder heads today are alloyed in such a way as to ensure high thermal shock resistance and long-term durability.

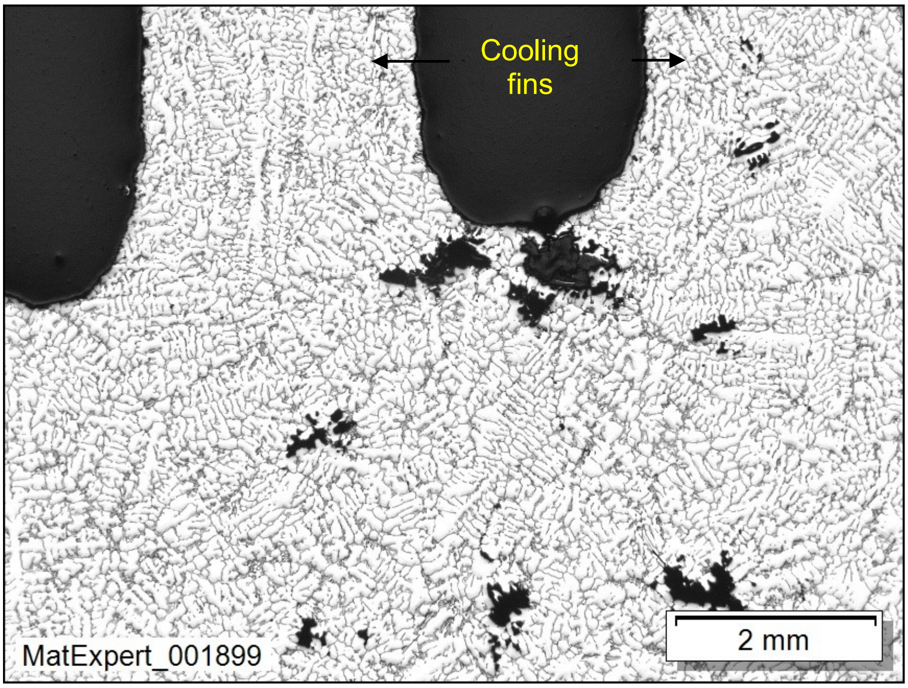


Figure 48: Microsection of the cylinder head's structure with solidification holes (left engine, cylinder 5).

A1.16.3.4.2 Propeller bearings

All of the ball bearings for the three propellers were metallurgically examined.

According to the chemical analyses, the material used for all inner and outer races is consistent with 100Cr6 steel used for common rolling bearings. The mechanical properties were determined using Rockwell hardness measurements on the end faces of the inner and outer races. The measured hardnesses are typical for this material when hardened and then tempered at low temperatures.

The fragments of the outer race from the ball bearing used on the centre engine underwent macro- and microfractographic analysis. A spherical impression can be seen in the area surrounding the origin of the fracture. Most of the fracture surfaces exhibit an intergranular fracture with a low level of ductility, which indicates a certain level of brittleness to the material. The fracture was most likely caused by the accident.

The bearing tracks on the inner races of all three ball bearings and the bearing track on the outer race of the bearing from the centre engine were analysed using scanning electron microscopy. All of the tracks exhibit wear in the form of material chipping, pitting and mechanical indentations (see figures 49 to 53). The residues found were subjected to micro-area analyses using EDX, which revealed high oxygen content as is typical of iron oxide or iron hydroxide (see section A1.16.4.5.2).

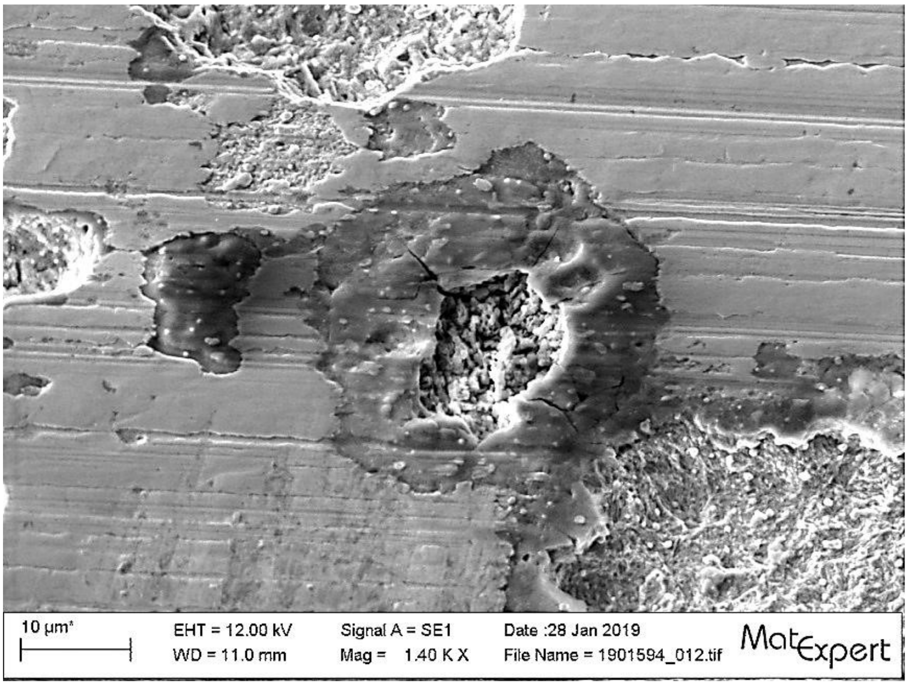


Figure 49: Ball bearing from the right engine, inner-race bearing track – material chipping and corrosive damage.

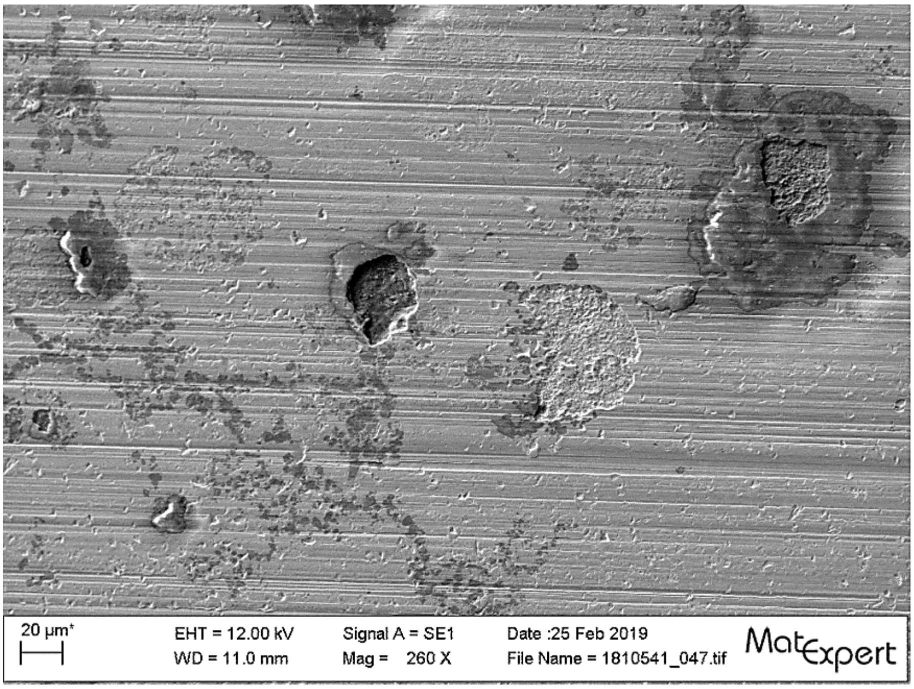


Figure 50: Ball bearing from the left engine, inner-race bearing track – material chipping, corrosion and minor pitting.

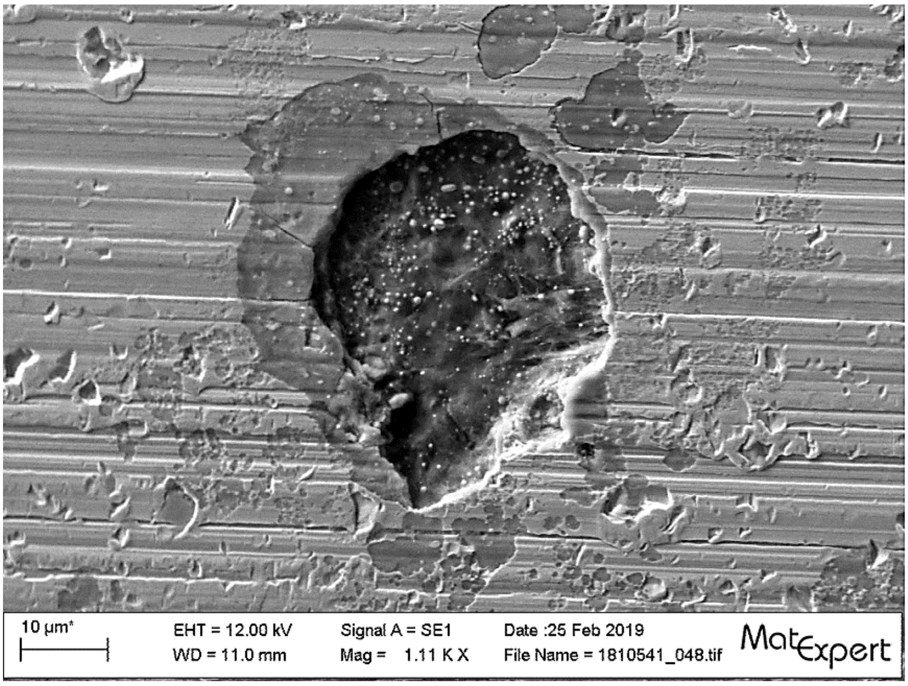


Figure 51: Close-up of figure 50.

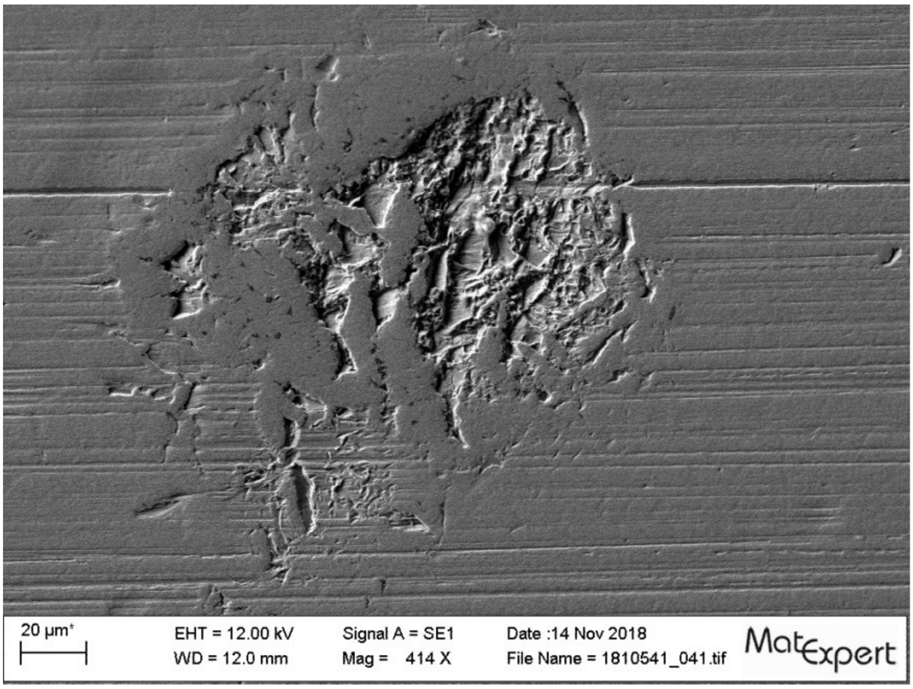


Figure 52: Ball bearing from the centre engine, outer-race bearing track – pitting, possibly due to foreign-body indentations.

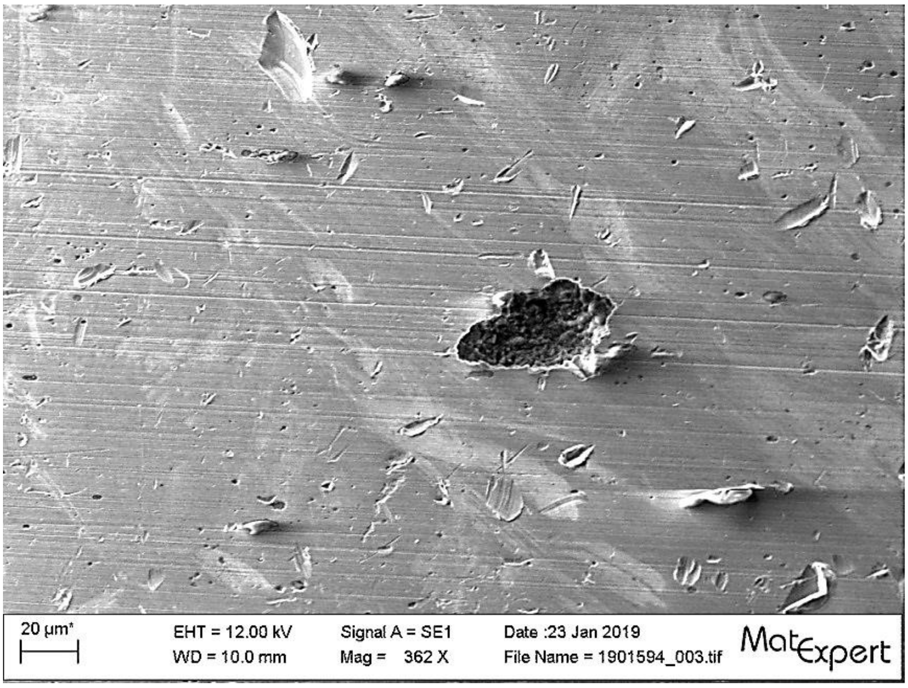


Figure 53: Ball bearing from the centre engine, inner-race bearing track – mechanical indentations, material chipping and pitting.

A1.16.3.4.3 Supercharger bearings

The supercharger bearing nos 3, 4 and 5 (see annex A1.12) from the left engine were metallurgically examined.

According to micro-area analysis, both races as well as the rollers from roller bearing no. 3 are made of 100Cr6 steel, which is often used for the production of rolling bearings, and the roller cage is made of brass. The two races from ball bearing no. 4 are also made of 100Cr6.

The mechanical properties of the races from bearing nos 3 and 4 as well as the rollers were assessed using Vickers hardness measurements. The measured values correspond to usual values for a hardened material.

All the bearings examined exhibited corrosion and were tribologically[4] damaged. On the bearing tracks and guide surfaces, evidence of material chipping, pitting, abrasive wear, intergranular cracks and flat-rolled corrosion was found (see figures 54 to 60). The inner and outer races from bearing nos 3 and 4 had become magnetised. This causes ferromagnetic particles such as any material abraded during use etc. to be attracted and damage the bearing tracks as well as the rolling elements of the bearings and severely interfere the tribological system.

The general condition of the bearings is poor, and the damage found indicates that the supercharger's bearings were at risk of sudden failure. This would lead to a loss of power and possibly to engine failure.

Bearing no. 5 displayed a similar picture.

The damage shows that the installed bearings did not meet requirements.

Figure 54: Bearing no. 3 – cylindrical roller with wear.

[4] Tribology: The science of friction, wear and the lubrication of interacting surfaces in relative motion.

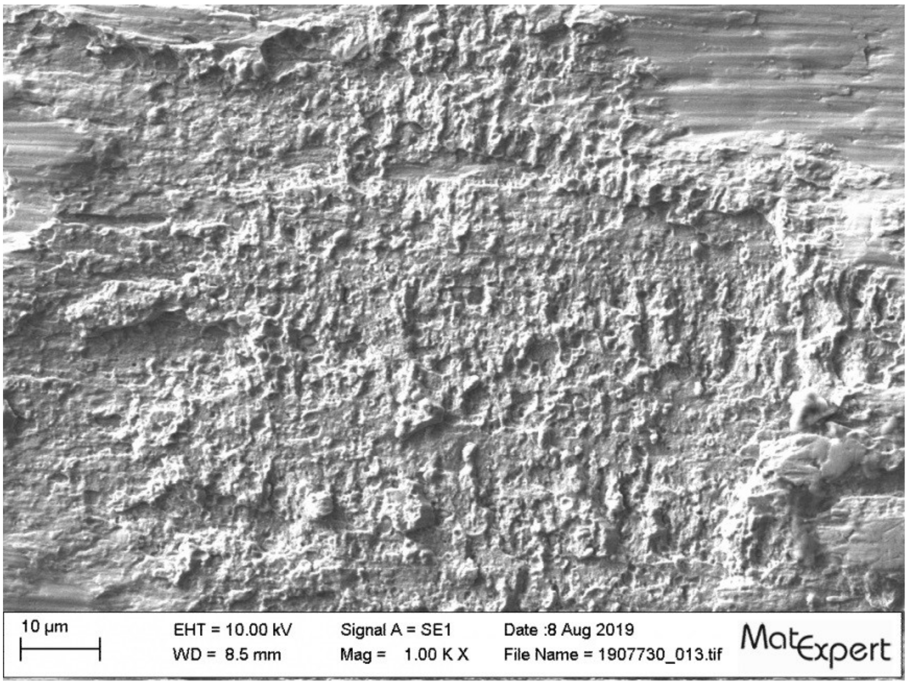


Figure 55: Close-up of the worn area – material chipping and cavitation.

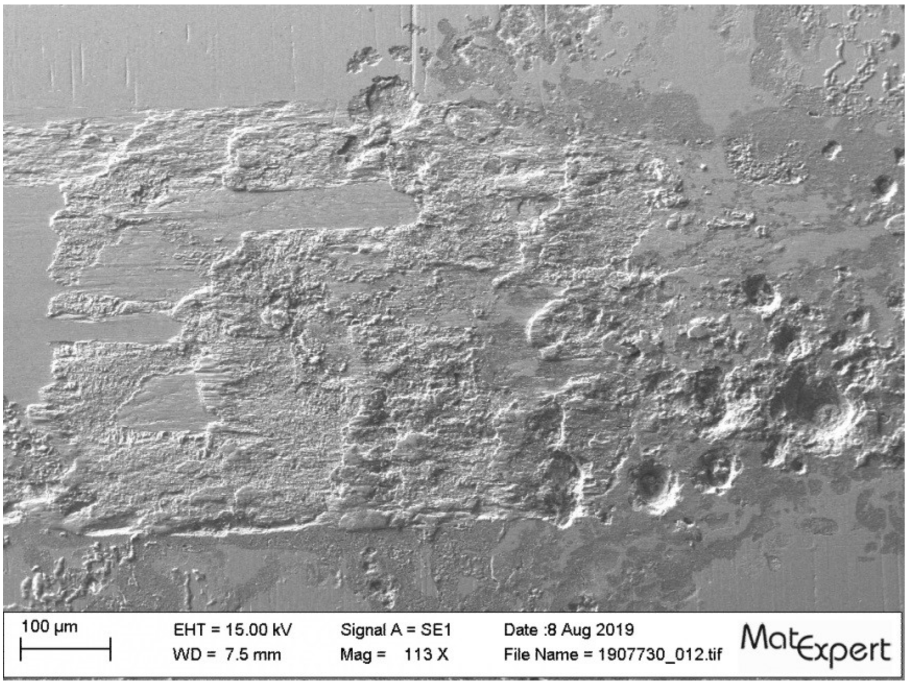


Figure 56: Close-up of the worn area – pitting.

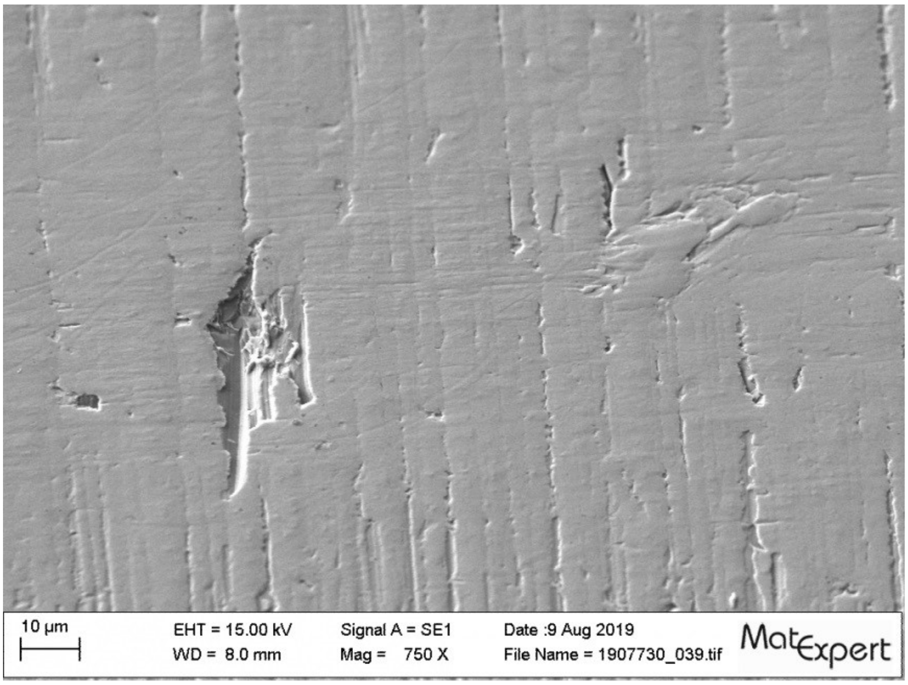


Figure 57: Bearing no. 3, outer-race bearing track – smoothed stop point and material build-up.

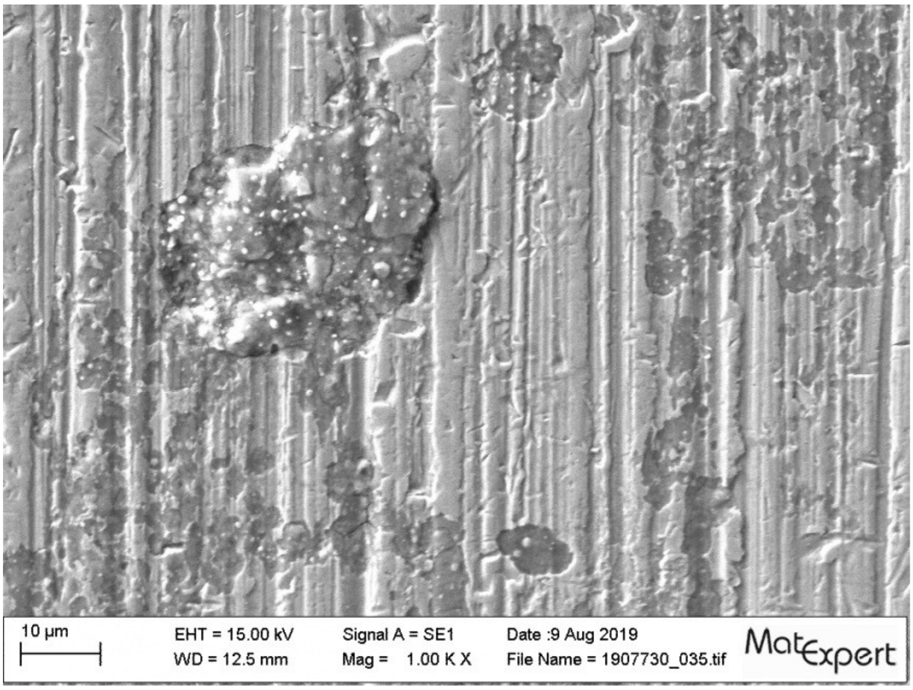


Figure 58: Bearing no. 3, outer-race bearing track – flat-rolled corrosion and abrasive wear.

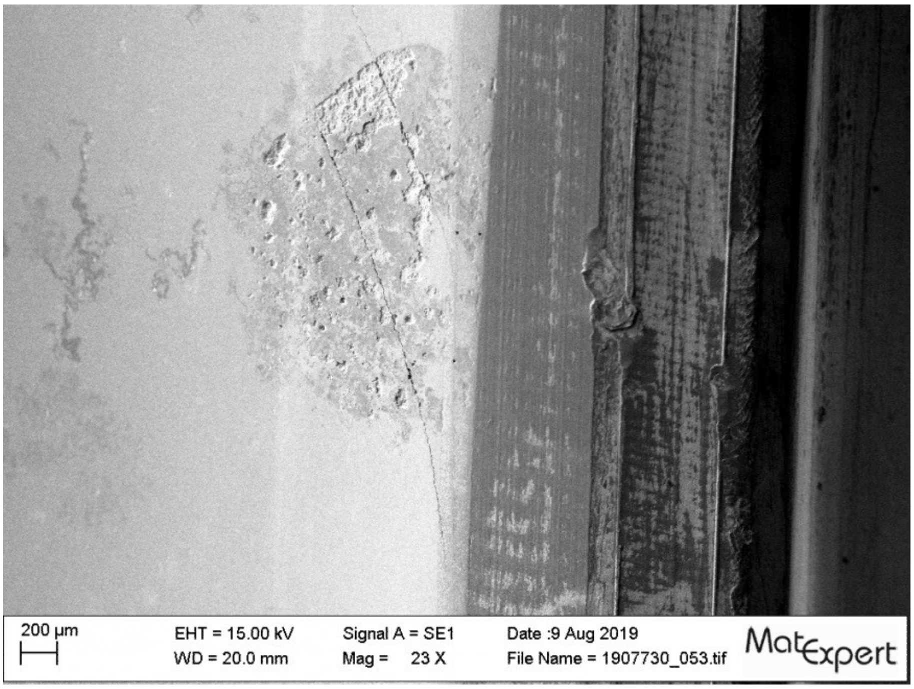


Figure 59: Bearing no. 4, outer-race bearing track – damage due to material chipping and cracks.

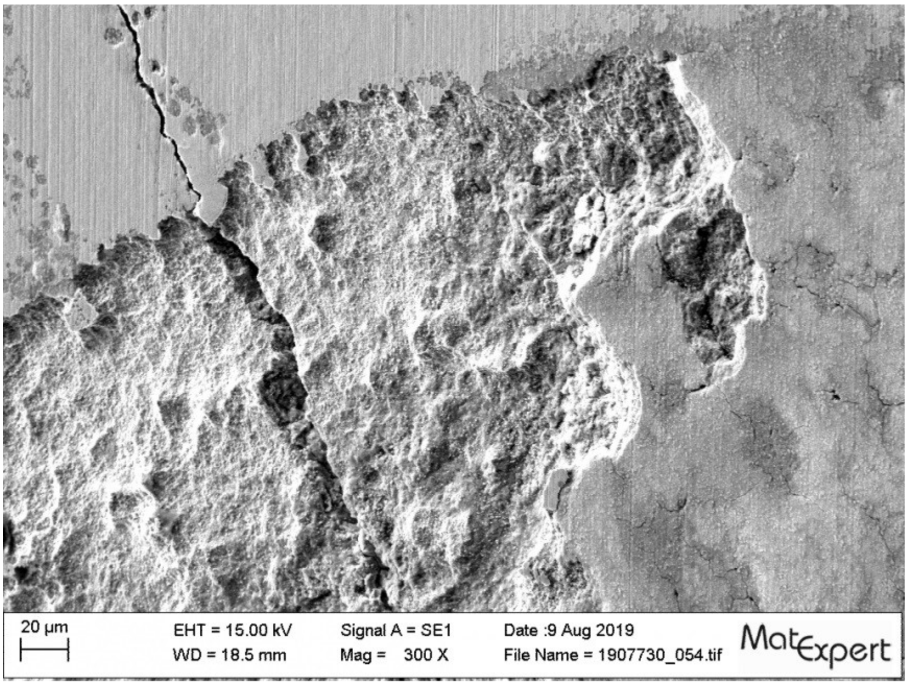


Figure 60: Close-up of figure 59.

A1.16.4 Corrosion analysis

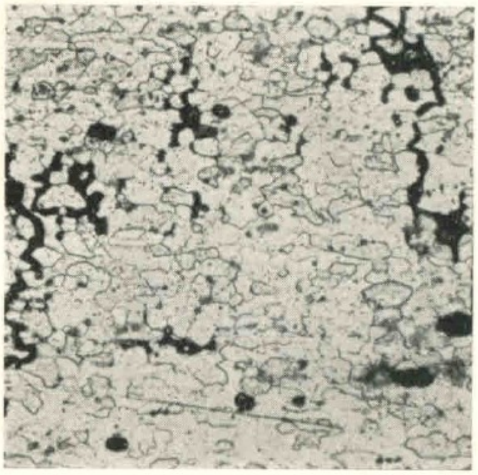
A1.16.4.1 General

When exposed to a certain environment, such as a lack of surface protection, corrosion is able to penetrate Duralumin along the material's grain boundaries. This is known as intergranular corrosion. This phenomenon is also called intergranular attack. This type of corrosion cannot be detected from the outside without appropriate aids, such as a microscope or scanning electron microscope. The ageing of the material due to exposure to heat increases the risk of intergranular corrosion.

When intergranular corrosion occurs, the static strength and fatigue strength are reduced. Depending on prior damage and loads, these strengths are significantly reduced.

Contact corrosion is a type of galvanic corrosion. This occurs, for example, when Duralumin comes into contact with steel and the two material surfaces are exposed to moisture. Contact corrosion often results in pitting.

Duralumin's susceptibility to corrosion was already well known during the production period of the Ju 52/3m g4e aircraft. For example, the susceptibility of AlCuMg alloys to intergranular corrosion was described in book 28 of "*Werkstoffkunde für den Flugzeug- und Motorenbau*" (a series of books on material science for aircraft and engine construction), published in 1937 (see figure 61).



V = 200

Abb. 24. Al-Legierung (Gattung Al-Cu-Mg). Interkristalline Korrosion

Das Seewasser ist an den Korngrenzen in das Material eingedrungen und hat den Zusammenhang des Gefüges gelockert

Figure 61: Illustration of an AlCuMg alloy with intergranular corrosion from book 28 of "*Werkstoffkunde für den Flugzeug- und Motorenbau*" by Ing. Cl. Böhne.

With the appropriate heat treatment, the examined AlCuMg alloy is not susceptible to intergranular corrosion when it is subjected to a corrosive environment but pitting usually occurs.

Intergranular corrosion is therefore not the typical form of corrosion, it only occurs under the following conditions:

- In the event of unfavourable heat treatment, e.g. quenching too slowly after solution heat treatment and/or artificial ageing;
- In the event of thermal stress after ageing;
- In the presence of a corrosive medium, such as combustion gases or condensation.

Stress corrosion cracking can occur in AlCuMg alloys under special circumstances. In addition, it is also possible for corrosion fatigue (a type of corrosion caused by a combination of conditions) to occur.

Intergranular corrosion causes cracks to form that give rise to the notch effect and can lead to the total failure of the component. Likewise, intergranular cracks form the ideal conditions for fatigue cracks to develop. This also applies to the connections between the steel joints and the aluminium spar tubes, which have been secured using rivets made of identical material (see figures 25 and 26).

Usually the aluminium alloy used is less corrosion-resistant than the steel used for the connecting joints. However, research has shown that the spar material is more corrosion-resistant when artificially aged, which explains the severe corrosion of the steel joint. Depending on the state of the microstructure, there are shifts in the corrosion potential between the pairing of aluminium and steel. Consequently it is possible that, when in an unfavourable structural state, the AlCuMg alloy creates an electrochemical environment that leads to the steel also corroding.

The material pairing of steel and an AlCuMg alloy is fundamentally problematic and this is accentuated in an aggressive environment. In this case, it is important to ensure that the metals are insulated from each other by a non-conductive material, e.g. by a coat of paint.

A1.16.4.2 Manufacturer's instructions regarding corrosion protection

In section 0, 'General', of the operating manual for the Ju 52/3m g4e aircraft, the manufacturer wrote the following regarding corrosion protection under 'Partial overhauls and major overhauls':

"*Partial overhauls are to be carried out after approximately 300 operating hours*.

[…]

Particular attention must be paid to the surface protection conforming with specifications.

Major overhauls are to be performed after approximately 1,500 operating hours.

For this, all larger parts, such as the outer wings, empennage, controls, engine parts, etc. are to be dismantled and thoroughly inspected; in addition, the surface protection and all equipment are to also be overhauled. Any necessary repairs are to be made so that the final condition of the aircraft is as close to factory-new as possible."

Furthermore, in the same section under 'Cleaning and Paint Care' the following instructions are given:

"*At certain intervals, the entire coating must be carefully inspected inside and out for damaged areas, flaking, blistering and cracking, etc. caused by weathering. Any damage must be repaired in accordance with the information given in the 'Junkers Repair Instructions'.*"

In section 5, 'Surface protection', of the repair instructions (*Ausbesserungsanleitung*) for Junkers metal aircraft, the manufacturer provided the following information under 'Preliminary remarks':

"*Surface protection (corrosion-proofing) is intended to protect the material against all kinds of corrosion and thus increase the service life of the aircraft*.

[…]

In aircraft, corrosion is mainly caused by atmospheric influences (condensation), seawater and the electrical currents triggered when parts of different potential are connected (placed on top of each other).

The protection used must be easy to apply, durable, attractive and easy to repair or renew.

[…]

The decision as to whether the surface protection is to be repaired or renewed depends on whether or not sufficient protection is guaranteed during continued operation. Any increase in weight due to extensive paint application can also be a deciding factor. If the paint is not cracked or flaked off, it is usually not necessary to apply a new coat.

Before painting, the parts or areas concerned must be thoroughly cleaned with detergents (see 1a, 2a, 3a) as specified, avoiding sanding bare aluminium alloy with steel wool, sandpaper or wire brush as far as possible. The cleaned surfaces must be free of paint residues, oils, greases, dirt, scale, oxides, hand perspiration, etc."

A1.16.4.3 Fuselage

The sheet metal of the cabin floor near the aft hinge of the cargo door exhibited cracks, pronounced intergranular corrosion and pitting. In parts, the sheet was affected all the way through (see figures 62 to 64).

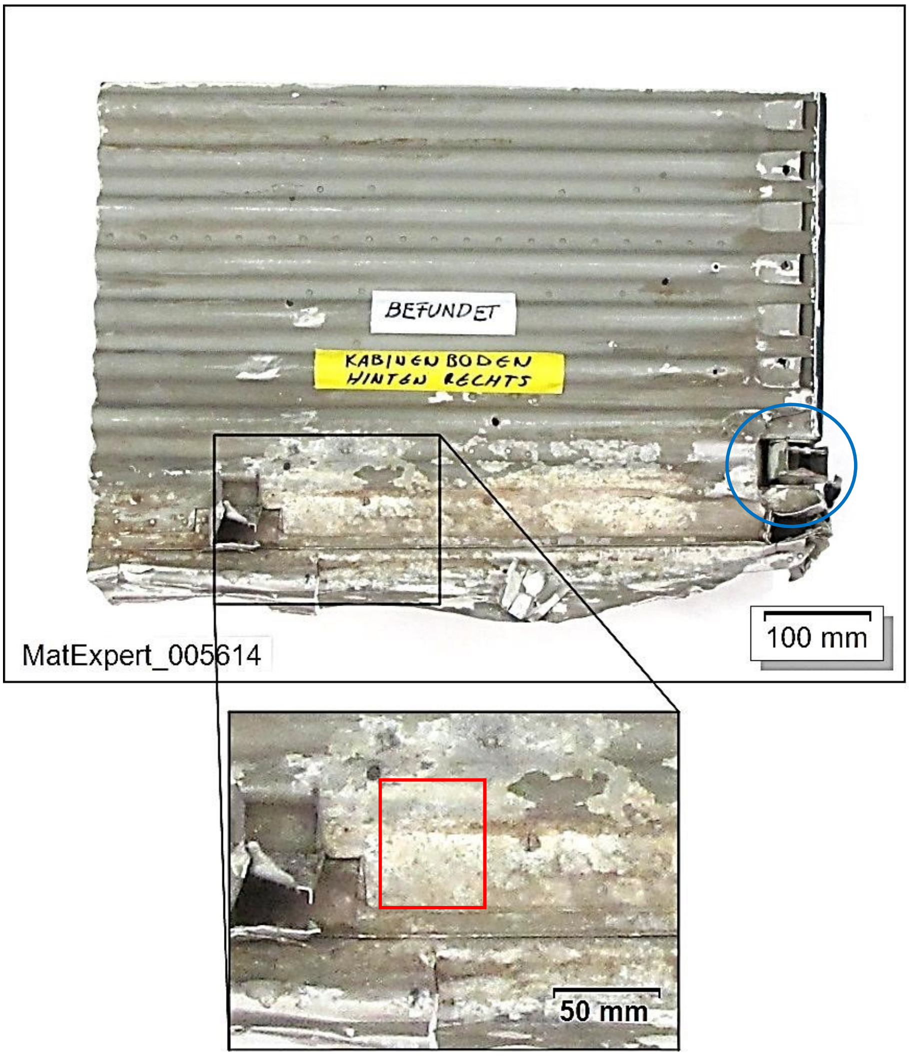


Figure 62: Corroded cabin floor from the aft right area (label text reads cabin floor, aft right). Samples were taken from the zone marked in red for the subsequent microsections. The blue circle marks the cargo door's aft hinge.

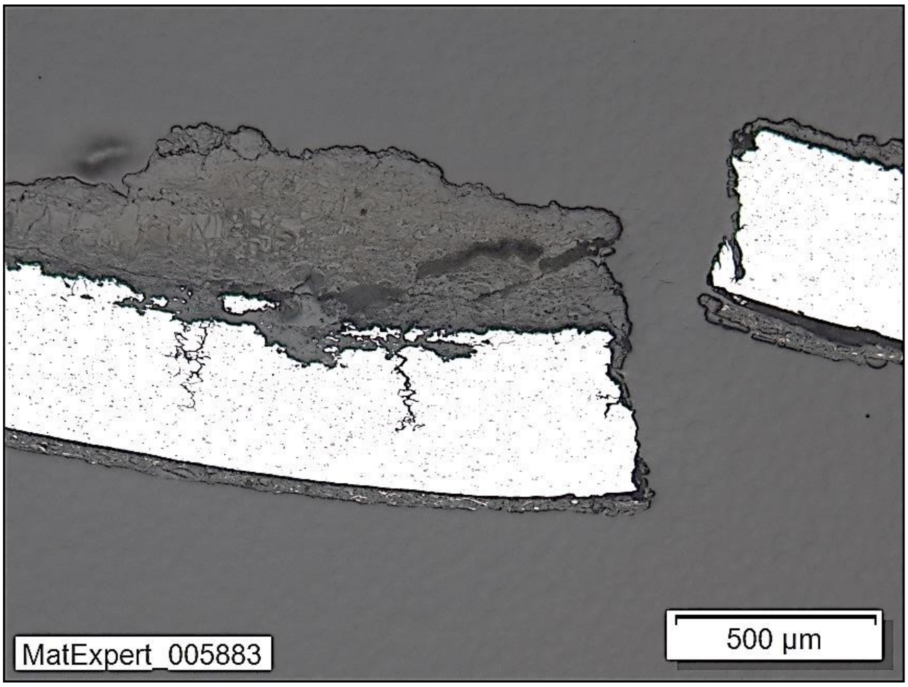


Figure 63: Microsection of the corroded sheet. Cracks with intergranular corrosion.

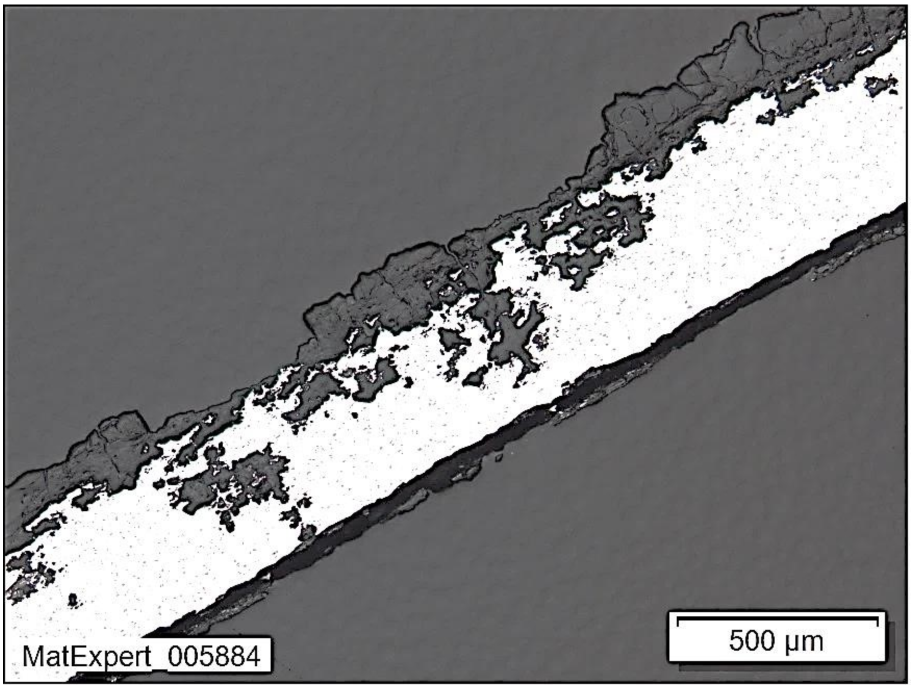


Figure 64: Microsection of the corroded zone; intergranular corrosion and pitting.

The hinge of the cargo door made of steel was severely corroded. Some of this corrosion was very advanced (see figure 65).

Figure 65: Severely corroded inner side of the cargo door hinge.

A1.16.4.4 Wing

Spar sections L1, L2u and 1Ru as well as the two joints from spar L1 were examined regarding corrosion in the laboratory. All examined spar sections corresponded chemically to hardened Duralumin Du44; the joints were made of steel. The lower spar sections and joints only exhibited remnants of the anti-corrosion paint. The corrosion protection was assessed to be insufficient.

Intergranular corrosion was found in lower spar section L1 (see figure 66), while on section 1Ru, pitting, as is common for this material, was found (see figures 67 and 68). The former only occurs when the material does not conform with the specifications and is the result of artificial ageing or thermal stress and grain boundary precipitation.

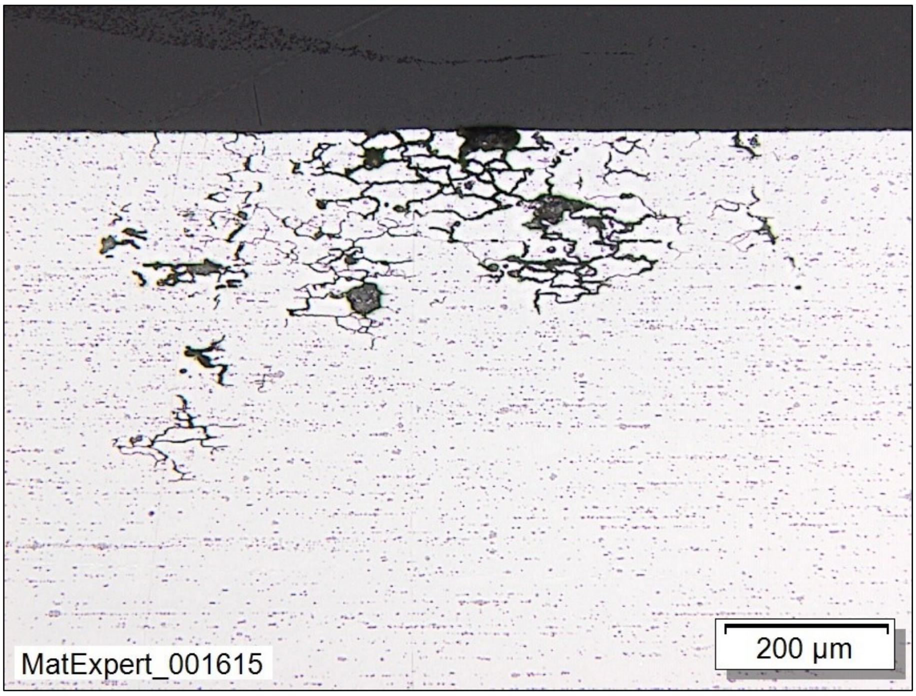


Figure 66: Microsection of lower spar L1 with intergranular corrosion.

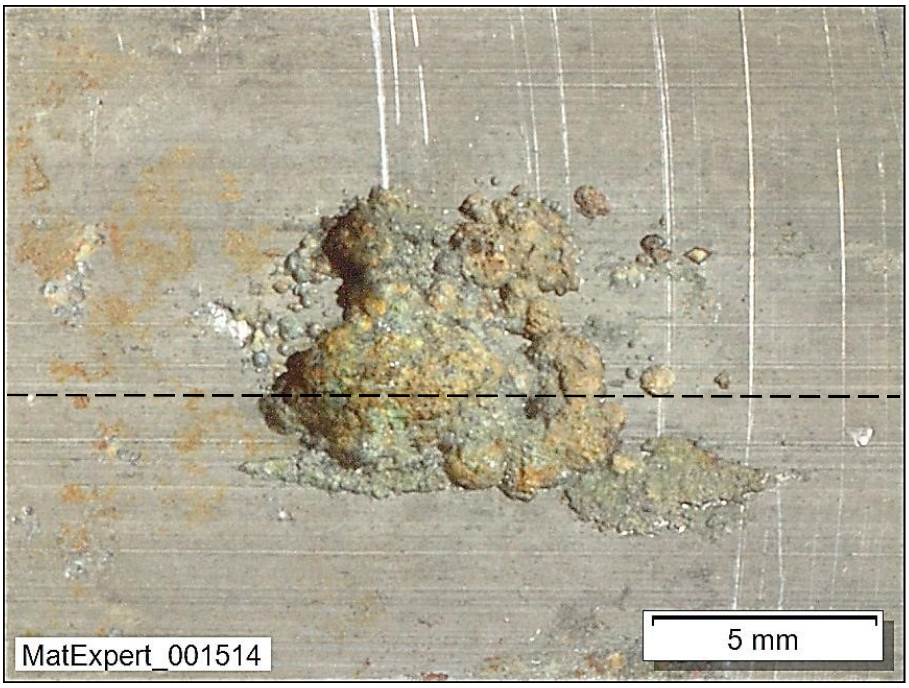


Figure 67: Pitting on spar section 1Ru (line of cross section, see figure 68).

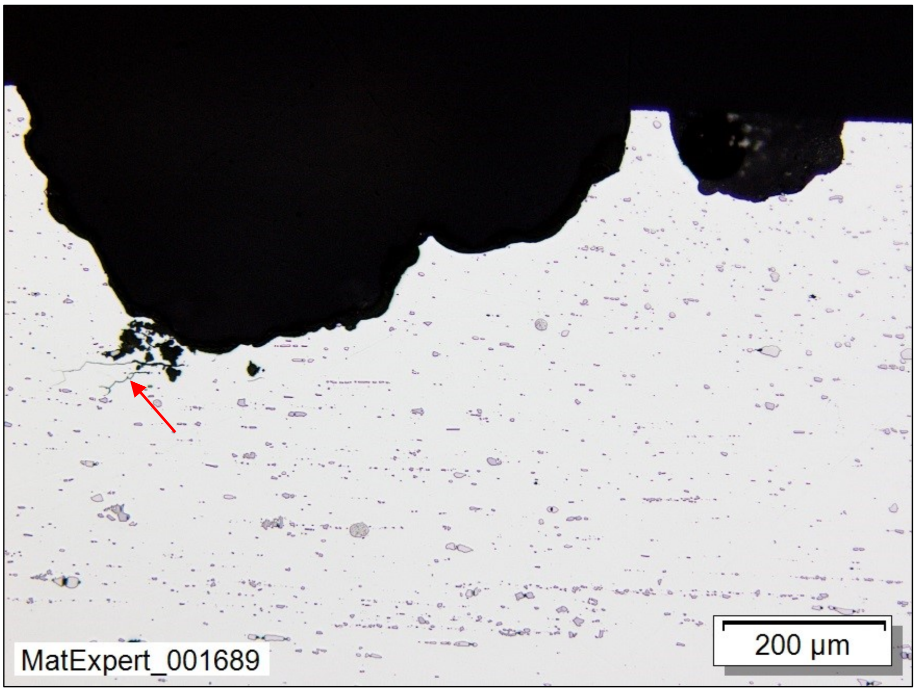


Figure 68: Microsection along the line as indicated in figure 67 with severe pitting and individual stress cracks (arrow).

Lower spar section L1 also exhibited intergranular corrosion outside of the point of contact between the spar and the joint. In some areas, signs of stress corrosion cracking were discovered. Likewise, some cracks exhibited areas that are typical of corrosion fatigue.

Joint 89 mounted on the left outer wing's lower spar L1 was examined for corrosion after being cut open. The joint is a welded steel construction. The inside, which was in contact with the aluminium spar, exhibited severe corrosion damage. Usually the aluminium alloy used is less corrosion-resistant than the steel used for the joints. However, research has shown that the material used for the lower spar is more corrosion-resistant when artificially aged, which explains the severe corrosion of the steel joint.

The corrosion isolated on spar section L1 mainly contained compounds of iron.

In the examined instance, given the position of the corroded lower spar section L1 in the left outer wing near the left engine, it is probable that the susceptibility only arose during operation as a result of heat from the engine. Engine exhaust gases are not only thermally problematic, but also contain reactive products or corrosion-promoting substances. Environmental conditions play a major role in this.

In addition to the contact surfaces between the joints and the spar, corrosion was found on the lower spar sections in the areas near the steel joints as well as in areas of wear caused by the panelling.

Examination revealed that the joints on upper spar section A exhibited a similar condition as those on lower spar section L1. Several intergranular cracks were also found.

The panelling was also examined in the laboratory for corrosion. Analyses using scanning electron microscopy show that the surface was partially covered with corrosion and exhibited corrosive damage (see figure 69). Metallographically, corrosion spots can be detected in some areas on the surface of the plating, underneath the coat of paint (see figure 70).

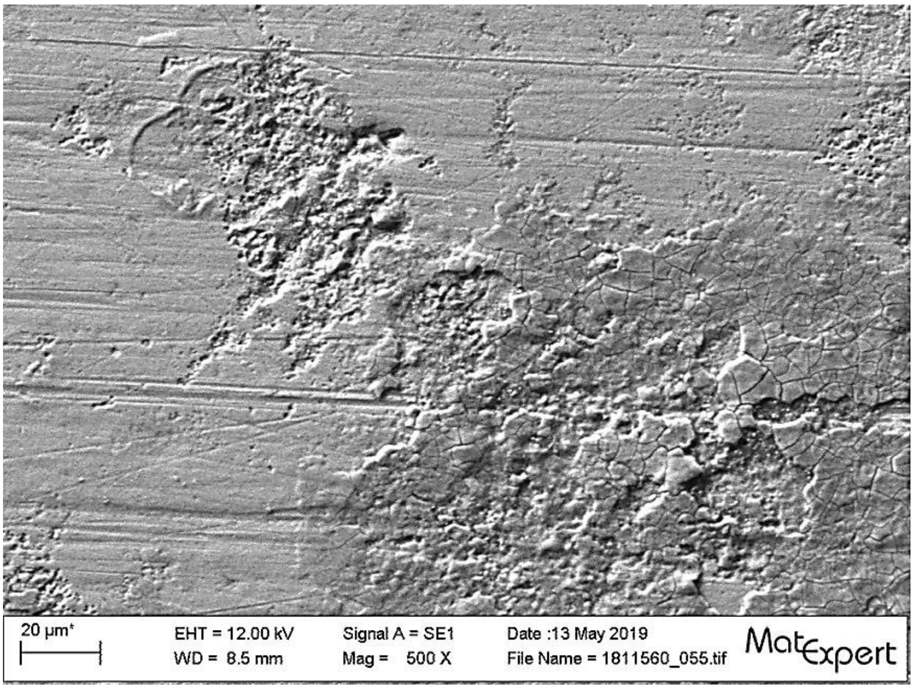


Figure 69: Outer surface with corrosion and corrosive damage.

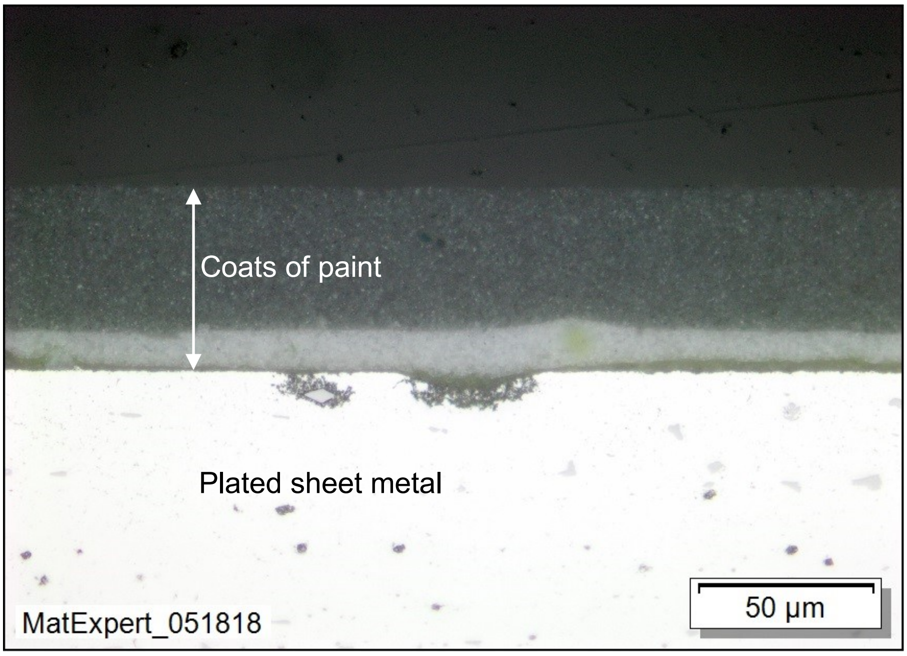


Figure 70: Microsection of corroded plated sheet metal under the layers of paint.

A1.16.4.5 Engine components

A1.16.4.5.1 Cylinder bores

Visual assessment revealed discolouration to the bore of several cylinders (see figure 71). Cylinder 1 from the right engine exhibited this discolouration and was subsequently examined in the laboratory for corrosion damage. This cylinder had been sourced from an engine that was recovered from wreckage located on a glacier. The coating to the bore of this cylinder consists of two different materials that were thermally sprayed onto the cylinder wall, which had been abraded by previous blasting (see section A1.16.3.4.1 and figure 72). Laboratory tests revealed that the top coating was open-pored and corroded in part.

This corrosion was identified as rust, which explains the red discolouration of the bore. The cause of the bond coat's detachment from the cylinder barrel (see figure 72) is indication of pre-existing corrosion damage.

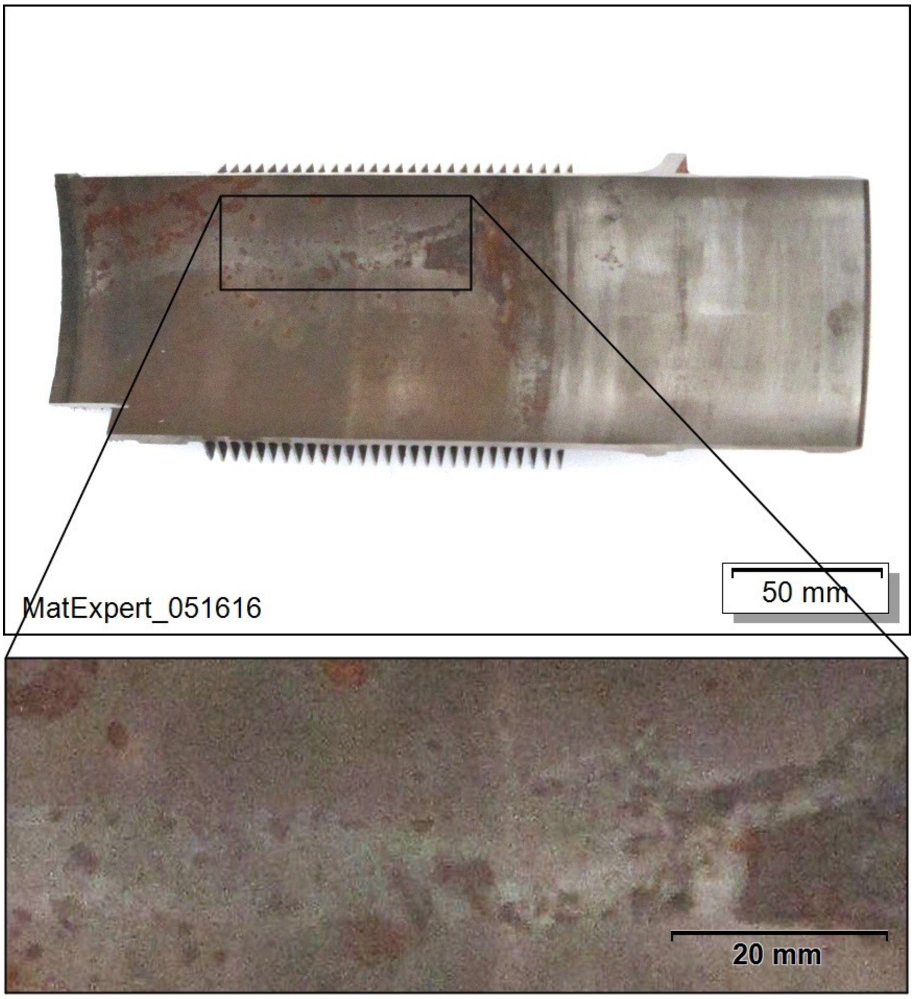


Figure 71: Right engine, bore of cylinder 1 – rusty surface.

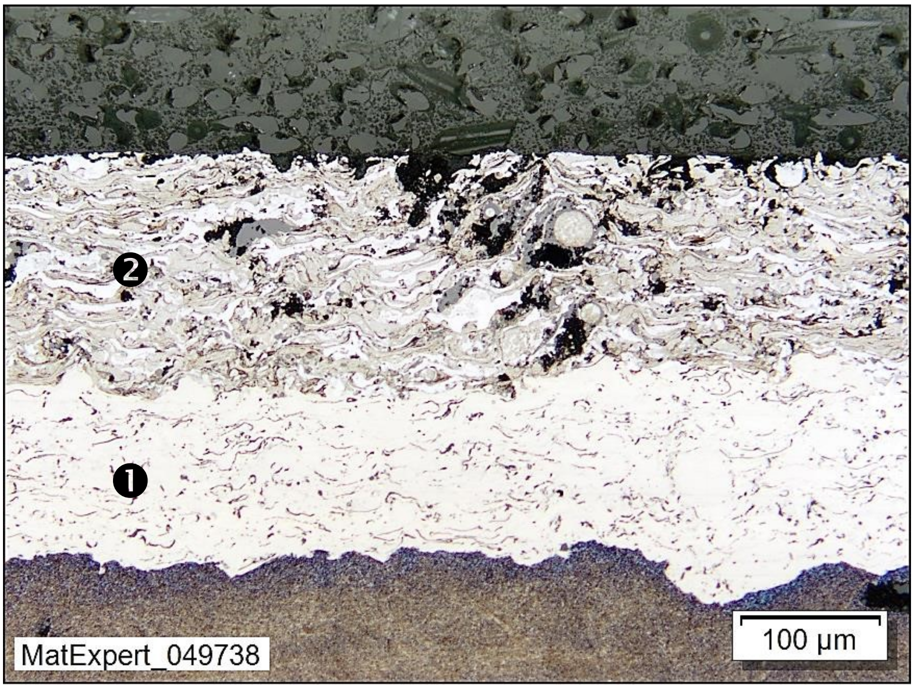


Figure 72: Close-up of the bore of cylinder 1 with two-layer thermal spray coating. Number (1) is the bond coat. Number (2) is the top coat, which is partially open-pored.

A1.16.4.5.2 Propeller bearings

The three propeller bearings were subjected to corrosion tests in the laboratory. For this purpose, the bearings were cut in half and the individual bearing components were analysed. All three bearings exhibited tribological and corrosive damage (see figures 73 to 75). As the corrosive damage to the bearing tracks and surfaces on the inner race fitting the shaft as well as on the outer race fitting the housing was found to have already existed for a long time prior to the accident, it has to be assumed that the corrosive damage caused the tribological damage to the bearings.

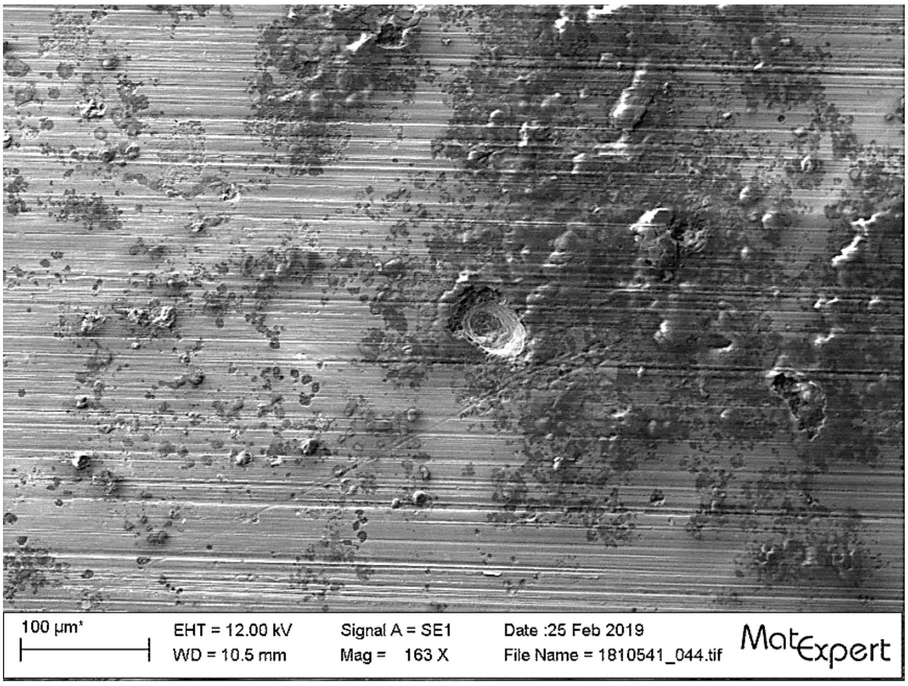


Figure 73: Ball bearing from the left engine, inner-race bearing track – corrosion.

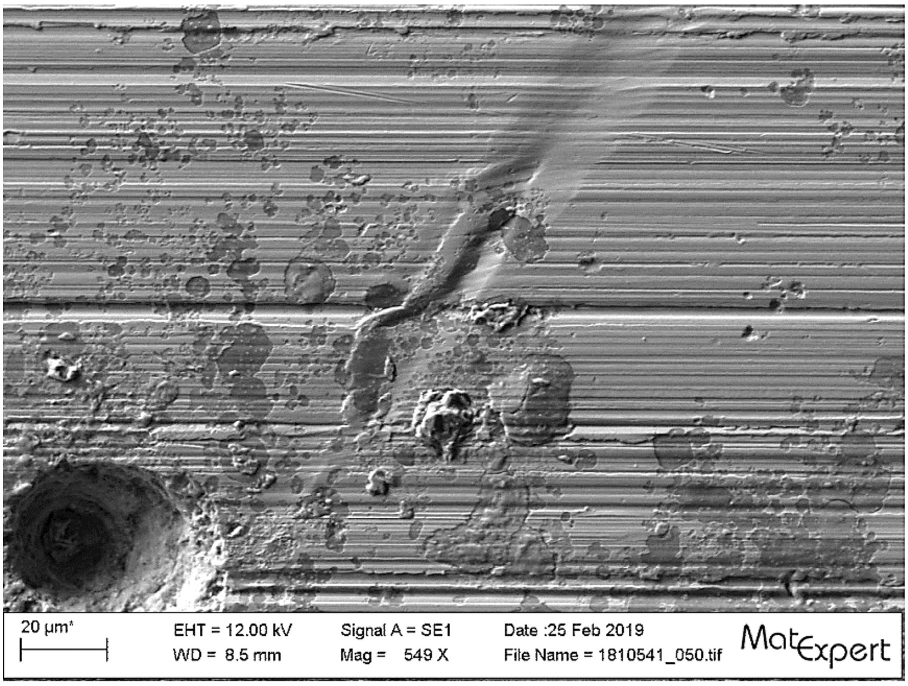


Figure 74: Ball bearing from the left engine, inner-race bearing track – pitting and indentation.

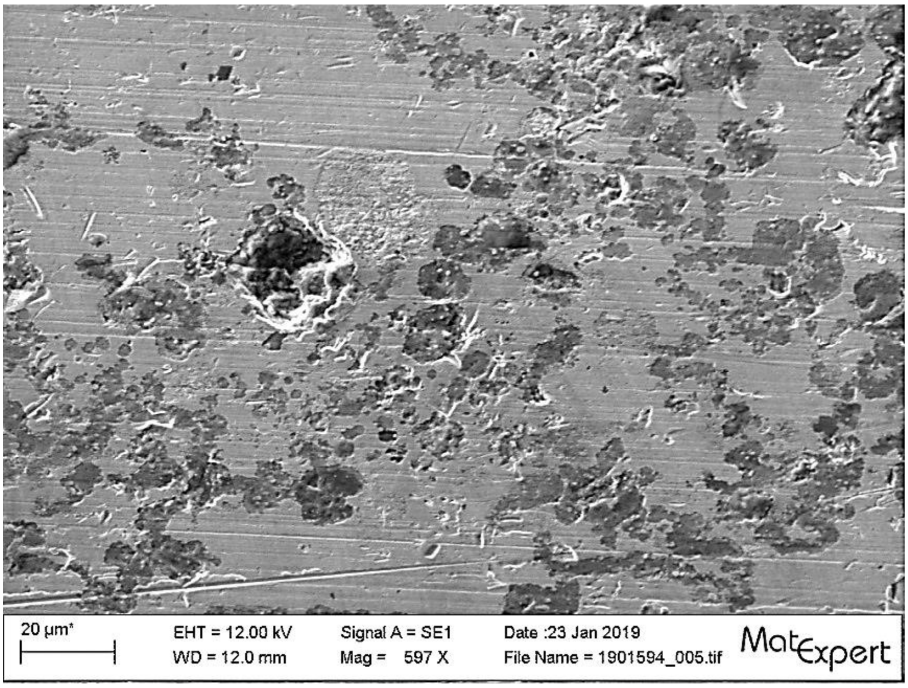


Figure 75: Ball bearing from the centre engine, inner-race bearing track – corrosion.

A1.16.4.5.3 Supercharger bearings

The corrosion tests in the laboratory for supercharger bearing nos 3, 4 and 5 (see annex A1.12) of the high-speed supercharger shaft from the left engine revealed the following results:

All three bearings were corroded. This corrosion was found on the end faces, the surfaces where the bearings were fitted as well as on the bearing tracks of the inner and outer races and the rolling elements (see figures 76 to 83).

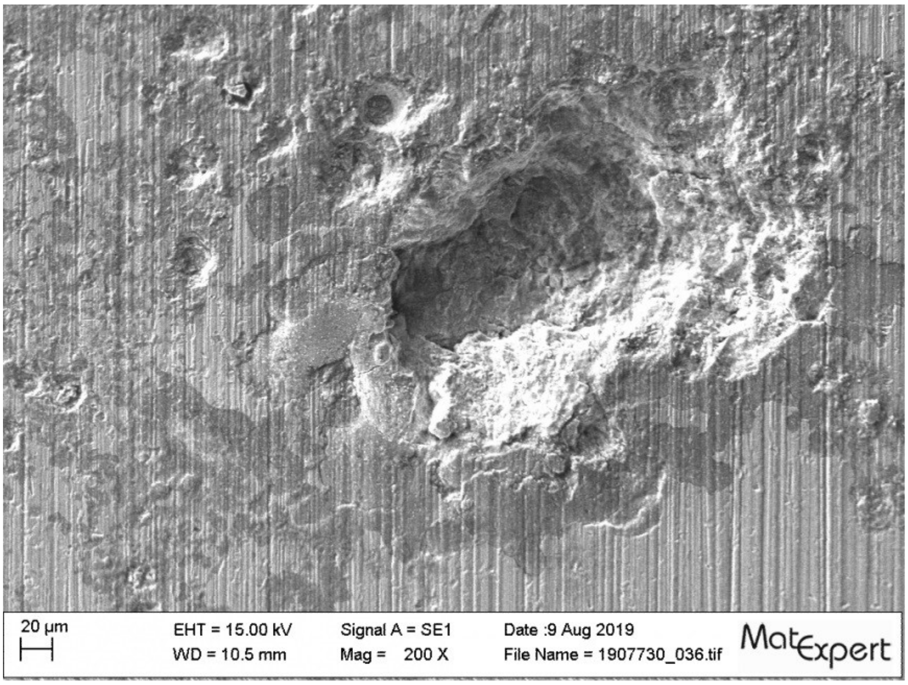


Figure 76: Bearing no. 3, outer-race bearing track – pitting.

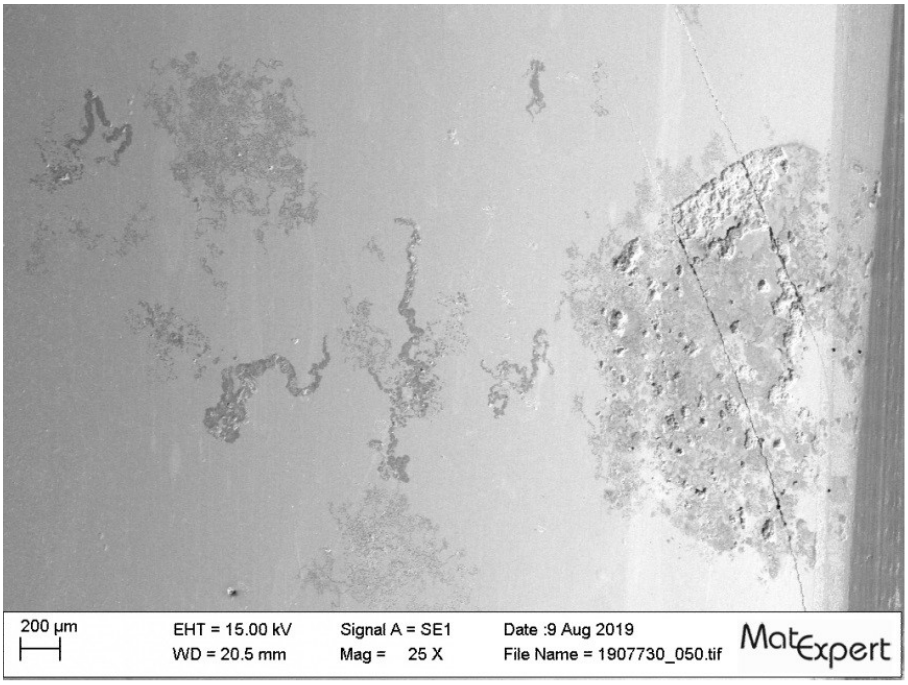


Figure 77: Bearing no. 4, outer-race bearing track – filiform corrosion and pitting with cracks.

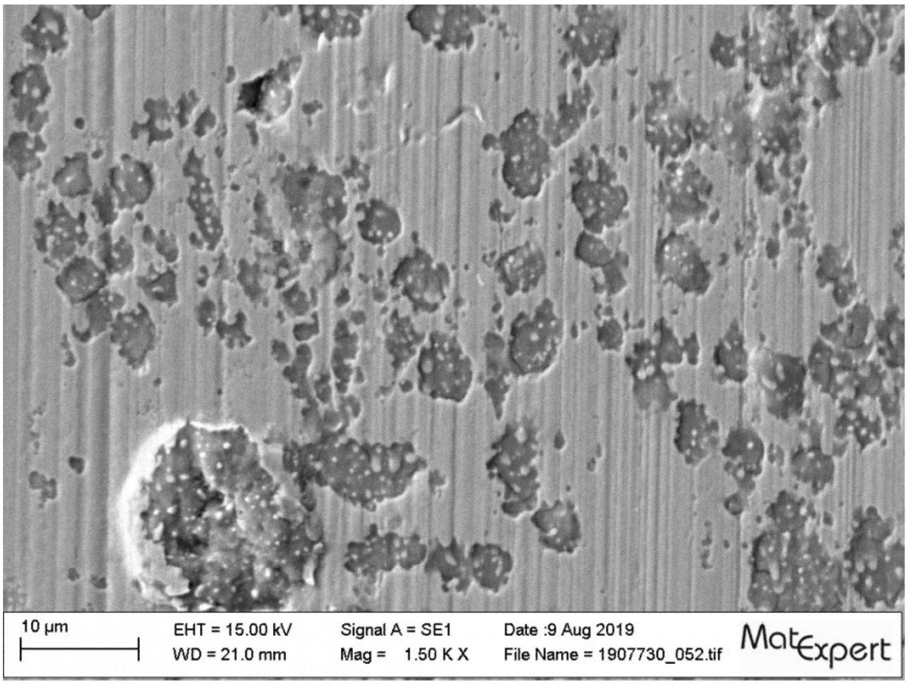


Figure 78: Close-up of figure 77.

Figure 79: Bearing no. 3, inner-race bearing track – pitting and filiform corrosion.

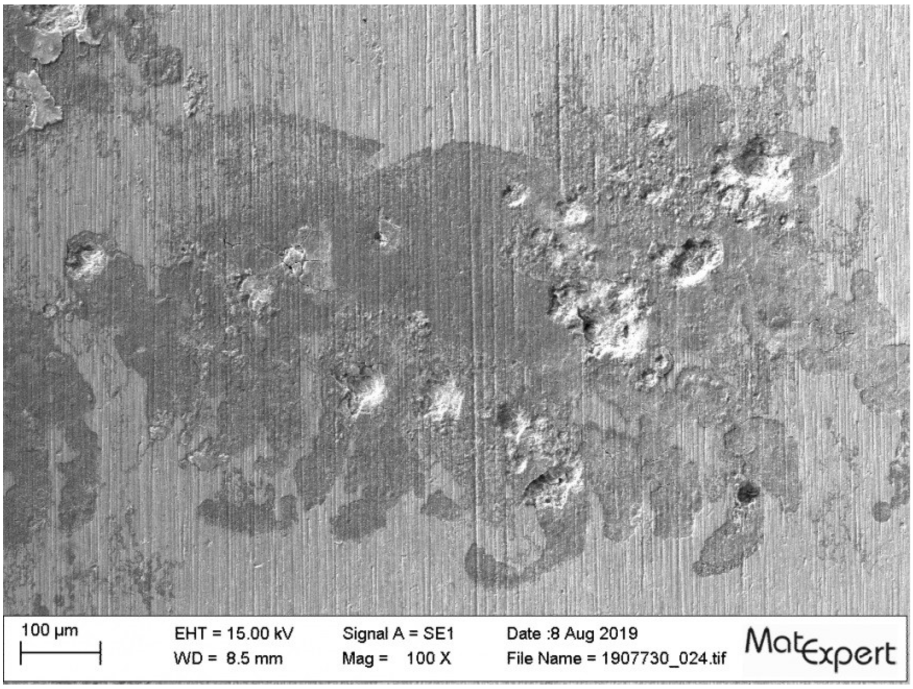


Figure 80: Close-up of figure 79.

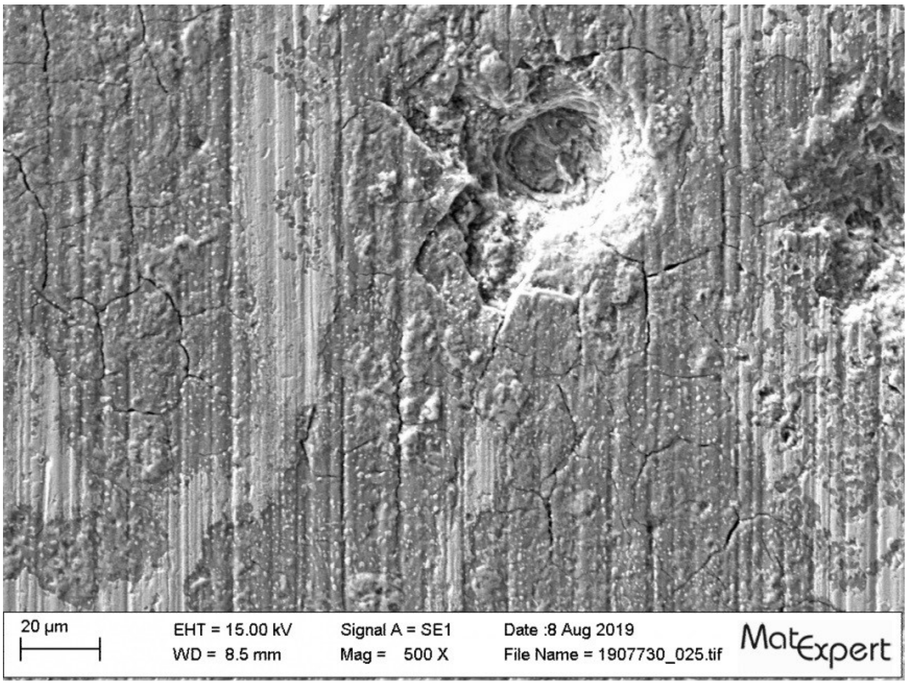


Figure 81: Close-up of figure 80 – stress cracks in the corrosion.

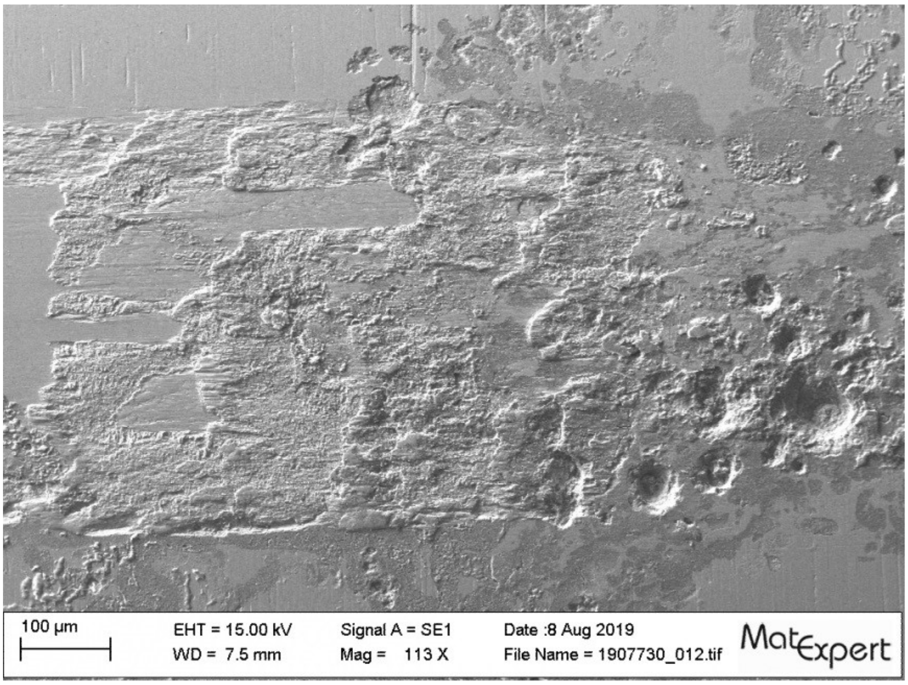


Figure 82: Bearing no. 3, cylindrical roller – pitting and corrosion.

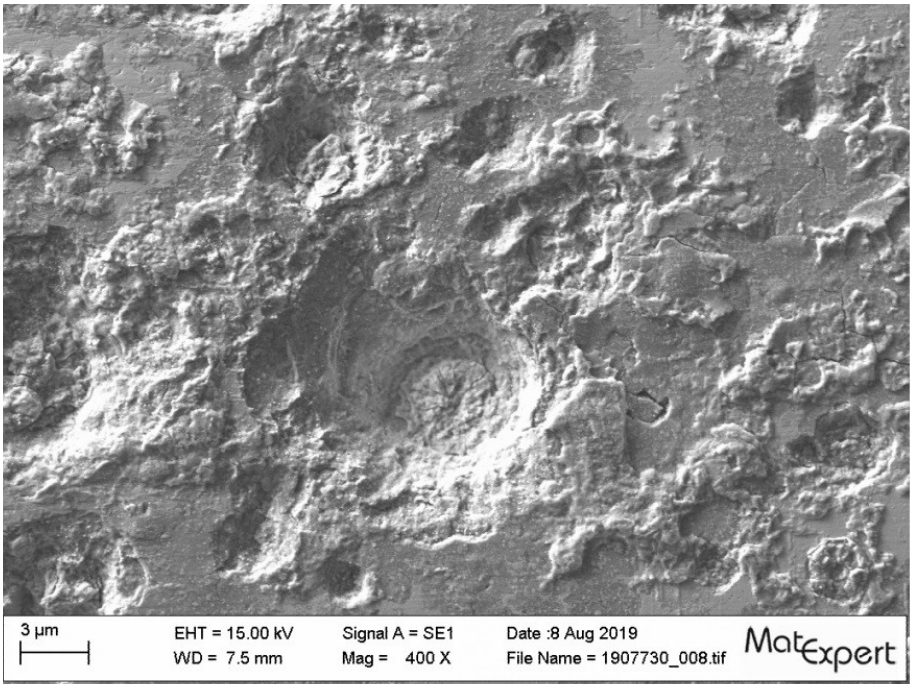


Figure 83: Close-up of figure 82.

Filiform corrosion and pitting were found on the bearing tracks and rolling elements. Flat-rolled corrosion was found on the bearing tracks. The corrosion mainly consisted of iron oxide and iron hydroxide. It was not possible to establish the cause of the corrosion, or rather the substance that caused it. However, in some places it was clearly evident that the corrosion spots were older and had been rolled over during operation.

In summary, the examinations revealed that all three bearings and their components were technically and functionally defective. Corrosion negatively affects the running behaviour and service life of rolling bearings.

A1.16.5 Forensic examinations

A1.16.5.1 Instruments

All instruments and indicator lights from the cockpit found after the accident were severely damaged. In some instances, only the dials remained. The instruments, warning lights and components of the engine control system that were able to help clarify the cause of the accident were examined by the Zurich Forensic Science Institute (FOR).

A1.16.5.1.1 Tachometers

All three tachometers were found as one unit. The lenses and the needles of the three instruments were no longer present. The instrument dials were removed and examined for needle markings (see figure 84).

Tachometer left engine	**Tachometer centre engine**	**Tachometer right engine**
		
The needle's impact mark was located in the approximate range of 1,900 rpm. Further markings were found between 1,800 and 1,900 rpm.	The needle's impact mark was located in the approximate range of 1,800 rpm.	The needle's impact mark was located in the approximate range of 1,850 rpm.

Figure 84: Tachometers for all three engines.

A1.16.5.1.2 Speed indicators

Of the two speed indicators, only the instrument dials, without needles, could be found. The two dials were examined for needle markings.

Dial 1:

The needle left scratch marks in the range of 200 km/h (see figure 85). The needle's counterweight left a notch above the letter 'k' of the km/h notation. The positioning of a comparable needle in line with the detected marks showed that the instrument needle should have indicated a value of approximately 202 km/h at the point of impact.

Figure 85: Speed indicator dial.

Dial 2:

Due to the numerous notch, grinding and abrasion marks that were found at various points on the dial and which were probably caused by parts of the instrument needle, it was not possible to come to a conclusion as to the instrument's actual indication at the time of the impact.

A1.16.5.1.3 Further examination of instruments

The display values at the time of the impact ascertained through further examination can be seen in table 1.

Examined instruments	Approximate indication
Fuel pressure indicator, left engine	4 psi
Fuel pressure indicator, centre engine	3.2 psi
Fuel pressure indicator, right engine	3.5 psi
Oil pressure indicator, left engine	85 psi
Oil pressure indicator, centre engine	80 psi
Oil pressure indicator, right engine	87 psi
Oil temp. input, left engine	65 °C
Oil temp. input, centre engine	indeterminable
Oil temp. input, right engine	65 °C
Oil temp. output, left engine	75 °C
Oil temp. output, centre engine	50 °C
Oil temp. output, right engine	85 °C
Voltmeter battery voltage	19–20 V

Table 1: Determined display values of the instruments examined.

A1.16.5.2 Warning lights

The cockpit was fitted with an ‘oil low pressure’ warning light for each engine. The forensic examination revealed that none of the three warning lights were lit at the time of the accident.

A1.16.5.3 Fuel valve battery

Forensic examination of the fuel valve battery revealed that, at the time of the accident, the fuel supply from the left- and right-hand fuel cells to the respective engines was selected.

A1.16.5.4 Engine control elements

A1.16.5.4.1 Full-throttle limiting mechanism

The control panel for main and high-altitude throttle regulation was severely damaged. The main throttle levers were deformed (see figure 86).

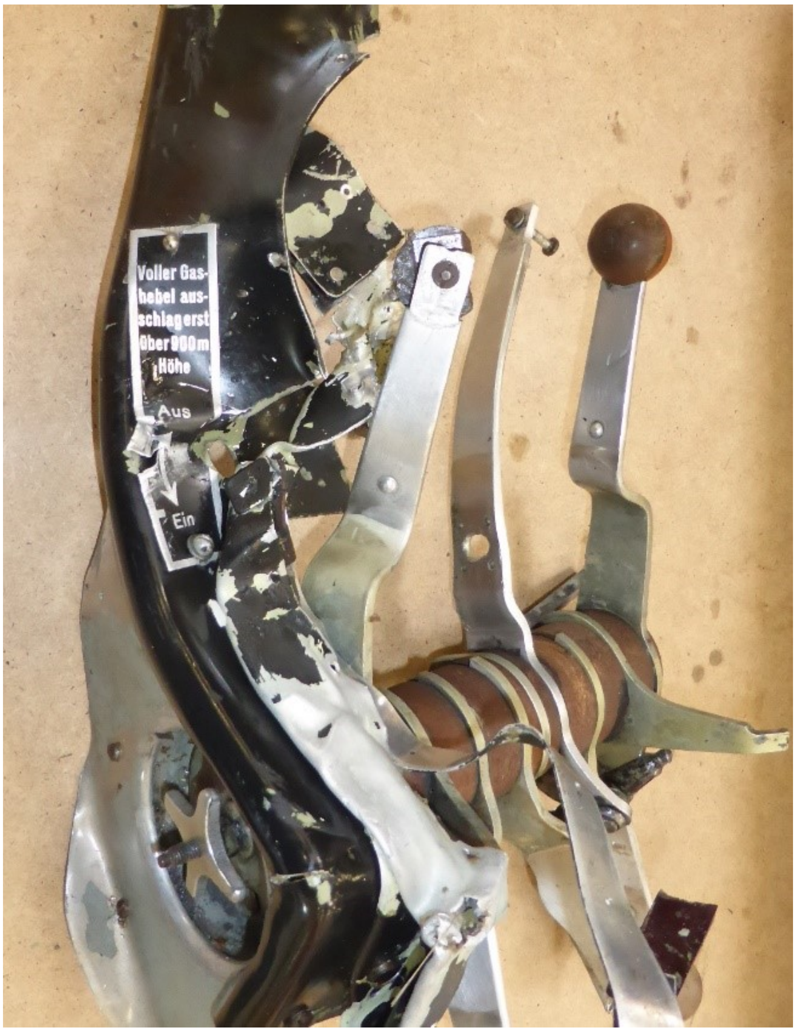


Figure 86: Deformed main throttle levers.

The three circled marks are located in the area where the limit stop bolts touch the front of the main throttle levers when in the ‘on’ position (see figure 87). Circled in red is the mark on the main throttle lever for the left engine, which was generated by the corresponding limit stop bolt (see figure 88). The direction of movement for the applied force is clearly visible in the image of the curved indentation, or notch.

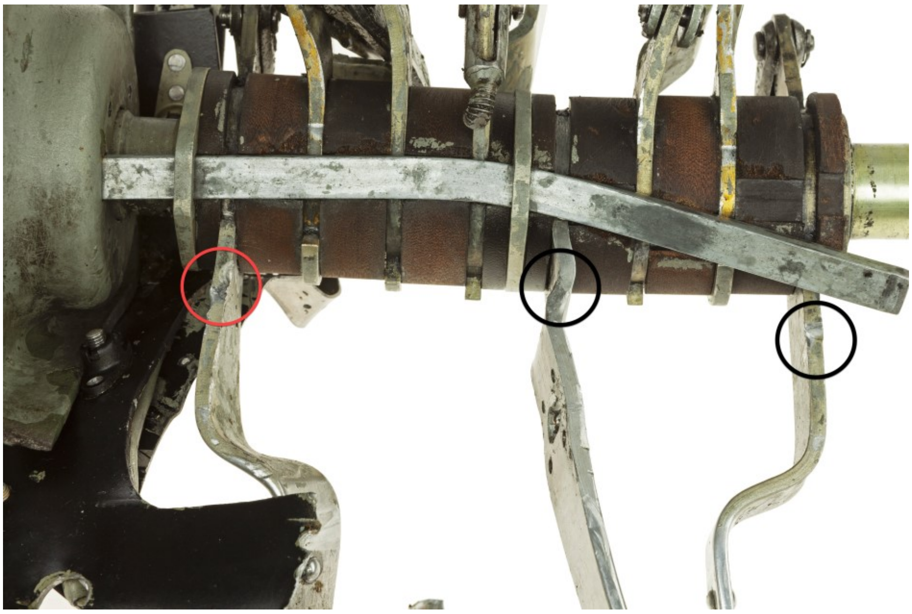


Figure 87: Front of the three main throttle levers with circled marks.

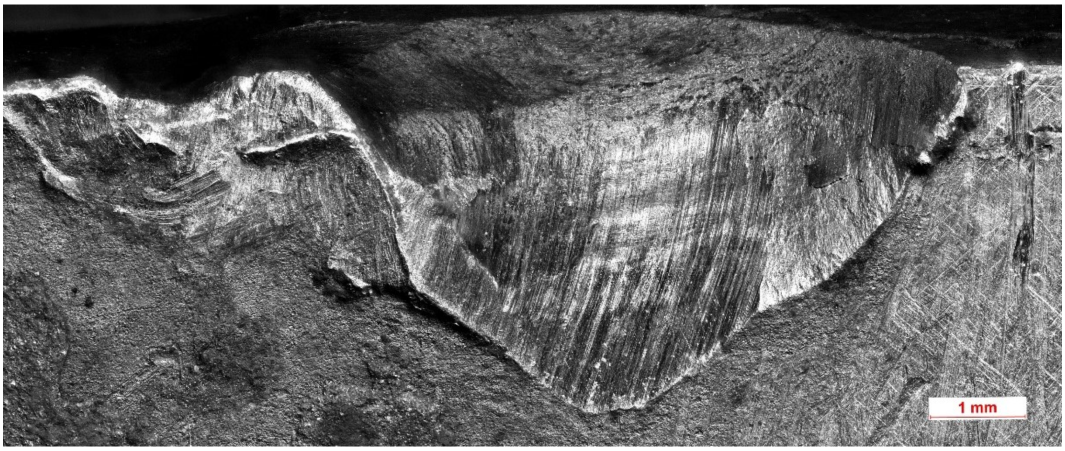


Figure 88: Notch mark on the main throttle lever for the left engine.

A fragment of the full-throttle limiting mechanism was found in the wreckage (see figure 89). On the limit stop bolt for the left engine, damage was found on 13 turns of the thread (see figure 90).

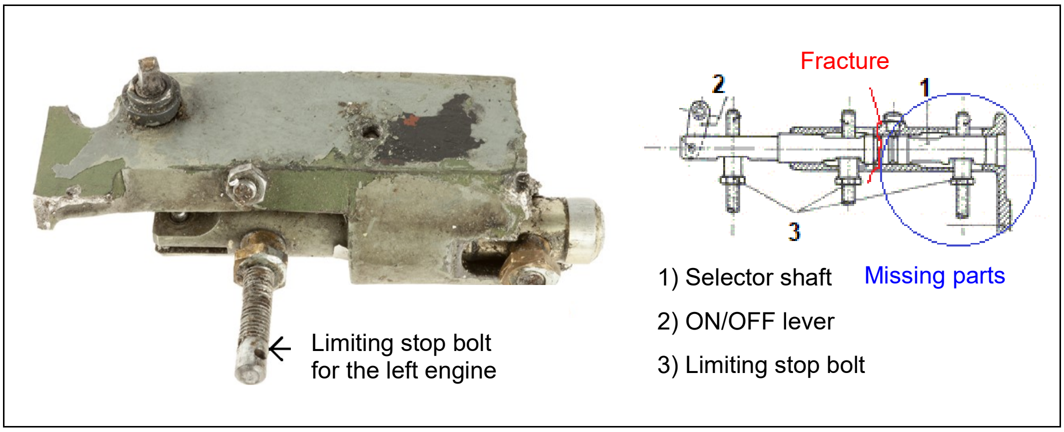


Figure 89: Fragment of the full-throttle limiting mechanism with limiting stop bolt for the left engine.

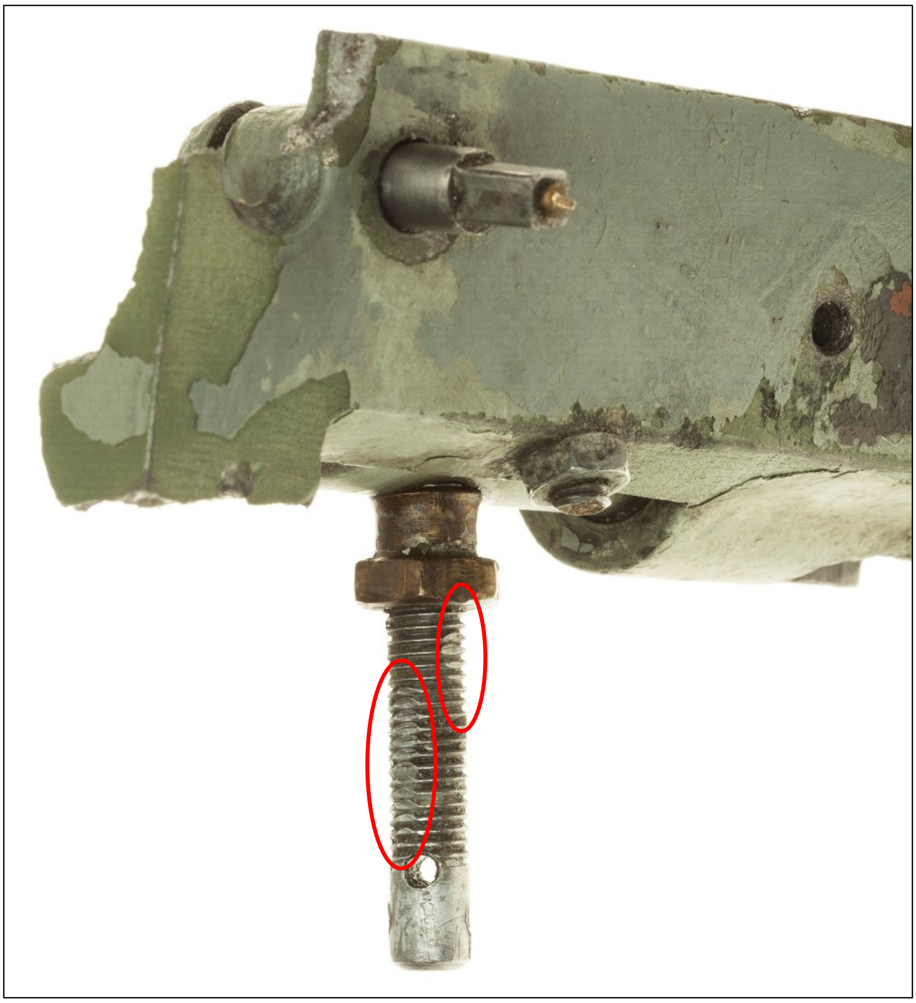


Figure 90: Limiting stop bolt for the left engine with damaged thread.

A1.16.5.4.2 Summary

These marks on the front of the main throttle levers and the damage on the thread of the limit stop bolt for the left engine could only have happened if the full-throttle limit had been set to 'on' at the time of the impact.

A1.16.5.5 Carburettors

The carburettors exhibited varying degrees of damage. With the carburettors for the left and the centre engines, the flange above the two butterfly valves was broken off (see figure 91).

The forensic analyses of the three carburettors focused on the positions of the butterfly valves and accelerator pumps at the time of the impact. The butterfly spindle is connected to the piston stroke rod in the accelerator pump via a linkage, ensuring these two elements move synchronously.

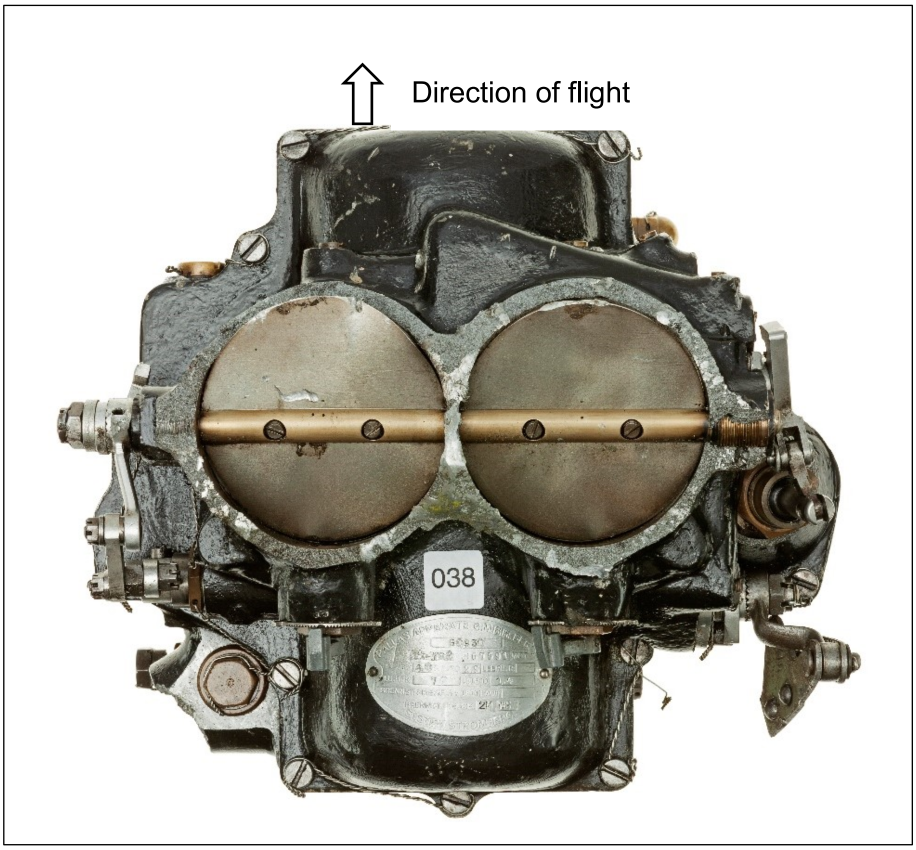


Figure 91: As an example, the carburettor for the centre engine is shown.

A1.16.5.5.1 Butterfly valves

Due to the arrangement of the carburettors on the engines, the butterfly spindles were positioned at 90 degrees to the direction of flight and the subsequent impact. The conditions for using witness marks on the butterfly valves to determine a potential last operating position were therefore unfavourable. In order to use any witness marks in this way, the butterfly valves would have had to have moved laterally in relation to the axial direction of the butterfly spindle and come into contact with the carburettor body.

Based on the lack of witness marks in the bores, it was not possible to determine exactly what position the butterfly valves were in at the time of the impact or immediately before it.

A1.16.5.5.2 Carburettor accelerator pumps

The accelerator-pump piston (see figure 92) is located at the top of the pump cylinder when the engine is idling. As the butterfly valve opens, the piston is pushed down by a connecting rod linked to a bell crank until it is at the bottom of the pump cylinder when the butterfly valve is fully open. As a result, the butterfly valve and the accelerator-pump piston run synchronously.

The maximum stroke for the piston in the pump cylinder is about 24 mm.

Figure 92: Accelerator-pump piston and pump cylinder.

A1.16.5.5.3 Accelerator-pump cylinder

The cylinders in the accelerator pumps were sectioned to allow the bores to be examined under a stereomicroscope. Abrasions that cannot be attributed to conventional wear caused by the piston movements during normal operation were visible on all of the bores (see figures 93 to 95). These abrasions do not run axially in a straight line, but are slightly curved or jagged.

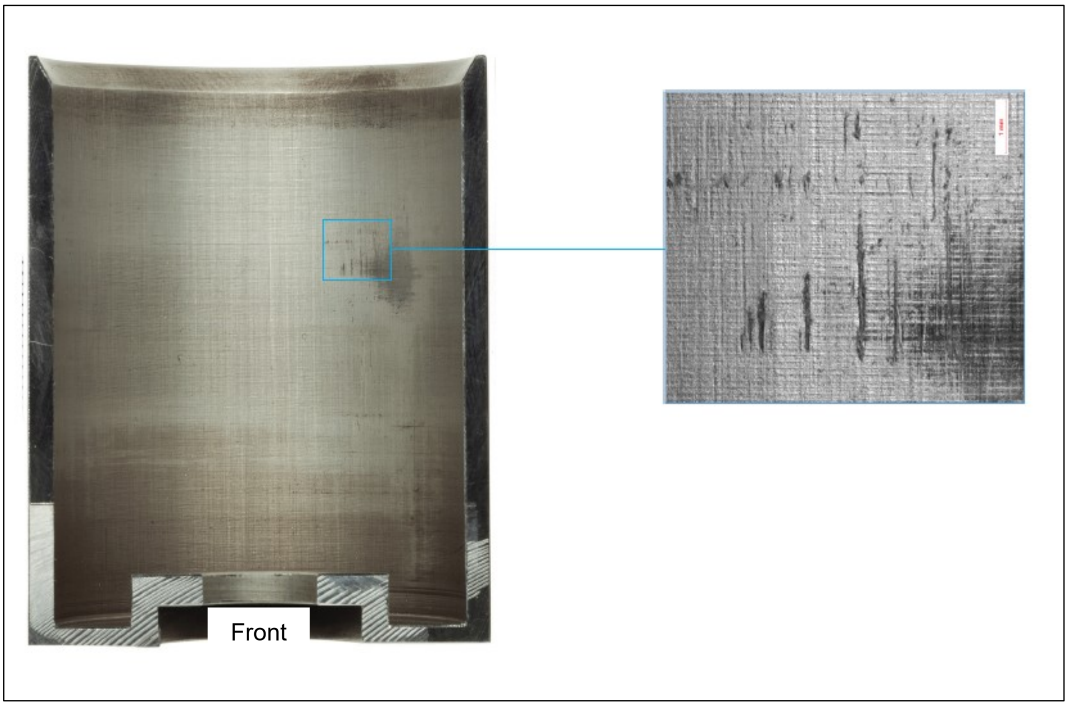


Figure 93: Abrasions in the pump cylinder from the carburettor for the left engine.

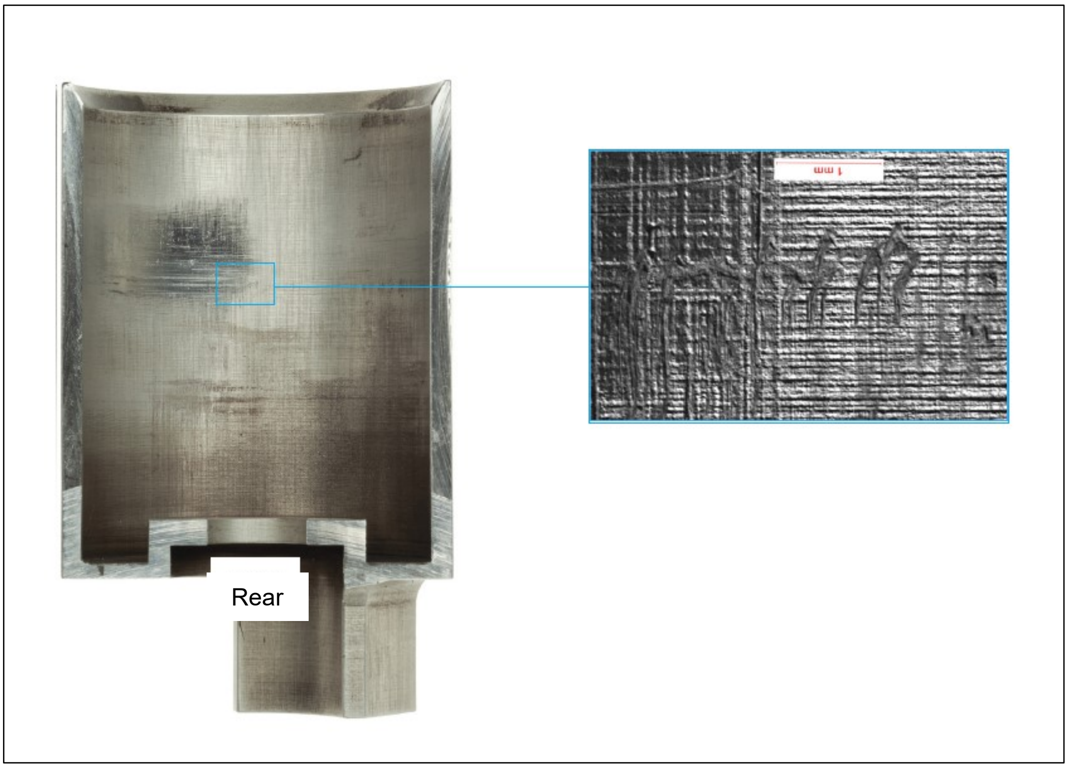


Figure 94: Abrasions in the pump cylinder from the carburettor for the centre engine.

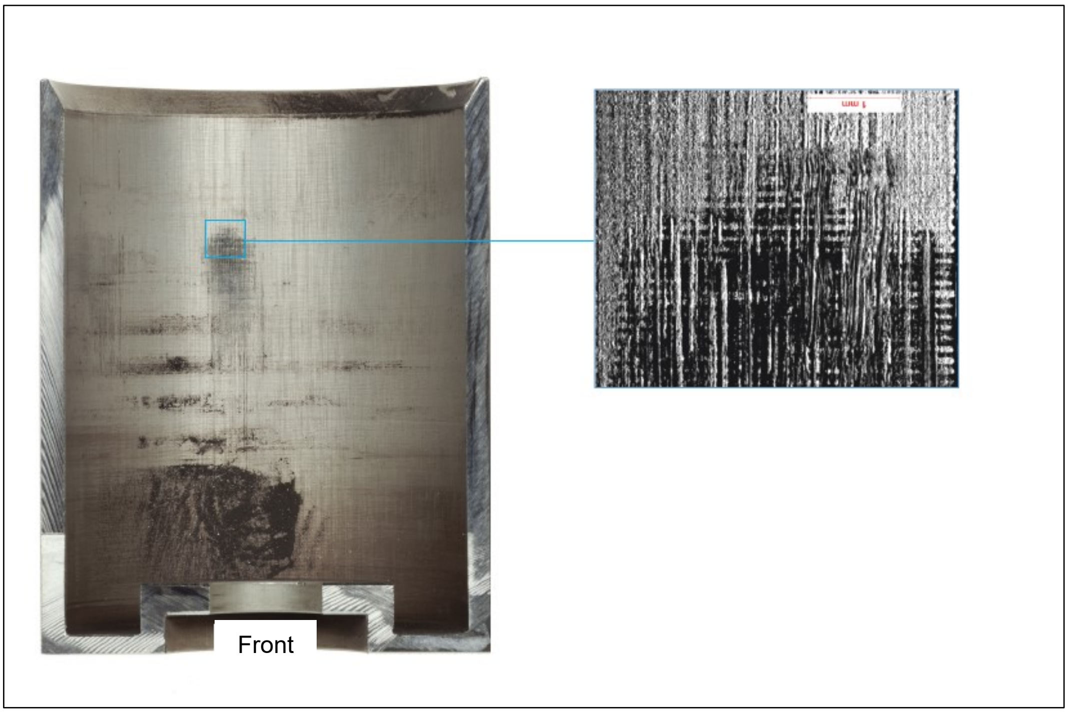


Figure 95: Abrasions in the pump cylinder from the carburettor for the right engine.

A1.16.5.5.4 Accelerator-pump piston

All three pistons were inspected for damage and other abnormalities under the stereomicroscope. This revealed that the chamfer at the lower end of the piston (see red arrow in figure 96) was not damaged on any of the pistons. However, all of the pistons exhibited signs of wear and abrasions on the chamfer where the upper end of the piston skirt (green arrow) transitions into the sealing ring. These abrasions can be plausibly attributed to the corresponding curved and jagged abrasions on the pump cylinder bores.

Below is an example of the marks on the accelerator-pump piston from the carburettor for the centre engine.

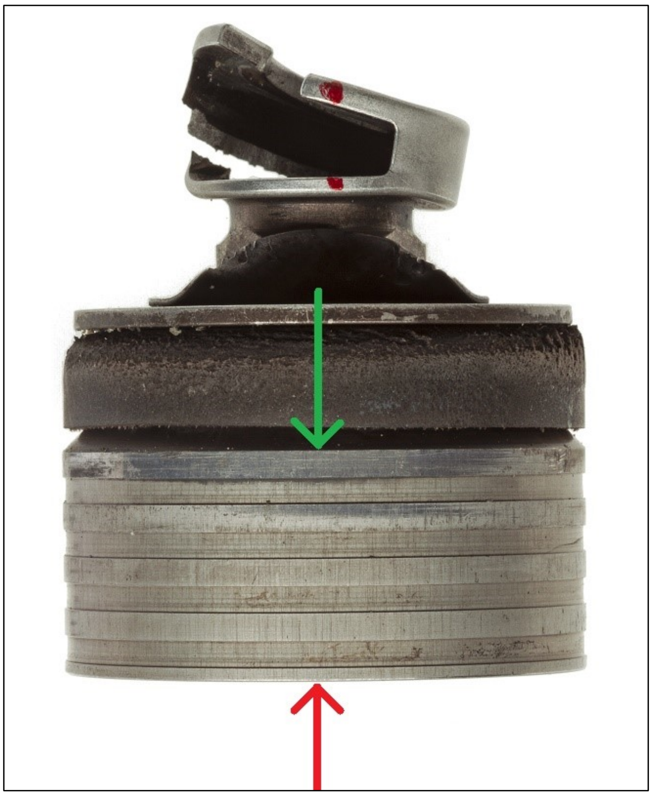


Figure 96: Accelerator-pump piston from the carburettor for the centre engine.

A1.16.5.5.5 Evaluation

A change in the throttle position during impact cannot be ruled out. As in this carburettor the butterfly spindle and the accelerator pump move synchronously due to levered connections, the position of the piston in the accelerator pump's cylinder could have changed immediately before the marks were made.

Due to this uncertainty, it is not possible to definitively reconstruct the butterfly valve positions.

A1.16.6 Summarised evaluation

A1.16.6.1 Material properties

A1.16.6.1.1 General

The Ju 52/3m g4e aircraft is a low-wing monoplane with an all-metal construction. Duralumin is the primary material used, important connecting pieces such as joints etc. are made of steel. The different metals were combined with each other and assembled into a structure using rivets made of Duralumin or steel. Corrugated panelling made of Duralumin was riveted to the airframe.

A1.16.6.1.2 Properties of Duralumin and corrosion protection

Duralumin is an alloy of aluminium with copper and magnesium that is high in strength and features good plastic elongation values. The favourable mechanical properties are achieved by thermal after-treatment and subsequent natural ageing.

The corrosion resistance properties of Duralumin are generally limited. It can be surmised that prolonged exposure to temperatures above 80 °C can make Duralumin more prone to corrosion. Thermal stress above 120 °C drastically increases the material's susceptibility to corrosion; this is referred to as a thermal ageing process. The corrosion penetrates the material along grain boundaries, which drastically reduces the strength of the material. Corrosion attack is intensified when the alloy is in contact with another metal, such as steel. The corrosion of the aluminium is difficult if not impossible to detect from the outside.

The aircraft manufacturer was aware that Duralumin is a very sensitive material in terms of its susceptibility to corrosion. For this reason, the manufacturer's instructions repeatedly refer to and stress the importance of intact corrosion protection (see section A1.16.4.2) and that after partial or major overhauls, the condition of the corrosion protection is to be as close to factory-new as possible. However, these instructions were not implemented by Ju-Air in their aircraft maintenance programme (AMP). Furthermore, a corrosion protection programme – as had been requested by FOCA – was not drawn up (see annex A1.6). Examination showed that the majority of the corrosion protection layer on the inside of the aircraft structure was no longer intact and corrosion was detected in many places.

For the above reasons, components made of Duralumin and parts in contact with Duralumin must therefore be provided with surface protection, such as a coat of paint. Intact surface protection effectively prevents corrosion from penetrating the Duralumin along grain boundaries and destroying the material.

Aluminium sheet can be effectively protected against corrosion using coats of paint and through plating. If there is a risk of contact corrosion, both of the parts in contact with each other must also be galvanically separated by using corrosion-prohibiting paint.

Scientific studies on the ageing and fatigue behaviour of Duralumin are scarce.

A1.16.6.2 Aircraft structure

The wing spars made of Duralumin were damaged by intergranular corrosion as well as pitting; the joints made of steel were rusted. The rivets, like the spars, also exhibited evidence of intergranular corrosion. Pitting and surface corrosion was identified in the contact area between the rivets and both the joint and spar tube. Fatigue fractures and intergranular fractures, which clearly occurred before the accident, were detected in the rivets and other structural parts.

The analysis of a spar fracture originally concealed by a joint showed a ductile spontaneous fracture and a fatigue fracture with typical striations. Extensive corrosion damage and further cracks were uncovered in the contact area between the joint and the spar tube. This corrosion was intergranular, resulting in a loss of wall thickness. One crack was an intergranular fracture with striations, i.e. a fatigue crack.

Cracks caused by intergranular corrosion were found mainly in the contact area between two layers of sheet metal and in the contact areas between the spar tubes made of Duralumin and the riveted-on steel joints as well as surrounding the rivets for fastening the panelling. Incipient cracks were found originating from the rivet holes in the spar tubes.

Intergranular cracks give rise to the notch effect and provide the ideal conditions for the initiation of fatigue cracks. This creates the risk of total failure of a component.

Corrosion damage and cracks running along the grain boundaries on important structural parts, such as the wing spars, the engine mounts and the fuselage spars could only be detected under the microscope or using SEM after dismantling the assemblies into their individual parts.

A1.16.6.3 Engines

In the examined cylinders that exhibited a net-like distribution of cracks, the bores were chrome-plated. This chrome plating is extremely hard, had cracks across the surface and exhibited peeling. The debris resulting from this peeling can find its way into the lubricating oil and cause serious damage to other engine parts, such as the bearings.

The examined cylinder with a red-discoloured bore had thermally sprayed-on bond and top coats. In places the top coat was open-pored, corroded and cracked or no longer bound to the underlying bond coat. This bore the risk that parts of the sprayed-on coatings could detach from the cylinder bore, which could have led to serious engine damage. The reconditioning of the cylinder walls according to this procedure was not covered by SB no. 1003.

The examined cylinders were honed to a diameter of 156.44 mm before coating. According to the 1939 operating instructions written by the manufacturer of the BMW 132 A3 aircraft engine, the cylinder is only permitted to be honed to a diameter of 155.90 mm. Unduly honing the cylinders to a diameter that is greater than stipulated by the manufacturer weakens the wall thickness of the cylinder barrel, creating a risk of engine failure.

Contents

A1. Factual information

A1.17 Information on organisations and their management

A1.17.1 Association of the Friends of the Swiss Air Force (VFL) and Ju-Air

A1.17.1.1 Structure and rights of the organisation

The Association of the Friends of the Swiss Air Force (*Verein der Freunde der Schweizerischen Luftwaffe* or VFL) was an association under Swiss law. According to its statutes (extract), one of the VFL's purposes was as follows: "*The VFL can perform demonstration and nostalgia flights on historic aircraft. To this end, it operates, inter alia, Ju-Air.*" Individuals who bought or used a ticket for a flight with Ju-Air automatically became a member of the association, while passengers on charter flights did not. The VFL operated Ju-Air by its board appointing a managing director. Consequently, Ju-Air was part of the VFL. The VFL formally acted as the air carrier for Ju-Air flights.

Since 1983, Ju-Air had regularly offered sightseeing flights to the public on its Ju 52 aircraft. The size of the fleet varied over the years and at times consisted of up to four Ju 52 aircraft (including a Spanish licensed CASA 352/A3[1]). In addition to aircraft of the Ju 52/3m g4e and CASA 352/A3 type, Ju-Air also operated an aircraft of the Douglas DC-3 type at times. In 2018, up until the accident on 4 August 2018, three Ju 52 aircraft were in service at Ju-Air: HB-HOP, HB-HOS and HB-HOT. Although other historic aircraft were operated by the VFL (also for passenger transport), they were not part of Ju-Air.

The official certificates and documents of the Federal Office of Civil Aviation (FOCA) – in particular the air operator certificate (AOC), the licence, the permits as well as the audit and inspection reports – were each issued to the VFL with the addition of "*Dba: JU-Air*"[2] on the AOC.

Most notably, Ju-Air was in possession of the following certificates and licences issued by FOCA:

- Air operator certificate (AOC), last issued on 17 March 2016 – this certificate permitted Ju-Air to perform commercial air transport operations with passengers according to annex IV of European Regulation 216/2008[3] incl. its implementation rules.[4] The operations specifications annexed to the AOC restricted the rights given by the AOC to flights under visual flight rules with the Ju 52 aircraft registered as HB-HOP, HB-HOS and HB-HOT. The operations specifications also constituted the link between the AOC and Ju-Air's approval certificate as a continuing airworthiness management organisation (see below). The AOC was issued on the basis of European Commission Decision C(2009) 7633 (see annex A1.6), but did not declare this fact, despite said decision stipulating that this be declared.

[1] The CASA 352/A3 aircraft, registered as HB-HOY, is owned by the German Association of Friends of Historic Aircraft (*Verein der Freunde historischer Luftfahrzeuge e.V.* or VFL e.V.) and was operated by the (Swiss) VFL until it was decommissioned in 2016.

[2] Dba: Doing business as...

[3] 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.

[4] The AOC of 17 March 2016 replaced the AOC of 1 September 2014. The AOC of 1 September 2014 had granted Ju-Air the same rights as the AOC of 17 March 2016.

- Licence issued on 1 December 2010 – this licence permitted Ju-Air to "*offer commercial air transport* [...] *to passengers"* within the scope of the AOC valid at the time.
- Approval certificate as a continuing airworthiness management organisation (CAMO) according to annex I (part M) of European Regulation 2042/2003[5], issued on 12 June 2012 – this approval was included in Ju-Air's AOC through the operations specifications. It permitted Ju-Air to manage its aircraft's continuing airworthiness independently (see section A1.17.2).
- Approval certificate as a maintenance organisation according to annex II (part 145) of European Regulation 1321/2014[6], issued on 21 June 2017 – this approval allowed Ju-Air to carry out maintenance work on its Ju 52 aircraft itself (see section A1.17.2).

These certificates and approvals had been issued by the heads of the responsible division of FOCA ('Safety Division – Aircraft' and 'Safety Division – Flight Operations', see section A1.17.7.2).

A1.17.1.2 Flight operations and business model

In the years leading up to the accident on 4 August 2018, Ju-Air mainly used its Ju 52 aircraft for commercial passenger air transport from spring to autumn. Sightseeing flights for individual bookings or small groups generally took place on Wednesdays and Saturdays, taking off from Dübendorf Air Base. Charter flights and adventure tours were also offered. Each year, there was an adventure tour to Bolzano in Northern Italy, which – just like the Locarno adventure tour – was a two-day event. Furthermore, Ju-Air attended aeronautical or military-related events where it offered sightseeing flights on one of its Ju 52s. Several times a year, Ju-Air also stationed one of its Ju 52 aircraft in another European country for a few days and carried out sightseeing flights from there. In Germany, for example, sightseeing flights regularly took off from Leverkusen, Mönchengladbach, Egelsbach near Frankfurt and Oberschleissheim near Munich. Flights were often made from Mainz-Finthen Airport to the Hunsrück low mountain range. In Austria, flights regularly took off from Wels taking passengers to the pre-alpine region around the Attersee and Traunsee. Innsbruck, in Tyrol, was another base where Ju-Air flights repeatedly took off. France was a destination for Ju-Air flights too. Ju-Air's Ju 52 aircraft were sporadically used for feature filming and low-level overflights as an event attraction.

Between 2008 and 2017, Ju-Air carried out an average of around 900 flights per year, transporting approximately 13,000 passengers each year. In each of these years, less than 2 % were passengers on non-commercial flights. The rest, over 98 %, were passengers of commercial air transport operations. Ju-Air estimated that over 50 % of passengers wanted to experience a flight on a Ju-Air Ju 52/3m not because of their own enthusiasm for flying, for historic aircraft or for technology.

A1.17.1.3 Staffing numbers

In 2018, the parts of the VFL involved in the operation and maintenance of Ju 52 aircraft (Ju-Air) counted eight members of staff on payroll and 96 volunteers. Some

[5] Commission Regulation (EC) No 2042/2003 of 20 November 2003 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.

[6] Commission Regulation (EU) No 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.

of the paid staff also volunteered for the VFL in their spare time. The team of volunteers was made up of the following:

- 12 administrators;
- 30 in-flight service personnel (ISP) / tour guides;
- 27 helpers for aircraft maintenance, aircraft preparation and restoration;
- 27 pilots.

Collectively, these 96 volunteers worked for the VFL for approximately 14,000 hours a year.

Out of the 27 pilots:

- 15 were former pilots of the Swiss Air Force; 1 was an active pilot of the Swiss Air Force
- 25 were active or former pilots of a conventional airline with flight operations mostly under instrument flight rules.

A1.17.1.4 Relevant air operator personnel

A1.17.1.4.1 Introduction

According to rule ORO.GEN.210 (a) of European Regulation 965/2012, the operator shall appoint an accountable manager. This person *“shall be responsible for establishing and maintaining an effective management system.”*

Rule ORO.GEN.210 (b) of the same regulation requires the operator to nominate a person or group of persons *“with the responsibility of ensuring that the operator remains in compliance with the applicable requirements.”* In addition, the operator *“shall ensure that all personnel are aware of the rules and procedures relevant to the exercise of their duties.”* Rule ORO.AOC.135 (a) specifies that the operator *“shall nominate persons responsible for the management and supervision of the following areas:*

- *flight operations*;
- *crew training*;
- *ground operations*; and
- *continuing airworthiness*”.

The nominated persons for flight operations, crew training and ground operations are described below, details of the nominated person for continuing airworthiness can be found in section A1.17.2.

Operators were advised[7] to appoint a compliance monitoring manager (CMM) to comply with rule ORO.GEN.200 (a)(6) of European Regulation 965/2012.

A1.17.1.4.2 Accountable manager

Ju-Air’s accountable manager (ACM) had the following qualifications and professional experience:

- Qualified precision mechanic, studied mechanical engineering[8];

[7] Acceptable means of compliance (AMC) and guidance material (GM) to annex III ‘Organisation requirements for air operations’ (part ORO) of Commission Regulation (EU) 965/2012 on air operations, consolidated version including issue 2, amendment 12, December 2017; AMC1 ORO.GEN.200(a)(6) and GM1 ORO.GEN.200(a)(6).

[8] Studies completed at a polytechnic (*Höhere Technische Lehranstalt, or HTL)*

- Professional experience at various technical companies;
- Transport pilot on McDonnell Douglas DC-9 aircraft for a major airline;
- Officer in the Swiss air defence ground corps (now part of the Swiss Air Force).

The ACM was a pilot with the rank of 'captain' at Ju-Air and, according to his own statements, had more than 5,000 flying hours on type Ju 52/3m aircraft (including the licensed CASA 352).

The ACM at the Ju-Air air operator also acted as the ACM for the Ju-Air maintenance organisation and as deputy ACM for Naef Flugmotoren AG. He is referred to as person A in section A1.17.3.2.2.

A1.17.1.4.3 Nominated person flight operations

Ju-Air's nominated person flight operations (NPFO) had the following qualifications and professional experience:

- Transport pilot on McDonnell Douglas MD-80, Airbus A320 and A330 aircraft for a major airline;
- Pilot and type rating instructor (TRI) on Bombardier Challenger 605;
- Pilot and TRI on Bombardier Global Express;
- Several managerial positions at an air operator;
- FOCA inspector overseeing commercial air transport operators (2002 to 2004);
- Type rating examiner (TRE) on behalf of FOCA at various air operators.

The NPFO was a pilot with the rank of 'captain' at Ju-Air. At the time of the accident, he had been Ju-Air's NPFO (initially Ju-Air's 'postholder flight operations') since 2014. He was also head of Ju-Air's approved training organisation (ATO) as well as the TRI and – on behalf of FOCA – TRE for Ju 52/3m aircraft.

As this person had previously worked as a FOCA inspector, FOCA granted him exemption from the official assessment to be approved as Ju-Air's NPFO, which is usually mandatory.

A1.17.1.4.4 Nominated person crew training

Ju-Air's nominated person crew training (NPCT) had the following qualifications and professional experience:

- Former pilot of the Swiss Air Force on various types of fighter jet;
- Transport pilot on McDonnell Douglas DC-9 and MD-80 as well as Airbus A310, A320, A330 and A340 aircraft for major Swiss airlines;
- Pilot, TRI and TRE on Airbus A320, A330 and A340.

The NPCT was a pilot with the rank of 'captain' at Ju-Air, and also acted as a Ju-Air training captain and ground instructor as well as TRI and TRE on Ju 52/3m aeroplanes. Previously, the NPCT had been Ju-Air's 'postholder crew training', and they were also head of Ju-Air's approved training organisation (ATO).

A1.17.1.4.5 Nominated person ground operations

Ju-Air's nominated person ground operations (NPGO) had the following qualifications and professional experience:

- Qualified business person, studied tourism[9];
- Professional experience at various companies within the tourism industry.

The NPGO had never had any formal training in aviation (flight crew, engineering, aircraft handling, flight operations or flight planning). At Ju-Air, she worked in operational planning, as an assistant to the ACM and as in-flight service personnel (ISP). The NPGO had never had instruction on Ju-Air's flight planning procedures (fuel planning, mass and centre of gravity calculation, etc.).

The official FOCA assessment to be approved as Ju-Air's NPGO contained two multiple choice questions on the topic of load, mass and centre of gravity. This person passed the assessment, which was in an open book format and did not include manual calculation or verification of a load sheet.

A1.17.1.4.6 Safety manager and compliance monitoring manager

The person acting as Ju-Air's safety manager (SM) as well as compliance monitoring manager (CMM) had the following qualifications and professional experience:

- Qualified motor mechanic;
- Graduated from a technical college[10];
- Private pilot licence aeroplane and private pilot licence helicopter;
- Worked for a film production company specialising in aerial videography;
- Various training courses in safety management and quality management for airlines.

Before becoming Ju-Air's SM and CMM, this person had already worked as Ju-Air's quality manager for several years. He was accepted as Ju-Air's SM and CMM by FOCA without having to undergo FOCA's assessment. There were no regulatory stipulations regarding qualifications or other prerequisites for the role of SM. FOCA felt that this person met the requirements as set out in EASA's guidance material for the role of CMM. These stipulations were that the CMM should have relevant knowledge, background and experience of the operator's activities as well as compliance monitoring experience. EASA considers the role of the CMM to be the monitoring of whether the operator's activities comply with the legal stipulations and the requirements defined by the operator itself.[11]

The SM/CMM at the Ju-Air air operator also acted as the CMM for the Ju-Air maintenance organisation and as the SM as well as CMM for Naef Flugmotoren AG. He is referred to as person D in section A1.17.3.2.2.

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[9] Studies completed at a higher vocational school (*Höhere Fachschule or HF)*

[10] Course completed at a technical college (*Fachoberschule für Technik)*

[11] Acceptable means of compliance (AMC) and guidance material (GM) to annex III 'Organisation requirements for air operations' (part ORO) of Commission Regulation (EU) 965/2012 on air operations, consolidated version including issue 2, amendment 12, December 2017. AMC1 ORO.GEN.200(a)(6)(c)(3): "*The compliance monitoring manager should* [...] *be able to demonstrate relevant knowledge, background and appropriate experience related to the activities of the operator, including knowledge and experience in compliance monitoring*; [...]." AMC1 ORO.GEN.200(a)(6)(c)(1): "[...] *The role of the compliance monitoring manager is to ensure that the activities of the operator are monitored for compliance with the applicable regulatory requirements, and any additional requirements as established by the operator* [...]."

A1.17.1.5 Operational flight plans

Ju-Air understood an operational flight plan (OFP) as being a one-page (A4) document, on which information on crew, route, fuel, mass, and centre of gravity was recorded for a flight (see illustrations at the end of annex A1.1). The information on mass and centre of gravity listed in the OFP was also regarded as the load sheet; at Ju-Air, the load sheet was therefore part of the operational flight plan.

According to part A of Ju-Air's operations manual (OM-A), the OFP must also record calculations of flight performance, in particular for take-off and cruise, if limitations in this regard have to be observed for a flight.[12] However, there is no space for such calculations on the OFP and in practice such calculations have never been recorded on any OFP at Ju-Air (see the illustrated OFPs for the outward and the accident flight in annex A1.1).

The template (valid version at the time of the accident as per OM-A) for Ju-Air's operational flight plans did not stipulate the flight altitudes for the individual waypoints or minimum flight altitudes for sections of the route or areas to be defined (see illustrated OFPs for the outward flight and the accident flight in annex A1.1). According to the OM-A of 1998, however, "*safe altitudes and minimum levels*" as well as "*planned altitudes and flight level*" were part of every operational flight plan at the time. The OFP template referenced there, which was supposed to be illustrated in OM-B, was however not illustrated in the OM-B of the time. It was therefore not possible to verify if and how these flight altitudes were actually included in the operational flight plans at the time.

FOCA accepted Ju-Air's practice of not preparing OFPs for training flights and proficiency check flights.

A1.17.1.6 Load, mass and centre of gravity

With the aim of maintaining a high level of safety, CAT.POL.MAB.100 of European Regulation 965/2012 states that, "*During any phase of operation, the loading, mass and centre of gravity (CG) of the aircraft shall comply with the limitations specified in the AFM, or the operations manual if more restrictive*."

The limits for mass and centre of gravity from Ju-Air's Ju 52 aircraft flight manual (AFM) can be found in annex A1.6 to this final report. There are no other or more restrictive operating limits in OM-B.

A1.17.1.7 Flight planning software

Ju-Air's pilots used the JU-OFP software to prepare their flights, or rather to produce their operational flight plans including the load sheet. This flight planning software has the following features:

If a flight or series of flights is to be planned using JU-OFP, one of the following two options must first be selected: "*A to A flights*" or "*A to B flights*".

The "*A to A flights*" option allows a series of flights to be planned that start and end at the same airport (A to A) and where passengers do not carry checked baggage. With the "*A to A flights*" option, it is not possible to define a route as a sequence of waypoints.

The "*A to B flights*" option, on the other hand, allows for flights to be planned from A to B and, to this end, also allows for the route to be planned using waypoints.

[12] Extract from section 8.1.10.1 of OM-A: "*Performance data (i.e. take-off performance, en-route performance and landing performance) must be considered for each flight and, if limitations have to be observed, the calculations shall be recorded on the OFP.*"

The list offered by the software contains about 1,000 waypoints in Western Europe defined by name and coordinates. Most notably, it includes the following waypoints, which would have allowed a detailed description of the routes intended to be flown during the 2018 Locarno adventure tour:

- Stäfa (town);
- Rapperswil (town);
- Küssnacht am Rigi (town);
- Buochs (aerodrome);
- Alpnach (aerodrome);
- Brünig (pass);
- Gotthard (pass);
- Oberalp (pass);
- Meiringen (aerodrome);
- Grimsel (pass);
- Nufenen (pass);
- Bellinzona (town);
- Lukmanier (pass);
- Segnes (pass);
- Mollis (aerodrome).

Using the selected waypoints and further information, a table is generated in the OFP, which – for each waypoint – contains the calculated distance and duration from the last waypoint, i.e. the estimated time elapsed (ETE), the calculated time of the overflight, i.e. the estimated time overhead (ETO), and the expected remaining fuel at this waypoint. This table also contains blank fields for each waypoint, in which the pilots can enter the actual time of the overflight and the actual amount of fuel remaining during the flight for monitoring purposes (see illustrated OFPs for the outward and accident flight in annex A1.1, as well as section A1.17.1.14).

Furthermore, the flight planning software allows the following parameters to be defined for A to B flights, either by selecting the relevant option or by entering a number:

- Passengers (“*weight of passengers*”, option of a statistically conservative gender estimate or actual mix of genders);
- “*Flight kit*” (additional technical equipment and tools);
- Passenger luggage in the rear underfloor storage compartment (“*PAX luggage* [...] *in hold*”);
- Crew luggage in the rear underfloor storage compartment (“*Crew luggage* [...] *in cabin cargo*”).

By default, the following values are selected for these parameters:

- Passengers: 17 × 86 kg = 1,462 kg;
- “*Flight kit*”: “*Flight kit small (25 kg)*”;
- Passenger luggage: “*No luggage*”;

- Crew luggage: “*No luggage*”.

The values selected or entered here are used by the flight planning software to calculate the mass and centre of gravity and are thus incorporated into the OFP (see illustrated OFPs for the outward and accident flight in annex A1.1).

The following (notable) values were also programmed in the flight planning software. These were used by the software to calculate the mass and centre of gravity and could not be changed by pilots A and B of the accident flight as they were not senior-management pilots with administrator rights.

- HB-HOT in the basic aircraft condition was programmed to have a mass of 7,105 kg and an arm of 1.71 m.
- An arm of 1.30 m was programmed for the “*flight kit*”. In the text file, in which this and other values for the software were defined (initialisation file), the following comment was recorded: “*for luggage in toilet*”.
- An arm of 1.95 m was programmed for passenger luggage. This value had been incorporated into the software when it was first programmed in 2005 and was based on the then valid section 6.5 of the AFM (“*Mass and CG determination*”, see annex A1.6). To this end, the following comment was added in the initialisation file: “*cabin luggage*”.
- An arm of 7.00 m was programmed for crew luggage. To this end, the following comment was added in the initialisation file: “*for luggage in toilet*”.
- An arm of 2.3 m was programmed for the fuel – regardless of the remaining fuel quantity. This value too had been incorporated into the software when it was first programmed in 2005 and was based on the then valid section 6.5 of the AFM (“*Mass and CG determination*”, see annex A1.6).

Upon completion of flight preparation using the JU-OFP software, a visual OFP with charts and tables was produced that could be printed for the flight.

The pilots had two options for using the JU-OFP software for flight preparation. Option one: they had access to the software on a computer in the Air Force Center’s briefing room. Option two: the pilots were also free to install the software on a personal computer. The version of the software installed on the computer at the Air Force Center was in practice maintained by the NPFO, although this responsibility and what it involved was not recorded in writing anywhere. There was also no process defined for updating or maintaining the software that the pilots had installed on their personal computers. The basic aircraft figures for mass and arm could not be adjusted by the pilots on their personal computers as these values were password-protected. In practice, Ju-Air sporadically created new versions of its flight planning software updating the basic aircraft figures for mass or arm. Although the pilots were free to install the latest software version on their personal computers, they were not explicitly advised of the need to do so. Furthermore, a review revealed that following the re-weighing of an aircraft, resulting in new basic aircraft figures for mass and arm, Ju-Air repeatedly failed to release the updates of its flight planning software until several years later. The two OFPs for the 2018 Locarno adventure tour, for example, were prepared using software version 1.12, which was released on 22 January 2015. Version 1.12 was the latest version of the flight planning software. However, all three Ju 52 aircraft still in service with Ju-Air in 2018 were re-weighed after the release date of software version 1.12 (22 January 2015) – HB-HOP on 5 April 2016, HB-HOS on 10 April 2015 and HB-HOT on 21 December 2017.

According to Ju-Air, a special feature of its JU-OFP flight planning software was that it did not accept values lower than 7,000 (kg) for the aircraft’s basic empty mass, or rather, that it was not possible for it to be programmed in this way. The NPFO, which was responsible for maintaining (updating) the values programmed in the flight planning software, stated that he was aware that the figure of 7,105 kg for the mass programmed in the software for HB-HOT's basic empty mass had not matched the actual figure for some time[13] and that it should have been changed to the new, current figure of 6,845 kg. However, as the NPFO was of the opinion that a mass which was actually lower than that of the basic aircraft would be conservative with regard to safety, he considered the incorrect value programmed in the flight planning software as unproblematic. The NPFO also stated that they had simply overlooked the fact that the figure programmed in the flight planning software for the aircraft's arm when empty had not been 1.71 m for some time but was actually 1.81 m (see annex A1.6).[14]

A1.17.1.8 Procedure and quality assurance of flight planning

A1.17.1.8.1 Quality assurance by the flight crew

The quality assurance of flight planning before a flight was conducted in multiple stages at Ju-Air. First, as was usual in practice, the person responsible for flight preparation ("*Verantwortliche für Flugvorbereitung*", or VfV) as defined in the brief – this was generally the co-pilot appointed for the first flight in the series – carried out the flight planning for all flights in the series.[15] The flight plan was then checked by the commander of the respective flight. According to sections 8.1.2, 8.1.9.2 and 8.1.12 of OM-A, the commander of the respective flight had to check and sign the OFP and the information contained therein regarding mass and centre of gravity (load sheet) before the flight would take place. Problems arose when the series of flights were performed by two pilots who both had a Ju-Air rank of 'captain', taking turns as commander on each flight. This meant that, in such instances, the commander on-board and the VfV were the same person on every other flight. In theory, the OFP should then have been signed twice by the same person: once as the VfV under "*prepared by*" and once as the commander on-board under "*CMD signature*". As a rule, the person acting as co-pilot then signed the OFP under "*prepared by*", although this person had not created the OFP at all – but just simply so that the OFP was signed by two different people.

For the 2018 Locarno adventure tour, and thus for both flights, pilot A was the VfV (see annex A1.1). Pilot A's signature under "*prepared by*" on the OFP for the flight on 3 August 2018 and the time stamps on both OFPs for the adventure trip confirm that pilot A did indeed carry out the flight planning. Whilst the OFP for the flight on 3 August 2018 was also signed by the commander of that flight (pilot B), the OFP for the flight on 4 August 2018 was not signed by the flight's commander (pilot A) (see the illustrated OFPs for the outward and accident flight in annex A1.1).

A1.17.1.8.2 Quality assurance by the NPGO and NPFO

According to section 2.1.4.1 of OM-A, every second month, the 'nominated person ground operations' (NPGO) was given the task of manually recalculating and thus

[13] HB-HOT's last weight check – which took place on 21 December 2017 – established the aircraft's basic empty mass to be 6,845 kg. However, the aircraft's basic empty mass had not been 7,105 kg since the weight check of 16 February 2016.

[14] The arm for HB-HOT's basic empty mass had not been 1.71 m since the aircraft was weighed on 28 February 2006. Between then and 4 August 2018, HB-HOT was weighed six more times.

[15] According to section 1.4.2 of OM-A, however, "*The CMD must conduct complete flight planning (operations flight plan). This implies planning such as: route- and fuel planning, weight and balance, weather, overview of the restricted areas.*" The person responsible for flight preparation (VfV), or rather their tasks, are not defined in the OM.

checking the data for mass and centre of gravity contained in a randomly selected OFP. The NPGO stated that she had never manually checked or otherwise assessed the mass and centre of gravity contained in an OFP, nor had she ever tasked any subordinate to do so.

As per section 2.1.4.1 of OM-A, the 'nominated person flight operations' (NPFO) was also required to assess a randomly selected OFP every other month and to manually recalculate the mass and centre of gravity contained therein. The NPFO stated that, although he had regularly checked OFPs and the data for mass and centre of gravity contained therein, he had never noticed any discrepancies when doing so.

A1.17.1.9 Use of air traffic services

For commercial air transport operations, rule CAT.OP.MPA.100 of European Regulation 965/2012[16] clarifies that the operator is to ensure that "*air traffic services*[17] *(ATS) appropriate to the airspace* […] *are used for all flights*". An exception is made for operations under VFR by day of aircraft that are anything other than complex motor-powered aircraft and for certain helicopter operations – provided that the use of air traffic services is not required by airspace regulations and "*provided that search and rescue service arrangements can be maintained*".

The standard textbook used in Switzerland for instructing student pilots on radio communication during operations under visual flight rules[18] recommends contacting the flight information service for longer flights in class G or E airspace as well as "*for flights in topographically difficult terrain (e.g. the Alps)*".

Section 8.3.1.1 of OM-A states that radio "*communication with the appropriate Air Traffic Service (ATS) units shall be maintained as far as possible and at least as listening watch, and used for the analysis of potentially conflicting traffic*."

No contact was made with the flight information service for HB-HOT flights on 3 and 4 August 2018.

A1.17.1.10 Filing of an ATC flight plan

The obligation to submit an ATC flight plan ('flight plan filing') is described in the "*Standardised European Rules of the Air*" (SERA)[19] According to rule SERA.4001, an ATC flight plan must be submitted "*before departure*" if the flight crosses national borders, "*unless otherwise prescribed by the states concerned*". There are no such other arrangements between Switzerland and Italy.

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[16] 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. The applicability for Switzerland results from the DETEC Ordinance on the Implementation of Flight Operations Regulations in accordance with Regulation (EU) No 965/2012 of 17 December 2013 ('*Verordnung des UVEK über die Umsetzung der Vorschriften über den Flugbetrieb nach der Verordnung (EU) Nr. 965/2012 vom 17. Dezember 2013*', SR 748.127.7). The rules of European Regulation 965/2012 are also known as 'EASA-OPS' or 'AIR OPS'.

[17] Air traffic services comprise flight information services, alerting services, air traffic advisory services and air traffic control services (area, approach and aerodrome control services).

[18] Hollerer, Karthaus: VFR Voice Switzerland. 2009.

[19] The 'Standardised European Rules of the Air' (SERA) are governed by the Commission Implementing Regulation (EU) No 923/2012 of 26 September 2012 laying down the common rules of the air and operational provisions regarding services and procedures in air navigation and amending Implementing Regulation (EU) No 1035/2011 and Regulations (EC) No 1265/2007, (EC) No 1794/2006, (EC) No 730/2006, (EC) No 1033/2006 and (EU) No 255/2010, and in particular by its annex. The Swiss DETEC Ordinance on Traffic Regulations for Aircraft (SR 748.121.11) refers to this European regulation.

For flights crossing the Alps, the official VFR-Guide for Switzerland recommends "*to submit an ATC flight plan*" as a "*safety precaution*".

OM-A calls to mind that the main purpose of filing an ATC flight plan for Ju-Air flight operations was to enable search and rescue activities to be initiated as quickly as possible, should a flight be overdue. With regard to the obligation to submit an ATC flight plan, section 8.1.8 of OM-A (under "*ATC Flight Plan*") states that such a flight plan must be filed by the flight crew for commercial flights across national borders and for flights from or to an ATC-controlled airport. Furthermore, it states that the flight crew must ensure the ATC flight plan is filed before the aircraft is boarded.

Regarding the obligation to submit an ATC flight plan, section 8.1.11 of OM-A (under "*ATC Flight Plan*") states that such a flight plan must always be filed – with the exception of local flights. Sections 8.1.11.1 and 8.1.11.2 go on to state that the commander must ensure the ATC flight plan is filed promptly and must also verify in the pre-flight briefing that the plan has actually been filed.

No ATC flight plan was filed for HB-HOT's flights on 3 and 4 August 2018.

A1.17.1.11 Supplemental oxygen for crew and passengers

The decrease in air pressure combined with increased altitude can lead to physical and psychological symptoms of oxygen deficiency in humans. The symptoms, and from which altitude or partial pressure of oxygen they occur, vary greatly from person to person and are also dependent on other factors. Depending on the source, negative effects on well-being, concentration, perception and performance (altitude sickness, hypoxia) can occur at an altitude of just 10,000 ft AMSL (pressure altitude). The symptoms can be delayed, reduced or prevented by inhaling additional oxygen.

With the aim of achieving the desired level of safety, European Regulation 965/2012 therefore lays down rules for the equipment and use of supplemental oxygen. The following applies in particular to commercial air transport operations:

- Non-pressurised aircraft are to be equipped with supplemental oxygen for the pilots for the entire flying time at pressure altitudes above 10,000 ft (rule CAT.IDE.A.240).
- Non-pressurised aircraft are to be equipped with supplemental oxygen for the passengers for the entire flying time at pressure altitudes above 13,000 ft (rule CAT.IDE.A.240).
- Pilots must use "*supplemental oxygen continuously whenever the cabin altitude exceeds 10 000 ft for a period of more than 30 minutes and whenever the cabin altitude exceeds 13 000 ft"* (rule CAT.OP.MPA.285).

Ju-Air did not carry supplemental oxygen for the pilots or passengers on board its Ju 52 aircraft. In section 8.8 of OM-A, Ju-Air therefore declared that, "*During normal operation, the cabin altitude must not rise above 10 000 ft*," i.e. its crews must not fly at above 10,000 ft (pressure altitude) during normal operation.

When asked, Ju-Air explained that it had not operated any flights equipped with supplemental oxygen. If at all, flights would only ever be above 10,000 ft very briefly, which did not require supplemental oxygen for crew or passengers. Ju-Air also explained that, in order to comply with the 10,000-ft rule in flight, Ju-Air pilots equated the pressure altitude with the 'navigational' altitude above sea level, which they in turn read from the altimeters with the QNH setting in the cockpit.

An evaluation of 216 flights operated by Ju-Air during the 2018 flying season, based on radar data and written documents, produced the following results:

- At least 15 flights were carried out at pressure altitudes above 10,000 ft.
- In fact, at least six flights were performed at pressure altitudes above 10,000 ft for more than five minutes.
- During at least four flights, the pressure altitude of 11,000 ft was reached or exceeded.
- On 12 May 2018, with 12 passengers on board, HB-HOT was flown at pressure altitudes above 10,000 feet for at least 21 minutes. During this flight, a maximum pressure altitude of 13,100 ft was reached. The co-pilot on this flight was a member of Ju-Air's management team.
- On 28 June 2018, with 17 passengers on board, HB-HOS was flown at pressure altitudes above 10,000 ft for at least nine minutes. During this flight, a maximum pressure altitude of 12,500 ft was reached. The commander on this flight had already acted as the commander on the HB-HOT flight of 12 May 2018 travelling at a pressure altitude of 13,100 ft.

A1.17.1.12 Terrain awareness warning system

With the aim of achieving the desired level of safety, rule CAT.IDE.A.150 (b) of European Regulation 965/2012 specifies that, in commercial air transport operations, aeroplanes powered by reciprocating engines with a maximum certificated take-off mass exceeding 5,700 kg or an MOPSC[20] of more than nine are to be equipped with a terrain awareness and warning system (TAWS).

Ju-Air's Ju 52 aircraft with a maximum certificated take-off mass of 10,500 kg and an MOPSC of 17 or 18 (see annex A1.6) were not equipped with a TAWS. According to FOCA, this failure to equip the aircraft with a TAWS was permissible pursuant to European Commission Decision C(2009) 7633.

A1.17.1.13 Sterile cockpit

Rule ORO.GEN.110 (f) of European Regulation 965/2012, together with rule ORO.GEN.005, specifies that operators conducting commercial air transport operations are to define procedures and instructions "*for a sterile flight crew compartment*".[21] According to FOCA, these rules also applied to Ju-Air.

Ju-Air's operations manual (OM) does not include explicit procedures or instructions for a sterile flight crew compartment. However, the following two activities, described in writing and common practice at Ju-Air, seem to be of importance with regard to a (non-)sterile flight crew compartment:

- Passenger access to the cockpit during the flight;
- Passenger announcements by the pilots during the flight.

The checklist for cruise required the pilot monitoring to switch on the seat belt sign for passengers "*in strong turbulence*". At cruise level when the seat belt sign was not switched on, passengers were free to move around within the aircraft and to visit the cockpit. During such cockpit visits, which occurred regularly in practice – including during the accident flight – one passenger was permitted to stay in the area between the pilot and the co-pilot. When doing so, the passenger could talk

[20] MOPSC: Maximum operational passenger seating configuration. According to European Regulation 965/2012, "*the maximum passenger seating capacity of an individual aircraft, excluding crew seats, established for operational purposes and specified in the operations manual*."

[21] European Regulation 965/2012 defines a "*sterile flight crew compartment*" as "*any period of time when the flight crew members are not disturbed or distracted, except for matters critical to the safe operation of the aircraft or the safety of the occupants*."

to the pilots, although communication was difficult due to the noise of the engines. This meant the visiting passenger was sometimes given the observer headset available in the cockpit. In this context, it should be mentioned that instances of pilots being distracted by passengers were known among the Ju-Air cohort of pilots. Reportedly, on several occasions, for example, the pilot flying had unintentionally changed the attitude of the aircraft due to having been distracted and thus reduced the speed to such an extent that the assisting pilot (or pilot monitoring) had to intervene.

The checklist for cruise also required the assisting pilot to make passenger announcements "*as needed*" via the PA system (speakers and headphones in the passenger cabin). What was meant was to provide information about the route and the scenery that they are flying over. Such announcements were regularly made during Ju-Air flights and there is evidence that this was also the case during the HB-HOT accident flight of 4 August 2018 (see section 1.1.2 of the final report).

There was no indication in the checklists or in the OM that the seat belt sign should be switched on, for example, when there is a high workload in the cockpit or during demanding mountain flying, or that no passenger announcements should be made during such phases.

A1.17.1.14 Checking the fuel level

In order to detect unexpectedly high fuel consumption or loss of fuel due to a leak at an early stage, it is common and good practice to regularly check the amount of fuel still on board during the flight and compare it with the values calculated in advance (fuel check). In section 8.3.4.2 of OM-A, Ju-Air has defined this procedure for its own operations as follows, "*a formal fuel check must be performed at least*":

- At the top of climb;
- At the top of descent, and
- At intervals of no longer than one hour during a flight.

The values obtained during the check are then to be entered in the operational flight plan (OFP).

Common practice at Ju-Air was as follows: A review of several hundred Ju-Air OFPs archived for recent years revealed that fuel checks had been carried out and documented on very few flights. Remarkably, even for flights lasting two hours or longer, often no fuel checks had been completed and documented. This was also the case for flights that were carried out after resuming flight operations following the accident on 4 August 2018. To that effect, the OFPs for the following flights were also checked:

- Locarno adventure tours 2013 to 2018;
- Bolzano adventure tours 2013 to 2018.

No fuel checks had been recorded in the OFPs for these transalpine flights either.

A1.17.1.15 Calculation of minimum take-off roll

A1.17.1.15.1 Requirements for minimum take-off roll

Ju-Air's Ju 52 aircraft were three-engined, performance class C aircraft (see annex A1.6). The HB-HOT flight on 4 August 2018 was a commercial air transport operation (see annex A1.1). According to rule CAT.POL.A.400 of European Regulation 965/2012, three-engined aircraft of performance class C in commercial air transport are subject to the following regulations: In order to achieve the required level of safety for take-off, the distance from the start of the take-off roll required by the aircraft to reach a height of 50 ft above ground with all engines operating within the maximum take-off power conditions as specified in the aircraft flight manual multiplied by a factor of 1.25 shall not exceed the take-off run available (TORA).

A1.17.1.15.2 Calculation for take-off on 4 August 2018

According to the HB-HOT 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 reconstructed take-off mass (9,387 kg) and for an ambient temperature in Locarno of ISA + 15 °C was approximately 700 m[22], and 875 m when multiplied by a factor of 1.25. Calculated using the take-off mass according to the pilots' OFP (9,737 kg), these distances amount to 760 m[23], and 950 m when multiplied by a factor of 1.25.

The take-off run available on runway 26R at Locarno Aerodrome where take-off occurred was 670 m (see section 1.10 in the main part of the final report).

It should also be noted that the temperature at take-off in Locarno was 31 °C. In actual fact, this corresponds to ISA + 17 °C. The aircraft flight manual does not, however, contain any information on the length of the take-off run for temperatures exceeding ISA + 15 °C. According to section 8.1.10.1 of Ju-Air's OM-A, extrapolation of flight performance data is explicitly not permissible. It was therefore not possible to obtain permissible values from the aircraft flight manual to calculate the required take-off run for the prevailing atmospheric conditions in Locarno at the time of take-off.

A1.17.1.15.3 Systemic investigation of previous take-offs

Systemic investigation of the required take-off run available is documented in section A1.17.1.23.

A1.17.1.16 Safety management

A1.17.1.16.1 Purpose and components of the safety management system

The safety management system (SMS) is integrated into the Ju-Air management system and primarily described in Ju-Air's operation management manual (OMM). This set-up is intended to adhere to the requirements specified in the European regulations[24] that are binding for Switzerland in this respect, as well as to the European[25] and national recommendations issued by FOCA[26].

According to the Ju-Air's OMM, essential declarative elements of the SMS are as follows:

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22 This figure results from linear interpolation of the values 630 m for a take-off mass of 9,000 kg and 720 m for a take-off mass of 9,500 kg. According to section 8.1.10.1 of Ju-Air's OM-A, such interpolation of flight performance data is permissible.

23 This figure results from linear interpolation of the values 720 m for a take-off mass of 9,500 kg and 805 m for a take-off mass of 10,000 kg.

24 Article 1, paragraph 1(b) and paragraphs 8.a.4 and 8.a.5, of annex IV to 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; article 5, paragraph 1, as well as rule ORO.GEN.200 of 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.

25 Acceptable means of compliance (AMC) and guidance material (GM) to annex III 'Organisation requirements for air operations' (part ORO) of Commission Regulation (EU) 965/2012 on air operations, consolidated version including issue 2, amendment 12, December 2017.

26 FOCA GM/INFO 'Certification Leaflet Management System' dated 7 November 2017.

- Safety policy;
- Safety culture;
- The safety management system itself.

According to the OMM, essential personnel/organisational elements of the SMS are as follows:

- Safety manager (SM);
- Compliance monitoring manager (CMM);
- Safety review board (SRB);
- Safety action group (SAG).

According to the OMM, essential procedural elements of the SMS are as follows:

- Feedback and reporting;
- Internal safety investigations;
- Safety reviews;
- Safety studies;
- Safety surveys;
- Hazard identification and risk management;
- Safety performance monitoring and measurement;
- Decision tree for determining culpability of unsafe acts.

The above essential elements are explained below.

A1.17.1.16.2 Safety policy

Section 1.1 of the OMM sets out Ju-Air's safety policy. This safety policy was signed by Ju-Air's accountable manager (ACM) and contained the following statements (extract):

- "*Ju-Air is committed to ensure the safest operation possible, satisfying authorities' and customers' expectations*."
- "*Every employee and volunteer is expected to show commitment to communicate in writing, or verbally to the Flight Safety Organisation, any incident that may affect the integrity of safety, including flight, maintenance and ground safety* […]."[27]

A1.17.1.16.3 Safety culture

Communicated in an unclear manner in parts, section 4.3.1 of the OMM sets out Ju-Air's safety culture, stating that it is essentially supposed to be based on the following:

- A culture of flexibility: being open to change
- Reporting culture: everyone involved is encouraged to report incidents that deviate from known standards and guidelines, as well as hazards and errors, without fear of being penalised
- A culture of learning: willingness to implement proactive and corrective measures

[27] It is not clear from the OMM what is meant by "*Flight Safety Organisation*".

A1.17.1.16.4 The safety management system itself

Section 4.1.1.1 of the OMM specifies that "*A safety management system (part of CMM*[28]*) is an organized approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures* [...]". According to this section of the OMM, the safety management system's overriding objectives are as follows:

- To identify hazards;
- To ensure that measures to reduce risks and hazards are implemented;
- To continuously monitor and regularly review the achieved safety performance;
- To reduce hazards by taking measures and assessing the effectiveness of these measures;
- To "*clearly define lines of safety accountability*".

Section 4.1 of the OMM is also dedicated to the objectives of the safety management system. According to this, Ju-Air's SMS ensures the following (excerpt), the majority of which matches the objectives in section 4.1.1.1 in terms of content:

- "*Systematic recording and analysis of any kind of feedback including occurrences and latent conditions;*"
- "*Reactive, proactive and predictive analysis of hazards and assessment of their risks*;"
- "*Eradication, mitigation and maintenance of risks to or below acceptable levels*."

A1.17.1.16.5 Safety manager (SM)

According to section 3.5 of the OMM, the safety manager (SM) is responsible for the development, management and maintenance of an effective safety management system. His duties and responsibilities include the following:

- Facilitate hazard identification, risk analysis and risk management;[29]
- Monitor the measures taken to reduce hazards and evaluate the effectiveness of these measures;
- Provide periodic reports on safety performance;
- "*Ensure initiation and follow-up of internal occurrence/accident investigations*".

Section 4.4.5 of the OMM states that, "*The Safety Manager is responsible to note and identify the reported hazard and assess its consequences and its risk in terms of probability and severity* […]." This contradicts the above-mentioned facilitation of hazard identification, risk analysis and risk management.

The safety manager (SM) is to systematically enter the items (events, hazards, problems, discrepancies, etc.), about which he had been notified through reports, into what is known as the pending items list (PIL). Progress of these items is then

[28] CMM: Compliance monitoring manager – as to how a safety management system, i.e. a set of business processes, is supposed to be part of a manager, i.e. a person, remains unclear.

[29] It should be noted that hazard identification, risk analysis and risk management are not listed as a duty or responsibility for the accountable manager (ACM) or another senior manager described in OM-A, including the NPFO (nominated person flight operations) or the NPGO (nominated person ground operations). Although section 7.5.1 of the OMM states that hazard identification is the responsibility of each member of staff, this refers to the identification of developing, emerging or newly identified individual hazards, not the identification of an entire range of generally applicable, fundamental hazards (see section A1.17.1.16.8).

updated in the PIL by the safety manager (SM) and implementation of the measures is constantly monitored using the PIL (section 12.6.2 of the OMM).

Ju-Air merges the role of the safety manager (SM) with that of the compliance monitoring manager (CMM).

A1.17.1.16.6 Compliance monitoring manager (CMM)

According to section 3.5 of the OMM, the compliance monitoring manager (CMM) has the following duties and responsibilities and tasks (excerpt):

- "*Ensuring that the activities of the organisation are monitored for compliance with the applicable regulatory requirements and standards as well as any additional requirements as established by the organisation*."
- "*Ensuring that these activities are being carried out properly under the supervision of the relevant head of the respective functional area.*"
- "*Monitors activities in the fields of flight operations, maintenance, crew training and ground operations, ensuring that the standards required as defined in the Operations Manual, the CAME*[30] *and the MOE*[31] *are maintained, under the supervision of the relevant nominated Person*."

In order to fulfil his duties and responsibilities, the CMM is entitled to the following rights (extract):

- Carrying out inspections and audits;
- All members of staff, including the accountable manager (ACM), being available to him;
- All working groups being open to him;
- Access to all official documents and manuals in draft and final versions.

A1.17.1.16.7 Safety review board (SRB) and safety action group (SAG)

As stated in sections 4.7 and 4.8 of the OMM, the two bodies 'safety review board' (SRB) and 'safety action group' (SAG) have been merged at Ju-Air.[32] It is unclear what this means, considering that – on the authority of different sections in the OMM – the organisation and responsibilities of the two bodies are different and in parts unclear and conflicting, as can be seen from the below.

Safety review board (SRB):

According to section 4.7 of the OMM, "*The safety review board is a high-level committee that considers strategic safety functions*." It states that the accountable manager (ACM) is its chairman. The other members are the "*heads of functional areas*"; specifics as to who they are, however, remain open. It goes on to state that the safety manager (SM) and others may attend SRB meetings where appropriate. According to the organisational chart in section 3.1 of the OMM, however, the SRB reports directly to the safety manager (SM).

According to section 4.7 of the OMM, the SRB meets once a year; according to section 4.10.2, they meet twice a year.

Section 4.7 of the OMM states that it is the SRB's responsibility to monitor the following (extract):

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[30] CAME: Continuing airworthiness management exposition

[31] MOE: Maintenance organisation exposition

[32] "*Due to the size of operation, Ju-Air merged the SRB and SAG*."

- The achieved safety performance in relation to the company's safety policy and the target safety performance;
- The effectiveness of the safety management processes;
- Hazard identification and reporting;
- Risk analysis and risk management.

In practice, twice a year a part of the management evaluation meeting (MEM) was declared as an SRB meeting. In those meetings, the safety manager (SM) primarily reported on his work with a particular focus on some statistics as well as presentations concerning safety performance and safety reviews (see section A1.17.1.16.12). In addition, the production of the previous year was reviewed and each person present reported on safety-related incidents in their area. The minutes available from 2014 onwards reveal the following:

- The SRB considered the achieved safety performance to be satisfactory in relation to the target safety performance.
- The SRB accepted the achieved effectiveness of the safety management processes, or rather, did not question them.
- Apart from 2015, when the processes concerned were subject to renewal and amendments, the SRB accepted the processes for hazard identification and reporting that were being followed in practice, and the results achieved.
- The SRB generally accepted the risk management practices adopted, but did regularly request additional, selective risk assessments. Nevertheless, several such risk assessments were then not carried out by the persons responsible.
- The failure rate of the engines was never a topic of conversation and their reliability was not challenged.
- Although the nominated person continuing airworthiness (NPCA) commented on the engines that had to be exchanged following an engine failure and mentioned that availability of replacement engines was limited, by contrast he repeatedly reported on the engines being in good condition and on the supposedly trouble-free flight operation.
- Time and again, the CMM communicated that all reports following an occurrence had been filed as required and that the occurrences had been processed correctly internally.

Safety action group (SAG)

According to section 4.8 of the OMM, "*The safety action group reports to and takes strategic direction from the safety review board.*" The SAG is chaired by the safety manager (SM). The other members are "*managers, supervisors and staff from operational areas*." Specifically, these are the nominated person flight operations and the nominated person crew training. The SAG is not included in the organisational chart.

When and how frequently the SAG is to meet is not defined in section 4.8 of the OMM.

According to section 4.8 of the OMM, the SAG has the following responsibilities (extract):

- "*Oversee operational safety*";
- "*Review risk assessment register*";
- "*Resolve identified risks*";

- "*Implement corrective action plans*";
- "*Ensure that corrective action is achieved within agreed timescales"*.

In practice, there were no dedicated SAG meetings. At the end of some minutes from the combined management evaluation meeting (MEM) and the safety review board (SRB) meeting, it was implied that at least some of the signatories were also members of the SAG. The mentioned minutes do not include any elements that systematically attend to responsibilities of the SAG (equivalent to the elements of the SRB, see above).

A1.17.1.16.8 Feedback and reporting

At Ju-Air, the handling of incidents, in particular the processes concerning the reporting of incidents, are regulated in the company's operation management manual (OMM) and in part A of its operations manual (OM-A). In many instances, the definitions of terms, procedures and forms set out in the OMM and OM-A are contradictory and inconsistent. For example:

- Who is responsible for filing an occurrence report and who it should be sent to are contradictory and to some extent not productive (see section A1.17.1.16.9).
- Depending on the text passage in OM-A, 'occurrences' may refer to just 'minor incidents' but also to 'serious incidents' and 'accidents' (see section A1.17.1.16.10).
- Organisation, headings, contents and references conspicuously frequently lack logic, are incorrect or outdated.

A1.17.1.16.9 Internal Ju-Air reporting channels

Depending on the source of the Ju-Air documentation, incident reports should be handled differently[33]:

- According to section 11.3.1 of OM-A, the pilot in command or any other person involved in or observing a serious incident or accident is responsible for reporting said event to the STSB (via the REGA reporting office), the ACM or their deputy, as well as to the CMM or head of training. Depending on how the text is interpreted, it is then either the ACM, the CMM or the head of training who is to notify FOCA and the safety manager (SM) of the reported incident.
- As specified in section 11.3.2 of OM-A, the "*occurrence*" has to be reported to the ACM or the CMM as well as to the head of training by the pilot in command or the instructor. According to this section of OM-A, however, the pilot in command is not responsible for reporting the occurrence to FOCA – this falls within the area of responsibility of the head of training.
- As per section 11.4.2 of OM-A, the commander (CMD) is responsible for reporting and passing on all "*occurrences*" listed in OM-A's section 11.5 to the "*relevant authorities*".
- According to section 7.5.1 of the OMM, flight crews must report "*occurrence items*", pursuant to section 11.5 of OM-A, to the ACM and the CMM/SM – in any case this has to be done by e-mail as well. Depending on the text passage, the NPFO (nominated person flight operations) or the NFO are also to be notified (the role 'NFO' is not defined at Ju-Air). It goes on to state that the CMM/SM then has to pass on the reported occurrences, as per section 11.5 of OM-A, to

33 Hereafter, only the designated internal Ju-Air reporting channels and addressees are described. Apart from this, FOCA and the STSB (notified via the REGA reporting office) are also mentioned as addressees, where Ju-Air made provisions for those two bodies to be notified.

FOCA – and that when doing so, the procedure has to be in line with section 11.4 of the OMM (this section regulates the code-share agreements that do not exist at Ju-Air, so in fact, they probably mean section 11.4 of OM-A).

- According to section 1.3.1.2 of OM-A, it is the NPFO which is responsible for passing on accident or occurrence reports to FOCA.
- As specified in the diagram in section 7.5.1 of the OMM, the 'OR' (referring either to 'occurrence report' or 'operational report' – depending on the text passage) is to be sent to the CMM/SM electronically or by paper, should an incident occur.
- As per the 'hazard and occurrence report' mentioned in section 12.1.1 of the OMM and previously the 'occurrence and hazard report', the completed form is to be e-mailed to safety@ju-air.com or a hard copy can be posted in a designated mailbox in the Ju-Air briefing room. According to section 7.5.1 of the OMM, e-mails sent to safety@airforcecenter.ch are forwarded to the ACM, CMM and NFPO. As part of the investigation into the accident involving HB-HOT on 4 August 2018, an e-mail was sent to safety@ju-air.com for testing purposes and a response requested. There was no reply, the probable reason being that the website www.ju-air.com has been focusing on dental hygiene and orthodontics in Ireland since at least 2014. [34]
- According to the CMM/SM, all incident reports are supposed to come to the CMM/SM first. The CMM/SM then – depending on requirement and by appropriate means – forwards the incident report to FOCA.

A1.17.1.16.10 Definitions of terms

Depending on the text passage in OM-A, 'occurrences' refer to just 'minor incidents' or to 'serious incidents' and 'accidents'. To this end, section 11.4.1 of OM-A states that, "*An occurrence is an event within the operation, which is in some way out of the ordinary, but which does not resemble the conditions for an incident or accident.*" On the very next line, however, the term 'incident' is then defined as a particular instance of an 'occurrence'. And a few lines later, the term 'accident' is also defined as a particular instance of an 'occurrence'. Section 11.5 of OM-A, which is not very aptly titled 'Aircraft Flight Operations', exclusively contains a list of event scenarios to which OM-A and the OMM refer in relation to the term 'occurrence', i.e. it explains which scenarios are understood by 'occurrence'. This comprehensive list includes the following items:

- *"Accident and serious incident;*
- *Risk of collision with another aircraft;*
- *Avoidance manoeuvre required to avoid a collision with another aircraft;*
- *Undershooting, overrunning or running off the sides of runways;*
- *Landings or attempted landings on a closed* [or] *occupied runway;*
- *Unintentional significant deviation from airspeed, intended track or altitude (more than 300 ft) regardless of cause;*
- *Erroneous entries into* [...] *performance calculations, or use of incorrect data;*
- *Aircraft unintentionally departing from a paved surface;*
- *Collision between an aircraft and any other aircraft, vehicle or other ground object;*

[34] Ju-Air's website can be found at www.ju-air.ch.

- *Fire;*
- *Occurrences which have* [...] *led to significant injury* [...] *but which are not considered reportable as an accident;*
- *Asymmetry of flight controls;*
- *Malfunction of any engine;*
- *Total failure* [of] *air data system".*

A1.17.1.16.11 Internal safety investigations

According to section 4.11 of the OMM, an "*internal safety investigation*" or, depending on the text passage, also a "*safety investigation*" was an investigation of an event that did not have to be reported to or investigated by the authorities.[35]

The decision to initiate an internal Ju-Air safety investigation was up to Ju-Air's accountable manager (ACM) or the safety manager (SM) – this is not made entirely clear in the OMM. The ACM or SM also put together the investigation team. According to the OMM, the next steps of the investigation would then be taken by the safety action group (SAG) or by the SM.

A1.17.1.16.12 Safety reviews

As far as Ju-Air is concerned, a 'safety review' is a presentation of data that shows the development of safety and allows the target performance to be compared to the achieved performance (see section A1.17.1.16.16).

The safety manager (SM) regularly presented safety reviews to the safety review board (SRB) (see section A1.17.1.16.7).

A1.17.1.16.13 Safety studies

As far as Ju-Air is concerned, a 'safety study' is a large-scale investigation of a broad, potential safety issue.

Ju-Air has never carried out a safety study.

A1.17.1.16.14 Safety surveys

As far as Ju-Air is concerned, a 'safety survey' is an investigation that focuses on a specific procedure or problem in daily operations and is based on the results of surveys or oral questioning.

Ju-Air has never carried out a safety study.

A1.17.1.16.15 Hazard identification and risk management

In section 4.4 of the OMM, nine pages are devoted to hazard identification and risk management. Content worth mentioning is as follows:

- Various terms of risk management are defined.
- Section 4.4.1 states that hazards that have been identified "*should be reported*" by staff, passengers and external contractors. Two examples listed include "*failure to follow standard operating procedures*" and "*potentially unsafe practices*".
- Section 4.4.5 states that "*all employees are obliged*" to report identified hazards.

[35] "*Internal Safety Investigation includes occurrences and events that are not required to be investigated or reported to the State.*"

- The differences between the reactive, proactive and predictive strategy of hazard and risk identification are explained and it is made clear that Ju-Air intends to use all three strategies for effective safety management.
- The reactive strategy is understood to be the identification of hazards and risks based on occurrences, incident reports and incident investigations (“*Analysis of what happened and why?*”).
- The proactive strategy is understood to be the identification of hazards and risks based on voluntary reporting, audits and surveys (“*Analysis of what happens and why?*”).
- The predictive strategy is understood to be the anticipatory identification of hazards and risks based on findings from change management and other sources – they are however not specified in detail (“*Analysis of what could happen and why?*”).
- Once the hazards and risks have been identified, the safety manager (SM), it says, is then responsible for conducting a risk assessment in accordance with the procedures described in detail.

In practice, 22 risk analyses on specific risks were carried out at Ju-Air from 2012 until the accident on 4 August 2018. The STSB examined the list of the 22 risk analyses carried out in greater detail and subsequently inspected some of the risk analyses. The risk analyses inspected include those for HB-HOT’s trip to the USA in 2012, for its operation at the Birrfeld air show in 2012 and for its operation at the Amlikon air show in 2013. The following stood out:

- The execution of several risk analyses, which had been decided as part of an MEM/SRB meeting, in fact never materialised.
- The hazards described in the risk analyses and therefore also the associated risks were almost always unclear, and sometimes not described at all.[36]
- Risks described in the risk analyses were allegedly reduced following mitigation, although, in some instances, no risk-reducing measures had actually been implemented.[37]
- In many instances, the risk analyses lacked transparency with regards to how the problem posed and the pertaining circumstances led Ju-Air to arrive at the implemented or pursued solution.
- Purely identifying risks and obtaining official approvals seems to have been sufficient to allow air operations to be carried out from aerodromes despite “*the aerodromes not complying with the requirements of the AFM and of OM-A to C*”.

Ju-Air has never carried out a risk analysis or hazard identification for general flight operations, VFR flying or flying in the mountains.

A1.17.1.16.16 Safety performance monitoring and measurement

As far as Ju-Air is concerned, ‘safety performance monitoring and measurement’ is a process in which the achieved safety performance is measured and quantified

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[36] One of the hazard designations was, for example “*Passagierabfertigung*”, meaning ‘passenger handling’. Another was “*Flight Operation: High density*”.

[37] An alleged mitigation measure was, for instance, for flight performance calculations concerning take-off, departure, cruise and diversion airport to be carried out correctly. Other examples of mitigation measures include that VFR charts are to be carried on board the aircraft and that, in the event of an engine failure, one should be aware of the reduced flight performance.

by using seven safety performance indicators (SPIs) so that it can be compared with the target safety performance. The safety reviews (see section A1.17.1.16.12) result from this process.

A1.17.1.16.17 Just culture and decision tree for determining culpability of unsafe acts

To enable a just culture[38] to be followed in practice, section 4.3.2 of Ju-Air's OMM contains a diagram that illustrates a procedure for classifying human misconduct at Ju-Air and the consequences of such classification. It remains unclear, however, who in the organisation should actually use this procedure and on what occasion. The procedure, named "*Decision tree for unsafe acts culpability*", was taken from a FOCA guideline[39], but Ju-Air made a minor amendment (see footnote 40). FOCA had based this model on one by James Reason "*for determining the culpability of unsafe acts*", but modified the model for its own purposes. Ju-Air and FOCA were unable to quantify the inter-rater reliability that would be important for testing the suitability of such a modified model. Ju-Air's version of the model is displayed in figure 1.

To start the procedure, the human error for which the decision tree is to be used has to be formulated. The answer to this initial question in the decision tree (yes or no) will lead on to the next question. This process is repeated until the level of culpability – graded in four severity categories – has been determined (at the bottom of the decision tree). Ultimately, depending on the severity category of the individual culpability, the analysed error is meant to consistently have certain defined consequences for the individual or the organisation, as are listed below (based on the individual level of culpability in descending order):

'Sabotage or malevolent act'	→	Severe sanction
'Reckless violation'	→	Final warning and negative performance appraisal
'Negligent error'	→	First written warning and increased supervision until behaviour is corrected
'Repeated incident with similar root cause'[40] or 'No-blame error'	→	To be documented for prevention, awareness and training purposes

In practice, this procedure was never used at Ju-Air until at least summer 2019. When applying this procedure to the behaviour of the crew involved in the accident and of certain other flight crews – which has been identified as very high-risk during this STSB investigation – their behaviour would have to be classified as reckless violations. According to Ju-Air's own process (see classification above), their behaviour should have been disciplined with final warnings and negative performance appraisals. Even in the weaker severity category, 'negligent error', Ju-Air should have issued written warnings to the pilots concerned and these pilots should have been supervised more closely. None of this, not even the documentation of an error for prevention purposes, happened at Ju-Air.

[38] A 'just culture' is generally understood to be a progressive business culture in which human errors that occur despite all precautions are accepted and analysed with the aim of continuous improvement, whereas intentional (malevolent) or grossly negligent (reckless) behaviour is consistently punished.

[39] FOCA: Guidance Material/Information – Certification Leaflet Management System. Version of November 2017.

[40] In FOCA's version of the model, a 'repeated incident with similar root cause' is classed in the same severity category of individual culpability as a 'reckless violation', therefore also resulting in a 'final warning and negative performance appraisal'. Ju-Air amended the model in this point for its own use.

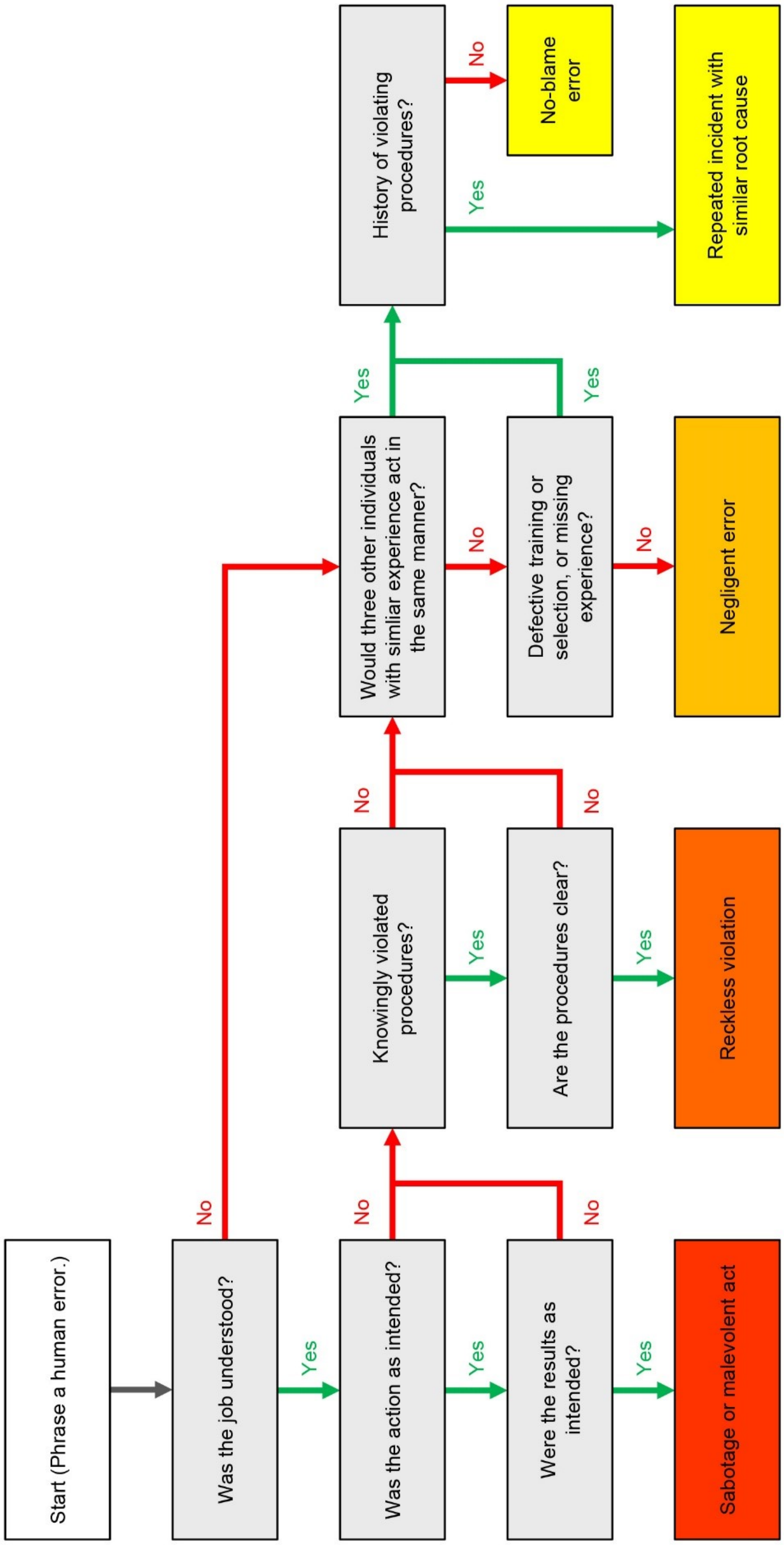

Figure 1: The "*Decision tree for unsafe acts culpability*" as per section 4.3.2 of Ju-Air's OMM.

A1.17.1.17 Reporting and incidents concerning technical aspects

A1.17.1.17.1 Legal basis and procedure

European Regulation 376/2014[41] called for a standardised and binding system for reporting occurrences and incidents. The European Commission subsequently created Implementing Regulation 2015/1018[42]. This detailed the incidents to be reported to the supervisory authority concerning flight operations and aircraft maintenance.

Since 15 November 2015, mandatory reporting has to be carried out via the reporting portal provided by the European Union. The reports are automatically forwarded to FOCA.

The instructions concerning mandatory reporting of incidents according to European Regulation 2015/1018 were stipulated in section 2.18 in the respective MOEs of Ju-Air and Naef Flugmotoren AG. These instructions were sent to all members of staff.

In both MOEs, section 2.18, the following was stated in this respect:

"All members of staff are to forward their report to the compliance monitoring manager within 72 hours. The latter is to send the report to http://www.aviationreporting.eu within 72 hours. The CMM is to support the monitoring Ju-Air and FOCA.

Incidents that have to be reported are such incidents in which the operational safety was or could have been at risk, or such incidents which could have led to an unsafe operational situation in which the aircraft, crew, passengers or people and objects in the vicinity of the aircraft are at risk.

[…]

Reports of faults and defects which may have an influence on the airworthiness of aircraft and/or components are to be reported by the technical manager or the CMM to FOCA as well as to the following parties:

- *The operator of the aircraft or the components concerned*
- *The manufacturer of the aircraft or the components*
- *The responsible FOCA inspector Airworthiness Zurich (STLZ)*"

Furthermore, section 2.18 in the MOE lists examples of events that are subject to mandatory reporting in accordance with European Implementing Regulation 2015/1018. Some of these are quoted below:

Structure:

- "*Damage to or defects in any structural component that could jeopardise the proper functioning of systems*."

Systems:

- *"The loss of a system's redundancy."*
- "*Failure, significant malfunction or damage to any main system, subsystem or set of equipment*." (see section A1.17.1.18)

[41] Regulation (EU) No. 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation, amending Regulation (EU) No. 996/2010 of the European Parliament and of the Council and repealing Directive 2003/42/EC of the European Parliament and of the Council and Commission Regulations (EC) No. 1321/2007 and (EC) No. 1330/2007.

[42] Commission Implementing Regulation (EU) No. 2015/1018 of 29 June 2015 laying down a list classifying occurrences in civil aviation to be mandatorily reported according to Regulation (EU) No. 376/2014 of the European Parliament and of the Council.

Propulsion systems (engines and propellers):

"*Failure or malfunction of any part of an engine resulting in one or more of the following*:

- *Escaping of parts/fragments.*
- *Uncontrolled internal or external fire or hot gas leakage*." (see section A1.17.1.18)

"*Engine mount failure*. […]

- *Damage to a life-limited part which results in the part being taken out of service before it has reached its full service life.*"

Propellers:

- "*Autonomous adjustment of the propeller pitch*" (see section A1.17.1.18.3)

Maintenance and repair of aircraft:

- "*Damage or problems (e.g. fractures, cracks, corrosion, delamination, detachment, etc.), whatever the cause (e.g. vibration, loss of stiffness or structural damage), to the primary structure or to a fundamental, if such damage or problem requires repair or partial or total replacement.*" (see annex A1.6)

The following are examples of occurrences that have to be reported, quoted from the MOE of Naef Flugmotoren AG:

Maintenance and repair of aircraft engines:

- "*Damage to a life-limited part which results in the part being taken out of service before it has reached its full service life.*"
- "*Damage to or problem with an engine or propeller*" (see sections A1.17.1.17.3 and A1.17.1.18)

A1.17.1.17.2 Malfunctions on the airframe and in systems

Based on Ju-Air's internal reporting system and FOCA documents, the STSB identified 13 occurrences concerning malfunctions or faults on the airframe and in systems between 2008 and the accident, and analysed them.

Number of occurrences	Description	Occurrences with information sent to FOCA
5	Malfunctions or faults during a flight rated as safety-related by the STSB	3
1	Safety-related defects detected during maintenance	1
7	Non-safety-related faults or malfunctions	3

Table 1: Malfunctions or faults on the airframe and in systems between 2008 and 2018.

A1.17.1.17.3 Malfunctions in the engines

Based on Ju-Air's internal reporting system and FOCA documents, 39 occurrences of engine malfunctions or engine-related system faults between 2008 and the accident are known to the investigation. Between 2013 and 2017, the annual output of the three to four aircraft in service was around 700 to 900 operating hours.

Number of occurrences	Description	Occurrences with information sent to FOCA
17	Engine malfunctions or engine-related system faults during a flight rated as safety-related by the STSB. 14 incidents saw a loss of power, and three of the 17 occurrences resulted in having to perform technical ferry flights (see last line in this table).	4
12	Engine malfunctions or engine-related system faults before or after flight. Four of these occurrences resulted in having to perform technical ferry flights (see last line in this table).	2
3	Cracks in the engine frame and a loose propeller detected during maintenance	3
7	Technical ferry flight performed with one engine inoperative or at reduced power	1

Table 2: Engine malfunctions or engine-related system faults between 2008 and 2018.

Out of the 17 flights that involved an engine malfunction or engine-related system fault during a flight, 14 were aborted. Reasons for aborting the flights were loss of oil pressure, vibrations or speed fluctuations. In one instance, the left engine failed completely.

A1.17.1.17.4 Evaluation

The maintenance organisations and the flight operations department did not consistently adhere to the obligation to report to FOCA. Between 2008 and the accident, a total of 52 occurrences concerning problems with airframes, systems and engines were identified. In contrast, only 17 reports were sent to FOCA (see sections A1.17.1.17.2 and A1.17.1.17.3).

Only four of the 17 occurrences involving an engine and rated as safety-related were reported to FOCA. In 14 out of 17 instances, the flight was aborted. Reasons for aborting the flights were loss of oil pressure, vibrations, development of smoke or speed fluctuations. On one occasion, the left engine failed completely. It is questionable whether FOCA was fully informed about the Ju 52 engines' poor condition due to this insufficient reporting.

Again, only four of the six incidents involving systems and rated as safety-related were reported to FOCA. Two cases in which the airspeed indicator was not functioning were not reported to FOCA.

Given the large number of volunteers in the maintenance organisations, it is essential to communicate safety-related incidents. This generally has a positive effect on quality.

These examples prove that reports concerning safety-related occurrences were not forwarded or processed in a way that improved safety. This prevented or at least substantially reduced what could have been learnt from such occurrences. Although the air operator formally had a safety management system in place, it was ineffective to a large extent.

A1.17.1.18 Incidents and reports concerning flight operations

In order to be able to draw conclusions regarding the situation at Ju-Air before the accident involving HB-HOT on 4 August 2018, regarding the aviation system in general, safety culture, reporting culture and flow of reporting, as well as the characters of pilots A and B, the history of Ju-Air as well as pilots A and B was reconstructed based on accidents, serious incidents and other safety-related occurrences. Over the course of this safety investigation, around 150 safety-related occurrences in flight operations involving Ju-Air's Ju 52 aircraft were identified. The below pages describe or mention the following:

- All known accidents since Ju-Air was founded in 1982;
- All known serious incidents from 2000 onwards;
- Other known occurrences of relevance from 2000 onwards;
- Reports from the public on occurrences from 2000 onwards;
- Incidents in which pilot A or B are known to have been involved.

The occurrences are described as follows:

<table>
<tr><td>[Date]</td><td>[Registration of the Ju-Air Ju 52 aircraft involved]</td></tr>
<tr><td colspan="2">[Description of the course of the event, roles of pilots A and B if applicable]</td></tr>
<tr><td colspan="2">[Description of the report and its processing in sections A1.17.1.18.1, A1.17.1.18.2, A1.17.1.18.3 and A1.17.1.18.5; role of pilot B involved in section A1.17.1.18.4]</td></tr>
</table>

Only events relating to the operation of Ju-Air's Ju 52 aircraft are included. Consequently, events involving other aircraft types that were or still are operated by Ju-Air or the VFL are not included.

Safety-critical occurrences taking place whilst flying in the mountains, which could only potentially be determined by subsequent analysis of flight data (see annex A1.18), were not considered here. Furthermore, the following summary does not include incidents involving flying at high altitudes without supplemental oxygen (see section A1.17.1.11).

Occurrences that took place abroad were not generally compiled. However, the occurrences abroad that have been captured by chance are taken into account in the compilation below.[43]

[43] Due to Ju-Air regularly operating flights abroad, particularly in Germany and Austria, and based on anecdotal evidence available to the STSB, it can be assumed that further incidents occurred during operations carried out in these countries. This also applies to the United States of America, where Ju-Air carried out flight operations in the summer of 2012.

Occurrences or alleged occurrences relating to Ju-Air flight operations, which had been brought to the attention of the STSB during the investigation into the accident involving HB-HOT on 4 August 2018 but which could not be substantiated, are not considered here.

The majority of occurrences involving primarily a technical problem as an immediate cause, especially engine and system malfunctions, are not considered here. These events are summarised in section A1.17.1.17.

A1.17.1.18.1 Accidents

As part of this investigation into the accident involving HB-HOT on 4 August 2018, the following Ju-Air accidents that occurred since the company was founded in 1982 were compiled:

29 May 1987	HB-HOS
On approach to Koblenz-Winningen Airport, Germany, the aircraft initially touched down before the runway. The flight crew lost control of the aircraft during the subsequent go-around. The aircraft broke away to the right at a low altitude above the ground and its right wing touched the ground. The aircraft then touched down again next to the runway, where it came to a stop. Nobody was seriously or fatally injured. The aircraft was severely damaged.	
An investigation was carried out by the German authorities in relation to this occurrence. No safety recommendations were issued.	

11 February 1998	HB-HOS
When landing at Samedan Airport, the flight crew lost control of the aircraft shortly after touching down on the runway. The aircraft came off the runway and collided with a wall of snow. Nobody was seriously or fatally injured. The aircraft was severely damaged.	
The occurrence was investigated by the Aircraft Accident Investigation Bureau.[44] No safety recommendations were issued.	

A1.17.1.18.2 Serious incidents

As part of the investigation into the accident involving HB-HOT on 4 August 2018, the following serious Ju-Air incidents that occurred in or after the year 2000 were compiled:

28 April 2001	HB-HOY
Upon landing at Mönchengladbach Airport, Germany, the aircraft was caught by a gust of wind whilst rolling to a stop, causing it to come off the runway. The aircraft had flown from Dübendorf and had passengers on board.	
This occurrence was reported by Ju-Air to the German Federal Bureau of Aircraft Accident Investigation, but was not subsequently investigated there. Ju-	

[44] The final report is available online (in German only): https://www.sust.admin.ch/inhalte/AV-berichte/1664.pdf

Air did not report the occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. This occurrence is not recorded in the Ju-Air safety management system.

14 January 2005	HB-HOY
At departure in the morning after a cold night, the wings and fuselage of the aircraft were covered with frost. The aircraft therefore took off from the runway at a greater speed than planned, immediately found itself in an aerodynamic condition that was unfamiliar to the pilots, and was difficult to control. Only after approximately 15 minutes in the air was the aircraft able to be controlled normally again.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in the Ju-Air safety management system. As corrective action, it was decided that flights in winter would only be carried out if the aircraft had been hangared beforehand. It is not known whether this action was then formally recorded in the written procedures. Today, there is no such provision in the OM.	

15 November 2005	HB-HOP
During a VFR flight by night, the flight crew was dazzled by flash photography in the cockpit to such an extent that their perceptive ability was temporarily diminished. The flight took place with passengers on board.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. The pilot reported the occurrence internally at Ju-Air using an 'operations report'[45]. This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in the Ju-Air safety management system. The pilot, who had reported the occurrence internally, suggested at the same time that flash photography in the cockpit be prohibited. Ju-Air did not take this or any other action to remedy the existing safety deficit.	

29 April 2006	HB-HOP
Upon landing at Payerne Air Base, the pilots lost directional control of the aircraft due to crosswind whilst rolling to a stop. In order to regain directional control whilst coming off the side of the runway, the power of the centre engine was first increased and shortly afterwards a go-around was initiated by setting the power on all of the engines. The subsequent landing was uneventful. During the incident, a runway light was hit and damaged, and one aircraft wheel was damaged. Three crew members and 17 passengers were on board.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. The pilot reported the occurrence internally at Ju-Air using an operations report. This occurrence is well-known	

[45] In earlier years, Ju-Air used 'operations reports' (ORs) for the reporting of an incident considered not to be safety-related by the person reporting it. An 'air safety report' (ASR), on the other hand, enabled a person to report an incident which they considered to be safety-related.

among the Ju-Air cohort of pilots and is recorded in Ju-Air's safety management system. After this occurrence, Ju-Air did not take any action to remedy the existing safety deficit. FOCA was informed of the occurrence by Ju-Air.

22 July 2006	HB-HOY
The aircraft's right engine caught fire while taxiing for take-off at Schleissheim Airport with 17 passengers on board. The aircraft was subsequently evacuated and the fire was extinguished by the fire brigade. The pilot who was supposed to perform the necessary steps from the cockpit by following the checklist did so without consulting the checklist and therefore forgot to activate the fire extinguisher in the process.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau and the German Federal Bureau of Aircraft Accident Investigation, despite reporting being obligatory. Ju-Air, on the other hand, reported the occurrence to FOCA by e-mail. This e-mail to FOCA from the then head of flight operations at Ju-Air stated that the crew had "*successfully extinguished the fire in accordance with the checklist for emergency procedures*". It also stated that, "*Nobody was placed at risk*." This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in Ju-Air's safety management system. After this occurrence, Ju-Air did not take any action to remedy the existing safety deficit.	

22 July 2007	HB-HOS
Upon landing at Dübendorf Air Base, the pilots lost directional control of the aircraft whilst rolling to a stop, at which point the aircraft came off the side of the runway. Three crew members and 17 passengers were on board.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. The pilot reported the occurrence internally at Ju-Air using an operations report. This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in the Ju-Air safety management system. After this occurrence, Ju-Air did not take any action to remedy the existing safety deficit.	

23 August 2009	HB-HOT
On approach to a runway that had been temporarily set up for an air show in Kestenholz, Solothurn, the aircraft touched down in an uncontrolled manner before the start of the runway. Three crew members and 17 passengers were on board. Pilot B acted as the co-pilot on this flight.	
Ju-Air did not report this occurrence to the then Aircraft Accident Investigation Bureau, despite reporting being obligatory. The pilot reported the occurrence internally at Ju-Air using an operations report. This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in Ju-Air's safety management system. After this occurrence, Ju-Air did not take any action to remedy the existing safety deficit.	

5 May 2012	HB-HOS
Due to an event taking place in the western part of Dübendorf Air Base, the runway was shortened from approximately 2.4 km to 1.4 km on this day. The western section of the runway was closed to flight operations, marked accordingly and covered in obstacles. After approaching runway 29 from the east, the aircraft touched down on the runway rather late and, considering the obstacles on the runway that were approaching from the pilots' perspective, full brakes were applied. As a result of this braking, the right-hand landing gear tyre disintegrated, causing the pilots to lose directional control of the aircraft. The aircraft came off the runway to the right, where it came to a stop in the pasture. Three crew members and five passengers were on board.	
Ju-Air did not report this occurrence to the STSB, despite reporting being obligatory. The pilot reported the occurrence internally at Ju-Air using an operations report. This occurrence is well-known among the Ju-Air cohort of pilots. It is recorded in the Ju-Air safety management system, where it is referred to as a 'tyre blow-out'. The internal Ju-Air report ('occurrence action report'), which is supposed to outline the action taken following the occurrence, is not very informative and does not address the essential problem. Corrective action was limited to the cohort of pilots being informed about the incident. In the process, the chief pilot stated, "*Conclusion: pilot error, inadequate situational awareness of the crew and lack of intervention by the co-pilot*." Ju-Air informed FOCA of the occurrence using FOCA's reporting form. In an internal document on determining the intensity of surveillance at Ju-Air, FOCA stated in the same year that there were in particular no issues regarding crew resource management (CRM) at Ju-Air (see section A1.17.7.4.3).	

22 March 2013	HB-HOP
During their final approach to runway 29 at Dübendorf Air Base after a flight at dusk, the pilots noticed that the first half of the runway at which they were aiming for landing was littered with obstacles (traffic cones). As a result, the pilots significantly increased the engine power and landed on the second half of the runway. It transpired that the traffic cones had been set up on the runway ahead of driving training by Zurich police the following day, but the pilots had not been informed about this.	
Ju-Air did not report this occurrence to the STSB, despite reporting being obligatory. This occurrence is well-known among the Ju-Air cohort of pilots and is recorded in the Ju-Air safety management system. The potential impact of such an occurrence has been assessed in Ju-Air's internal report as 1 out of a potential 5 points.	

16 July 2016	HB-HOP
HB-HOP was on a sightseeing flight from Dübendorf Air Base with 16 passengers on board in sunny weather conditions and with a visibility of around 35 km. During this sightseeing flight, an airprox occurred between HB-HOP and a hang-glider in the Pfiiffegg region (canton of Schwyz). The two aircraft came within a horizontal distance of 100 m and a vertical distance of 100 ft of one another.	

The pilots of HB-HOP stated that they had not noticed the airprox. The occurrence was reported to FOCA by the hang-glider pilot and subsequently investigated by the STSB.[46] A message regarding the occurrence, which the pilot of the hang-glider had previously sent to Ju-Air, was not answered by Ju-Air. Ju-Air did not report the occurrence to FOCA, despite its obligation to do so. The action "*Investigation STSB*" was noted in Ju-Air's PIL. As part of its investigation, the STSB produced a report on this occurrence, however, no safety recommendations were issued in response to this. In terms of aviation safety, the STSB found it incomprehensible that aircraft not equipped with a collision warning device were regularly used to perform commercial sightseeing flights with up to 20 persons on board[47]. The following was kept on record by Ju-Air: "*There is no need for further action.*" And although the pilots of HB-HOP had not seen the hang-glider in this instance, it was established "*that the Ju-Air pilots continue to use direct visual contact.*" Up to the day of the accident on 4 August 2018 involving HB-HOT, Ju-Air's Ju 52 aeroplanes had not been equipped with a collision warning system.

A1.17.1.18.3 Other noteworthy occurrences

As part of the investigation into the accident involving HB-HOT on 4 August 2018, the following other noteworthy Ju-Air occurrences that occurred in or after the year 2000 were compiled:

7 May 2005	HB-HOS
A forklift truck crossed the runway whilst the aircraft was on its final approach to runway 29 at Dübendorf Air Base. The forklift was crossing the grounds in connection with an event taking place at the airfield (motorcycle event 'Love Ride'). Earlier that day, whilst the aircraft was taxiing for take-off, an event minibus travelling on the airfield had already driven "*uncomfortably*" close to the aircraft on its taxiway.	
This occurrence is recorded in Ju-Air's safety management system. Action taken was limited to a discussion regarding future 'Love Ride' events.	

2006	Not recorded
Approach to Ecuvillens Airfield in the wrong direction	
Ju-Air reported this occurrence to FOCA. The occurrence is not recorded in the Ju-Air safety management system.	

1 April 2008	HB-HOP, HB-HOS, HB-HOT, HB-HOY
Entry into the control zone of Buochs Airport without clearance (airspace infringement)	

[46] The report is available online (in German only): https://www.sust.admin.ch/inhalte/AV-berichte/HB-HOP_Atos.pdf

[47] As part of the FOCA flight inspection on 13 September 2016, the Ju-Air inspector recommended that the installation of a Flarm collision avoidance system be evaluated in order to improve aviation safety.

The air navigation service provider reported this occurrence to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The occurrence is not recorded in the Ju-Air safety management system.

23 August 2008	HB-HOP
HB-HOP was on approach to runway 29 in Dübendorf when the speed indicator on both instruments fell to 105 km/h whilst flying through an area of heavy rain, and became jammed in this position. Shortly afterwards, the speed indicator jumped back to 150 km/h. The landing was uneventful.	
After landing, a Ju-Air mechanic blew through the pitot tube. No other complaints were raised for the subsequent flights. Neither the air operator nor the maintenance organisation reported this occurrence to FOCA.	

Spring 2010	Not recorded
Entry into the airspace above a US military training area and artillery firing range on German territory without permission and coordination (airspace infringement)	
This occurrence is recorded in the Ju-Air safety management system. Action taken was limited to informing the cohort of pilots about the occurrence and some “*lessons*” by Ju-Air’s head of operations. Such lessons included for example that drawing a line on the map remained part of flight preparation and that highlighting restricted areas along the flight path was imperative for flight preparation.	

2 June 2010	HB-HOP
The aircraft landed on runway 7 at Buochs Airport with the barriers to the intersecting public road open, despite Ju-Air pilots previously being briefed by local aerodrome operator staff.	
The aerodrome operator reported this occurrence to FOCA. It is not recorded in Ju-Air’s safety management system.	

25 June 2010	HB-HOS
Entry into the control zone of Alpnach Air Base without clearance (airspace infringement)	
The air navigation service provider reported this occurrence to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The occurrence is not recorded in Ju-Air’s safety management system.	

14 July 2010	HB-HOP
Entry into the control zone of Alpnach Air Base and of Buochs Airport without clearance (airspace infringement)	
The air navigation service provider reported this occurrence to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The occurrence is not recorded in Ju-Air's safety management system.	

29 August 2010	Not recorded
Multiple entries into the control zone of Alpnach Air Base, which was not active at the time, and into the also inactive control zone of Buochs Airport, where there were many flight operations that day, without issuing a mandatory blind transmission beforehand.	
This occurrence is recorded in the Ju-Air safety management system. Action taken was limited to reminding the cohort of pilots about observing control zones.	

26 March 2011	HB-HOP
When starting up the left engine, the flight crew noticed flames escaping from it. The flames were extinguished again shortly afterwards due to backwash from the propeller. The flight crew suspected a carburettor fire and decided to carry out the scheduled flight.	
The flight crew reported the occurrence internally using an operations report. On this form, the certifying aircraft mechanic released the aircraft to service by noting, "*No action required*". Neither the air operator nor the maintenance organisation reported this occurrence to FOCA.	

16 May 2011	HB-HOS
Entry into the control zone of Emmen Air Base without clearance and without radio contact (airspace infringement)	
The air navigation service provider reported this incident to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. This occurrence is recorded in Ju-Air's safety management system. Measures taken by Ju-Air to remedy the existing safety deficit are not known.	

23 September 2011	HB-HOP
A flight under visual flight rules[48] from Dübendorf to Sion was planned. After take-off from Dübendorf at 10:00 with 17 passengers on board, HB-HOP first flew at low altitude over Lake Greifensee and then continued climbing on a heading of 140 degrees. In the process, HB-HOP flew into clouds or fog. After a prolonged period of time under instrument meteorological conditions (IMC), HB-HOP was finally above the clouds, continuing the flight under visual meteorological conditions (VMC). When passing through the clouds, the commander, who was acting as the pilot flying, had repeatedly pointed out to a passenger standing in the cockpit that the passenger was not allowed to film. The commander on this flight was a pilot from Ju-Air's management team who had also worked as a pilot in the rank of captain for an airline in Switzerland and had been trained as an Air Force pilot. The co-pilot had worked in the rank of captain for an airline in Switzerland and had no background as an Air Force pilot.	
This incident was not reported to the air operator or FOCA immediately after it had occurred. The occurrence is not recorded in Ju-Air's safety management system. Following another flight under instrument meteorological conditions with the same commander about half a year later (see occurrence of 7 April 2012 below), the co-pilot filed a written flight safety report informing the safety manager at the time and other pilots from Ju-Air's management team about the occurrence. As Ju-Air initially failed to respond, the co-pilot additionally reported the occurrence to the Federal Office of Civil Aviation a little later – also by written flight safety report.	

7 April 2012	HB-HOS
A sightseeing flight under visual flight rules from Dübendorf was planned. A flight plan for the upcoming flight was not filed. After take-off from Dübendorf at 10:00 with 17 passengers on board, HB-HOS first flew over the city of Zurich at about 600 m AMSL and continued heading towards Mutschellen and Rudolfstetten. In this region, HB-HOS flew into compact clouds at low altitude. HB-HOS started to climb as there was rising terrain in the direction of flight. After having flown under instrument meteorological conditions for a few minutes, HB-HOS came out of the clouds in the region of Wohlen and continued its flight under visual meteorological conditions. As the flight continued, a 180-degree turn had to be performed in the region of Beromünster to avoid a dark cloud formation. The flight crew on this flight was the same as on 23 September 2012 (see above).	
The co-pilot decided not to go ahead with the other two sightseeing flights planned for that day involving the same commander[49]. Taking into consideration a similar occurrence that happened the year before (see occurrence of	

[48] Visual flight rules (VFR) require in particular that the aircraft is piloted under visual meteorological conditions and therefore out of the clouds at all times. When operation of an aircraft under VFR is not safe, because the visual cues outside the aircraft are obscured by weather (e.g. clouds), instrument flight rules (IFR) must be used instead. Ju-Air's Ju 52 aeroplanes were not licenced for flights under instrument meteorological conditions. In addition, IFR flights in Switzerland generally require the use of air traffic control services and the filing of a flight plan.

[49] For the flight that immediately followed, pilot B spontaneously stepped in as co-pilot.

23 September 2011 above) with the same commander, the co-pilot filed a written flight safety report informing the safety manager at the time and other pilots from Ju-Air's management team about the occurrence. As Ju-Air initially failed to respond, the co-pilot additionally reported the occurrence to the Federal Office of Civil Aviation – also by written flight safety report. There are no references to this occurrence in FOCA's Ju-Air files. Some time after the occurrence of 7 April 2012, a meeting was finally held at Ju-Air with regard to the occurrences of 23 September 2011 and 7 April 2012. The co-pilot, the commander involved and other pilots from Ju-Air's management team were present at this meeting, during which, the co-pilot was told that he was no longer required as a Ju-Air pilot with immediate effect. The STSB is not aware of any measures taken by Ju-Air or FOCA in response to the occurrence of 7 April 2012 to improve aviation safety. The occurrence is not recorded in Ju-Air's safety management system.

27 April 2012	HB-HOY
HB-HOY took off for a flight from Dübendorf to Frankfurt. After take-off, the flight crew noticed a beating sound coming from the centre engine, but the engine monitoring instruments displayed normal values. The flight crew decided to return to Dübendorf. After landing, the flight crew recorded the following in the tech log: "*Centre engine, oil loss and irregular operation.*"	
After the oil pressure, ignition and oil sump had been checked on the ground, a static test was carried out. The aircraft was then released to service by the maintenance organisation. One sightseeing flight was carried out the same day and six sightseeing flights the following day, each with 17 passengers on board. No complaints were logged for these flights. Nevertheless, the centre engine was subsequently removed from the aircraft and the cam disc replaced. Neither the air operator nor the maintenance organisation reported this incident to FOCA.	

August 2012	HB-HOT
In summer 2012, HB-HOT was being used for events and sightseeing flights in North America. On 10 August 2012, the aircraft took off from Toronto for an overflight back to Dübendorf lasting several days. At that time, the last inspection of all three engines and propellers was carried out approximately 21 operating hours beforehand. On the first leg of this overflight, from Toronto to Rivière-du-Loup, the aircraft mechanic on board had noticed unusual vibrations in the cowling of the left engine and informed the flight crew of this. No unusual observations were made either during the interval inspection in Iqaluit on 12 August 2012 or when the engine was rotated by hand over the days that followed.	
After the overflight, which lasted approximately 50 flight hours, an interval inspection was carried out on HB-HOT in Dübendorf. During a static test, vibrations and an unusually high engine speed were observed on the left engine at maximum power. During the interval inspection on this engine, it was subsequently discovered that one of the propeller blades could be rotated around its own axis by hand. Inspection to the second blade of this propeller also showed insufficient frictional resistance. The propeller was dismantled and sent to a	

company in Germany for inspection. Several loose rivets were found on the left engine frame and on the airframe near the engine frame. These were replaced by a metal worker. No other action was taken. Neither the air operator nor the maintenance organisation reported this incident to FOCA.

It is clear from the files of HB-HOT that there were several instances of loose propeller blades up until the time of the accident (see annex A1.6).

4 April 2013	HB-HOP

As part of a line check, HB-HOP was flying from Birrfeld to Dübendorf. Only the three pilots were on board: a commander, a co-pilot and an examiner[50]. The Zurich Airport control zone was entered via Bremgarten / reporting point W. HB-HOP then followed the Whiskey route to reporting point W1. In the course of this, the air traffic controller of Zurich Tower, operated by Skyguide, asked the HB-HOP pilots by radio whether they were interested in a low pass over runway 10. The pilots said to the air traffic controller that they were interested in such an overflight, although this was not part of the line check. Subsequently, they navigated the aircraft via Affoltern reporting point W2 from the west over the aforementioned runway 10. According to the commander, the flight altitude above the runway was approximately 50 m AGL. Shortly after the intersection of runways 10/28 and 16/34, HB-HOP turned to a south-easterly course, deviating from runway axis 10/28. Recorded data show, that when doing so, HB-HOP flew over the apron and the Zurich Airport buildings at low altitude. A few minutes later, HB-HOP landed on runway 11 of Dübendorf Air Base.

According to Ju-Air, members of FOCA's management team and the management of the operator of Zurich Airport witnessed the low overflight and considered the occurrence as a "*hazard to persons, aircraft and buildings*". In the same month, Ju-Air, the airport operator and Skyguide agreed that Ju-Air's Ju 52 aeroplanes would no longer perform low overflights over Zurich Airport. The letter referring to this matter from Ju-Air to its cohort of pilots ended as follows: *"Another bit of joy to fall prey to the spectre of safety, danger and mitigation."* Ju-Air's corrective action report states that the repetition of such an occurrence is considered "*extremely improbable*". Measures taken by FOCA are not known. Notably, there are no documents that would provide evidence of the agreement between the three aforementioned stakeholders following a corresponding FOCA ruling.

3 June 2013	HB-HOS

After the commercial flight from Straubing in Lower Bavaria to Dübendorf, the flight crew noticed that the panelling on the underside of the left-hand aileron was dented and ripped open near the leading edge. It could be reconstructed that the aileron had hit a fence whilst the aircraft was taxiing for take-off in Straubing.

[50] Type rating examiner (TRE, referred to by FOCA as 'examiners for pilot examinations' or just 'examiners') are appointed by FOCA after they have successfully passed a series of selection processes and completed a multi-stage training and examination programme with FOCA. In particular, examiners perform a pilot examination after the pilot has completed the relevant training with a flight instructor or type rating instructor, be this their initial training or professional development. According to FOCA, the office monitors the activities of the appointed examiners.

The pilot reported the occurrence internally at Ju-Air using an operations report. This occurrence is recorded in Ju-Air's safety management system. FOCA was informed of the occurrence by Ju-Air. Ju-Air declared that such an occurrence is intended to be prevented in the future by familiarising the pilots with the dimensions of the aircraft. Ju-Air also announced that it would check other airfields they approach for obstacles. It is not known whether this or any other action was actually taken by Ju-Air.

17 July 2014 18 July 2014 19 July 2014 21 July 2014	Not recorded
During four flights over the city of Basel that took place over four days during the Basel Tattoo[51], the flight altitude was below the minimum permissible level by 50 m or more in each instance.	
FOCA issued the commanders involved with fines of between 300 and 400 Swiss Francs. The fines were paid by Ju-Air. These occurrences are recorded in Ju-Air's safety management system. Ju-Air is not aware of any measures taken to remedy the existing safety deficit.	

9 August 2014	HB-HOP
As part of the 2014 Locarno adventure tour, the Ju 52/3m HB-HOP was climbing towards the north to cross the Alps after take-off from Locarno Aerodrome. During this climb, an airprox occurred between HB-HOP and a helicopter in the Lodrino region (canton of Ticino). According to the helicopter pilot, the two aircraft came within 50 m of one another. Three crew members and 15 passengers were on board.	
The helicopter company reported this occurrence to FOCA and the STSB. The occurrence is not recorded in Ju-Air's safety management system. Based on the legal situation at the time, no investigation was initiated by the STSB.	

20 June 2015	HB-HOP
After landing at Dübendorf Air Base, the aircraft taxied to its parking position. During a right turn, the balance weight for the right-hand aileron became entangled in a temporarily installed safety net. A mechanic rushed over and tried to solve the problem. He was hit by parts of the safety net that had suddenly been released, and suffered a dislocated shoulder. Pilot B acted as the commander on this flight.	
This occurrence is recorded in Ju-Air's safety management system. Ju-Air is not aware of any measures taken to remedy the existing safety deficit. In the occurrence reporting form for the attention of FOCA, Ju-Air stated, "*No action required due to no damage*."	

[51] The Basel Tattoo is an open-air music event, which has been held annually since 2006 and for around one week at a time in the Basel Kaserne.

5 July 2015	HB-HOP
The crew detected a malfunction of the airspeed indicators during their take-off run for the first sightseeing flight of the day in Oberschleissheim (Germany). They were displaying values that were clearly too low. The aircraft continued its sightseeing flight and landed in Oberschleissheim without any problems. After attempted troubleshooting by non-qualified personnel, the second sight-seeing flight began. This was then aborted during the take-off run due to the airspeed indicators not working. The flight crew did not record this in the tech log and the aircraft was flown to Dübendorf in this condition without any passengers on board. After this flight, the commander recorded the following in the tech log: "*Speed indication unreliable*". According to the technical files, no action was taken by the maintenance organisation in response to this entry. The following day, a 13-minute flight took place, even though both speed indicators were clearly not working reliably or at all. After this flight, another entry was made in the tech log: "*Both speed indicators faulty*".	
The system was repaired by the Ju-Air maintenance organisation. Neither the air operator nor the maintenance organisation reported this occurrence to FOCA.	

3 September 2015	HB-HOT
Entry into the control zone of Zurich Airport without clearance and without radio contact (airspace infringement)	
The air navigation service provider reported this event to FOCA. FOCA was unable to explain how it subsequently dealt with the notification and what consequences resulted from it. The occurrence is not recorded in Ju-Air's safety management system.	

2 October 2015	HB-HOS
Entry into the airspace above the Munich Oktoberfest without permission. Pilot B acted as the commander on this flight.	
This occurrence is recorded in the Ju-Air safety management system. Ju-Air is not aware of any measures taken to remedy the existing safety deficit. The potential impact of such an event has been assessed in Ju-Air's internal report as 1 out of a potential 5 points.	

8 April 2016	HB-HOP, HB-HOS, HB-HOT
Towards the end of a sightseeing flight from and to Dübendorf, Ju-Air's three Ju 52 aircraft flew in 'wide formation' via the city of Zurich / reporting point S entering the Zurich Airport control zone from the south. The formation then continued along the Sierra route to reporting point W1 and to Affoltern / reporting point W2. In the course of this, the air traffic controller of Zurich Tower gave the formation clearance for a low pass over runway 10. Shortly afterwards, the aircraft descended and flew over said runway at low altitude. A few minutes later, the formation landed at Dübendorf Air Base. The commanders of	

HB-HOS (lead aircraft of the formation) and HB-HOP were pilots from Ju-Air's management team.
A citizen of Rümlang filed a complaint, in response to which FOCA made some inquiries. However, on the grounds that the low pass had been cleared by the aerodrome control tower, FOCA did not open a case or take any further action. It is not known to what extent the agreement reached between Ju-Air, Zurich Airport and Skyguide following a comparable occurrence on 4 April 2013 (see above) played a role in FOCA's investigations and in its decision not to take any further action.

2 July 2016	HB-HOP
In the afternoon of 2 July 2016, a cold front moved across Switzerland from the west. Rain showers, some low clouds, a main cloud base at 1,200 m AMSL, thick cumulus clouds with a base at 1,000 m AMSL and gusts of wind of up to 25 knots were forecast for Dübendorf for the afternoon. The General Aviation Forecast (GAFOR) predicted 'marginal'[52] meteorological conditions for VFR flights for the main VFR flight route along Lake Zurich until 13:00 and between 15:00 and 17:00, and 'difficult' conditions for the period between 13:00 and 15:00. Shortly before noon, the main cloud base above Dübendorf was at about 930 m AMSL, there were a few low clouds and it was raining. The crew took off in HB-HOP from Dübendorf at about 12 o'clock for their first commercial sightseeing flight under visual flight rules and at approximately 14:00 for their second. At that time, there were also intermittent rain showers, a few low clouds and some clouds at approximately 1,500 m AMSL with a cloud cover above that. At 15:25 the crew took off for their third sightseeing flight with 17 passengers on board HB-HOP. At that time, a pronounced precipitation area moving east extended from the northern part of the canton of Zurich through the city of Zurich to the canton of Lucerne. By 16:10, this precipitation area had shifted to the eastern part of the canton of Zurich. At that time – on its way back to Dübendorf – HB-HOP flew over the village of Wolfhausen. Wolfhausen is situated about 20 km southeast of Dübendorf at 500 to 520 m AMSL. According to FOCA's evaluations, this flight was performed at an altitude of approximately 700 m AMSL, meaning about 200 m above ground. Pilot B acted as the commander on this flight.	
A citizen reported the occurrence to FOCA. FOCA then carried out investigations. These investigations revealed that the minimum required flight altitude for non-commercial VFR flights (300 m AGL) had not been complied with. Quoting FOCA, this had been "*justified because of an unforeseen deterioration in the weather*". The FOCA inspector responsible concluded that "*the flight preparation had been carried out properly and the weather had been correctly assessed*" for the HB-HOP flight in question. There is no evidence that the flight preparation documents were available to the FOCA inspector and that the inspector used Ju-Air's flight preparation policies for comparison. It remains unclear as to why the weather was "*correctly assessed*" by the pilots given that apparently the weather caused the crew to fly significantly below the minimum required flight altitude with 17 passengers on board. In any case, the weather development was no surprise. FOCA stopped its investigations and refrained from taking further action. The occurrence is not recorded in Ju-Air's safety	

52 As per the relevant definitions for this route 'marginal' means that the cloud base could be at 800 m AMSL.

management system. Ju-Air did not report this occurrence to FOCA, despite reporting being obligatory.

13 August 2016	HB-HOS
Entry into the control zone of St. Gallen-Altenrhein Airport without clearance and without radio contact (airspace infringement). The aircraft was in the control zone of St. Gallen-Altenrhein Airport, which extends from the ground up to 5,500 ft AMSL, for just over two minutes. It passed through this airspace on a route between reporting points V and Z at an altitude of approximately 4,000 ft AMSL while climbing and crossed the extended runway axis as well as the approach path of the instrument landing system to runway 10. For long stretches, the airspace was infringed by more than 1 km (lateral distance to the western boundary of the control zone).	
The air navigation service provider reported this event to FOCA. FOCA's subsequent inquiries concluded that – as per FOCA's opinion – the "*airspace infringement had only been minor*". And that for this reason, no criminal proceedings had been initiated. This occurrence was well-known among the Ju-Air cohort of pilots. The occurrence is not recorded in the Ju-Air safety management system.	

15 October 2016	Not recorded
During a flight over the city of Lucerne, a Ju 52/3m operated by Ju-Air dropped below the minimum flight altitude.	
The event was recorded in the EU reporting system[53] by a FOCA employee, but in a private capacity. The report subsequently reached FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The person who reported the event never received a response from FOCA. The occurrence is not recorded in Ju-Air's safety management system.	

18 April 2017	HB-HOP
During a line check, a failure of the left, wing-mounted engine was simulated shortly after take-off and at a low altitude above the runway. During this – and also due to a crosswind, the strength of which surprised the crew – the aircraft broke away to the side and strayed from the runway axis. The examinee reacted late, so the examiner intervened. The line check was also the subject of an inspection by FOCA and was accompanied by an inspector from FOCA. The FOCA inspector was sitting in the passenger cabin during the flight.	
According to Ju-Air, leaving the runway axis was considered tolerable by all parties involved. FOCA's inspection report contains no reference to this event. The occurrence is not recorded in the Ju-Air safety management system. However, the event was discussed within Ju-Air management according to the	

[53] http://www.aviationreporting.eu

minutes of a combined management evaluation and safety review board meeting. According to this record, the NPFO was instructed to ensure that in future "*such nonsense is avoided near the ground*" – "*FOCA or no FOCA*". The topic is concluded with the statement: "*We don't want an accident!*" With regards to the Ju 52 aircraft's behaviour in the event of one wing-mounted engine failure in terms of flight mechanics, Ju-Air stated that, "*It is not possible to maintain the runway axis with take-off power.*"

13 August 2017	HB-HOP
During several sightseeing flights from the German airport Friedrichshafen (EDNY) to the Alpstein Massif, Ju-Air's Ju 52 aeroplanes crossed the wildlife reserve between Säntis and Kronberg at low altitude several times.	
The low-level overflights caused a citizen to file a complaint with the police, whereupon FOCA carried out investigations and, in particular, secured the radar data from Skyguide. On the grounds that the wildlife reserve was not marked on the ICAO aeronautical chart of Switzerland, FOCA subsequently did not take any further action. According to unsubstantiated information from FOCA, however, the office had requested Ju-Air to "*train its pilots with regards to protected areas and to raise their awareness*". In February 2018, Ju-Air briefed their cohort of pilots about wildlife reserves by presenting them with a Powerpoint slide during a ground refresher training session.	

1 September 2017	Not recorded
During a weather reconnaissance flight over the city of Zurich with no passengers on board, the aircraft was flown at more than 200 m below the minimum required safety altitude of 300 m above ground. The commander of the Ju 52/3m was Ju-Air's deputy nominated person flight operations (NPFO), who was also the ground instructor, training captain, type rating instructor and type rating examiner at Ju-Air. This person also had a flying background as a fighter pilot in the Swiss Air Force and had worked for many years as a pilot for an air operator in Switzerland. The decision to conduct the weather reconnaissance flight was made in the presence of Ju-Air's accountable manager (ACM).	
FOCA fined the commander involved. The fine was paid by Ju-Air. This occurrence is well-known among the Ju-Air cohort of pilots. It is not recorded in Ju-Air's safety management system.	

20 September 2017	HB-HOS
Entry into the control zone of Meiringen Air Base without clearance and without radio contact (airspace infringement)	
FOCA fined the commander involved. The fine was paid by Ju-Air. This occurrence is recorded in Ju-Air's safety management system. The corrective measures taken were limited to the statement that pilots who are notified by FOCA of a criminal or administrative investigation must inform the Ju-Air CMM and keep them updated. It is noteworthy that Ju-Air's corrective action report[54]	

[54] "*Hazard and occurrence corrective action report*"

states that the repetition of such an occurrence is considered *"improbable"*. The potential impact of such an occurrence has been assessed in Ju-Air's internal report as 2 out of a potential 5 points.

9 May 2018	HB-HOS
Whilst an Air Force cargo aircraft (Beech 1900D T-729), which had landed on Dübendorf Air Base's runway 11 shortly beforehand, was still on the runway, HB-HOS crossed the holding-point line of this runway without clearance (runway incursion).	
The air navigation service provider reported this occurrence to FOCA. FOCA took note of the notification, but did not take any action. FOCA was of the opinion that there was "*no need*" for intervention. FOCA justified this on the grounds that an inspection carried out in 2016 had already revealed that Ju-Air did not have an incursion prevention programme and that Ju-Air was advised to introduce such a programme at the time. The occurrence is not recorded in Ju-Air's safety management system.	

23 May 2018	HB-HOP
Entry into the control zone of Buochs Airport without clearance (airspace infringement)	
The air navigation service provider reported this event to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The occurrence is recorded in the Ju-Air safety management system. The corrective measures taken were limited to a message given to the cohort of pilots regarding the occurrence by the NPFO. It is noteworthy that Ju-Air's corrective action report states that the repetition of such an occurrence is considered *"improbable"*. The potential impact of such an occurrence has been assessed in Ju-Air's internal report as 2 out of a potential 5 points.	

2 June 2018	HB-HOS
A sightseeing flight under visual flight rules[55] from Dübendorf was planned. After take-off from Dübendorf at 11:48 with 17 passengers on board, HB-HOS flew past the summit of the Gross Mythen at 12:06 at a distance of 45 m. Gross Mythen was covered in clouds at the time (see section A1.18.7.8).	
The occurrence is not recorded in Ju-Air's safety management system. FOCA had no knowledge of this occurrence.	

[55] Visual flight rules require in particular that the aircraft is piloted under visual meteorological conditions and therefore out of the clouds at all times. When it is not safe to fly under visual flight rules, because the visual cues outside the aircraft are obscured by weather (e.g. clouds), instrument flight rules must be used instead. Ju-Air's Ju 52 aeroplanes were approved for flights under visual flight rules only.

6 July 2018	HB-HOT
During a flight over the city of Munich, HB-HOT flew at approximately 180 m below the minimum required safety altitude of 300 m above ground (see sections A1.17.1.18.6 and A1.17.1.18.4). Pilot A acted as the commander on this flight, pilot B as the co-pilot.	
The occurrence is not recorded in Ju-Air's safety management system. FOCA had no knowledge of this occurrence.	

6 July 2018	HB-HOS
Contrary to the mandatory procedures, HB-HOS took off from Dübendorf Air Base without prior contact and coordination with Zurich Tower. This resulted in a conflict with a helicopter on approach to runway 34 at Zurich Airport.	
The air navigation service provider reported this occurrence to FOCA. FOCA was unable to explain how it subsequently dealt with the report and what consequences resulted from it. The occurrence is not recorded in Ju-Air's safety management system.	

A1.17.1.18.4 Further occurrences involving pilot B

As the crews during the occurrences logged as part of this investigation were not fully recorded, the following list is not necessarily complete. There is no evidence that pilot A was involved in such further occurrences.

22 October 2005	HB-HOP
Due to a high oil temperature, one engine was switched off during the flight.	
Pilot B: co-pilot	

23 August 2009	HB-HOT
Low oil pressure during a sightseeing flight	
Pilot B: co-pilot	

11 July 2010	HB-HOY
Engine malfunction during a sightseeing flight	
Pilot B: commander	

4 March 2014	HB-HOY
Bird strike shortly after take-off	
Pilot B: commander	

4 May 2016	HB-HOP
Due to a drop in speed on the left engine, the flight was aborted and the aircraft returned to the air base.	
Pilot B: commander	

A1.17.1.18.5 Reports from the general public

The following is a selection of reports submitted by the general public, which concerns observations from 2000 onwards and appear plausible in terms of content. The reports were compiled as part of this investigation into the accident involving HB-HOT on 4 August 2018:

Last 30 years	Registrations irrelevant
"[...] *For more than 30 years, Ju-Air has been operating its Ju 52 planes with constant gross disregard of the legal requirements regarding the minimum required safety altitude of 150 m AGL above uninhabited areas and 300 m AGL above inhabited areas, as well as with minimal horizontal distances to mountain ranges*. *In particular, mountain stations, some of which have large crowds of mountaineers or skiers, are regularly flown over at 20 to 30 m AGL in low-level flight.* […]".	
No evidence of previous reporting to the authorities or Ju-Air	

2005	Registration irrelevant
Passenger: "[...] [We were circling] *when the pilots reported that they* were *waiting for a 'rendezvous' with another* [plane]. *We saw a small plane flying straight* [...] *towards us as the Ju sloped down and dived. The passengers cried out. I suspected* [an emergency manoeuvre] *to avoid a collision* [or] *an over-confident prank* [on the crew of the other plane]. [...] *No explanation or apology* [by the crew] *followed*. […]".	
A report was made to the charterer, but no response was received by the person reporting the incident.	

Since 2010	Registration irrelevant
"[...] *Unfortunately, Ju-Air pilots are hardly concerned about minimum altitudes*. [...] [You] *can't shake off the feeling they like to fly as low as possible in order to give passengers the appropriate view*. [...] [When] *Ju-Air stopped caring about* [...] *minimum flight altitudes, I started documenting the flights for the purpose of filing a complaint with FOCA*. […]".	
However, no report was then made. ("[...] *based on various articles in the press,* [I doubted] *that Ju-Air would change its habits any time soon* [...] *because of a complaint by a nobody, and therefore did not report it* [to FOCA]. […]")	

2008	Registration irrelevant
Passenger: "[...] *during a Ju-Air flight, I noticed that the plane was flying very close to the terrain* [...]. [Which I] *perceived as a risk. Additionally, several 'Höpperli'*[56] *were flown during the flight as a 'gag'. It made me so sick, I had to throw up*. [...] *The 'Höpperlis' were not announced, but were executed several times without warning (at least five or six times). Afterwards some bad joke was made about 'us not falling asleep'.* [...] *Others also found it unnecessary and not funny, but no one else found it as bad as I did. All I know is that one of the other passengers hit their head a little too*. […]".	
No report was made to the authorities or Ju-Air. As a result of the experience, the passenger turned down a gift Ju-Air flight a few years later.	

2013	Registration irrelevant
Passenger: "[...] [As a glider pilot and pilot of motor-powered aircraft as well as a flight instructor] *I noticed that parts of the flight path were very close to the terrain*. [...] *My first thought was that I would not have flown closer to the terrain in a glider*. [...] [I] *wondered whether the escape routes were always suitable in case of a downdraught or engine failure*. […]".	
No report was made to the authorities or Ju-Air.	

2014	Registration irrelevant
Passenger: "[...] *During the flight, I* [a private pilot of motor-powered aircraft] *noticed that some of the planes flew very close to the terrain*. *Especially in the Urnerboden area, where the Urnerboden was approached practically at 90 degrees between the rocks.* [...] *An aircraft coming from Glarus, which would also have flown towards the Klausen pass, would have had difficulty evading (if at all,* [and then only] *to the left towards the middle of the valley).* […]."	
No report was made to the authorities or Ju-Air.	

2014	Registration irrelevant
Passenger: "[...] *flew over the valley end very, very close, it was frightening*. [As a private pilot of motor-powered aircraft] *my heart sank when I noticed that he didn't leave the valley a little sooner but flew towards the nearby crest of the valley*. […]. *Criminal. In my eyes problematic, with members of the public* [on board]. [...] *narrowly crossing the crest of the valley, it bothers me and frightens me*. [...] *in descent very steep* [bank attitude] *when turning*. [...] *Then, completely out of the blue, the crew makes a turn of no less than 90 degrees, you wouldn't believe it, to the left, towards the nearby mountain wall* [...]. *But that was the moment when fear grabbed me, I became scared stiff and could no longer understand, because this flying tactic at this, in my opinion, far too low altitude contradicted everything I had learned and practised when flying.* [...] [back then I] *thought (and told a friend in 2014): if they keep flying like that, one of these days there will be a disaster.* […]".	

[56] Swiss German for small jolts

No report was made to the authorities or Ju-Air. (The reason: "*out of laziness and cowardice*". "[...] *I didn't want to be portrayed as stupid or a coward or as 'a little PPL pilot*[57] *who doesn't understand'. Because I knew from the repeated claims in the media and Ju-Air's own advertising what hotshots the Ju pilots as experienced former airline and military pilots must be. And I know from my own experience from my many years of PPL life the kind of machos that are sometimes found among veteran aviators*. [...] [A friend who works in the nuclear industry], *was inclined to agree that addressing the crew would not have achieved anything, precisely because of the 'superstar attitude' of various veteran captains.* […]".)

2015	Registration irrelevant
Passenger: "[...] [I felt] *extremely uncomfortable on the routes where the plane flew close to rocks and in the mountains at a low distance from the ground*. *This is because I know that the Ju, due to its* [...] *low power, has little in reserve if something unforeseen should suddenly occur*. [...] *I had the impression that in certain situations the plane lacked the power to accelerate quickly. Also because of the close proximity to the ground.* […]".	
The passenger expressed his concerns to the pilots immediately after the flight. However, they played things down, stating, "*they had a 'sufficient air cushion' and had practised this in the military*."	

2018	Registration irrelevant
Passenger: "[...] *the pilots flew in what I consider to be an extremely tight circle*. *It also scared me. I would never have believed that the pilots or Ju 52 could fly such tight radii at such a low cruising speed. After the full circle, it carried on, barely squeezing between* [two mountains] [...]. *My wife covered her eyes. We only just made it in between the mountains*. […]".	
No report was made to the authorities or Ju-Air. (The reason: "*I cannot know which flight manoeuvres are normal or permissible for the Ju. There are experienced and well-trained pilots for that.* [...] *After landing, the plane was disembarked and the next flight was prepared straight away*. *You would have almost needed to intrude. No layperson would do this, no one wants to feel embarrassed or uncomfortable. Laymen do not want to criticise a professional's expertise*. [...] *From a passenger to a professional pilot (former military pilots)* [the giving and accepting of criticism] *will probably not have much of an effect.*")	

2018	Registration irrelevant
Mountaineers on the ground: "*Risky behaviour*. [...] *Although the summit* [of the Gross Mythen] *was largely in the clouds/fog,* [the plane] *flew past the summit extremely close to the side*. [...] *I filmed the scene* [see annex A1.18]. *I think that the images document the high level of risk-taking, which at least two pilots of Ju-Air took here, to impress the passengers.* […]".	

[57] PPL pilot: A pilot with a private pilot licence.

No report was made to the authorities or Ju-Air. (But: "[...] *Perhaps it would* [have] *be*[en] *different if there were an easier way to report*. *I'm thinking of an – anonymous, if desired – CIRS*[58], *as I know it from my work in hospital and* [as it is] *used internally by airlines*. […]")

2018	Registration irrelevant
Glider pilot on the ground: "[...] [On the first Ju flight observed by us glider pilots that day, the Ju flew] *at a low altitude over the* [Julier] *pass towards the Engadine*. […]. *In any case, it was an altitude at which only a few options were available. We watched the second flight from the Diavolezza mountain restaurant and the third from Punt Mers* [...]. *I was* [...] *surprised at the tactics involved in flying it: The Ju approached the Diavolezza mountain restaurant from the north approximately at the height of the ridge and flew very close in front of the mountain restaurant in a south-easterly direction, then made a long right turn in front of the Bernina Range, only to leave the basin again in the direction of the Morteratsch restaurant. During the right turn, the Ju lost a lot of altitude. The flight path was identical for both flights in front of the Bernina Range. As a glider pilot, I am surprised that a rather low-powered aeroplane flies so low over ridges into potential lee areas.* [...] *The things I saw include flight tactics which I consider unsuitable* [...]".	
No report was made to the authorities or Ju-Air. (The reason: "*I never considered reporting it to Ju-Air at any time as I didn't expect there to be any benefit. My experience in flying has shown that pilots with thousands of hours on airliners are not open to comments from glider pilots, even though we* [glider pilots] *may know the areas and wind conditions much better".*)	

A1.17.1.18.6 Flight below the minimum altitude over Munich

On 23 July 2018, the government of Upper Bavaria, Southern Bavaria Office of Aviation, contacted Ju-Air by e-mail and asked for the name of the person who was the "*responsible pilot*" of the Ju 52 registered as HB-HOT on 6 July 2018 at 12:50. The reason given for the request was that "*the information is needed as part of investigations into a non-compliance procedure*". The NPGO at Ju-Air received this e-mail. They were able to establish, based on the documents at their disposal, that the flight crew on the flight in question was made up of pilots A and B. The NPGO subsequently forwarded the e-mail to pilots A and B and asked them to contact the government of Upper Bavaria directly.

On 26 July 2018, pilot A contacted the government of Upper Bavaria and clarified that he himself had been the responsible pilot of HB-HOT on the day in question. His co-pilot had been pilot B.

On 30 July 2018, the Southern Bavaria Office of Aviation informed pilot A in writing that he would be accused of having "*flown over the city of Munich*" on 6 July 2018 at "*approx. 12:50*" as the pilot of the aircraft with the "*official registration number HB-HOT at an altitude considerably below the minimum required safety altitude"*. According to the complaint, pilot A's overflight "*at an altitude of approx. 121 m (266 ft)* [...] was *significantly below the minimum required safety altitude of 300 m* [...] *without holding the necessary authorisation*". The letter was addressed to pilot

[58] CIRS: Critical incident reporting system. A reporting system for the – if desired – anonymous reporting of critical incidents in the healthcare system.

A's home address and at the same time constituted an invitation to comment by 22 August 2018. Pilot A was carrying the letter with him during the accident flight.

Apart from the NPGO and pilots A and B, nobody at Ju-Air was aware of this accusation against pilot A; consequently, nobody was aware of this flight below the minimum required safety altitude. FOCA also had no knowledge of this event or the accusation.

The German authorities substantiated the accusation against pilot A to the STSB with radar data showing HB-HOT over the administrative district and the city of Munich. According to these radar records, HB-HOT first flew over the municipality of Neuried at an altitude of 121 m (corresponding to 266 ft) above ground and then over Munich's district 19 (covering Thalkirchen, Obersendling, Forstenried, Fürstenried and Solln) at an altitude of 151 m (corresponding to 497 ft) above ground.

The STSB's evaluation of the meteorological documentation available before and during the flight revealed that the flight had been planned and executed under marginal conditions for a VFR flight. The aircraft flew over the city of Munich below extensive stratus clouds that had a diffused base at approximately 300 ft AGL. The General Aviation Forecast also predicted embedded thunderstorms. The actual conditions during the flight thus corresponded to the pessimistic scenarios predicted by the aerodrome weather forecast along the route.

A1.17.1.19 Non-specific passages in the OMM

Numerous sections and subsections of the OMM contained passages, sometimes entire sections, that did not describe the situation at Ju-Air, but rather how the process or system discussed should or could be designed for a generic company. These passages obviously came from guidelines and templates for setting up an OMM and were copied into Ju-Air's OMM without being adapted to reflect the actual conditions at Ju-Air. These unspecific passages can be identified by the use of expressions such as "*it is recommended*", "*may*", "*shall be developed*", "*should be*" or "*the organisation*". Some examples of these passages include:

- "*Preferably, this should be combined with the business planning and steering process of the organisation, where the definition and communication of annual goals are part of it.*" (from OMM section 4.2)
- "*In order to strongly support and foster the organisation's Just Safety Culture the Decision Tree for Unsafe Acts Culpability may be recommended. The organisation may use the decision tree when analysing an adverse event or error.*" (from OMM section 4.3.2)
- "*The management system shall include the identification of aviation safety hazards entailed by the activities of the organisation, their evaluation and the management of associated risks, including taking actions to mitigate the risk and verify their effectiveness. A formal risk management process shall be developed and shall be maintained to ensure that analysis, in terms of likelihood and severity of occurrence; assessment, in terms of tolerability; and control, in terms of mitigation of risks to an acceptable level. Additionally, the levels of management who have the authority to make decisions regarding the tolerability of safety risks shall be specified.*" (from OMM section 4.4)
- "*Hazard identification systems will be non-punitive, confidential, simple and easy to use. Every effort should be made to promote confidence and trust in the system so that it is not seen as a means of allocating blame.*" (from OMM section 4.4.1)

- "*The Safety Performance Monitoring and Measurement should be a process by which the safety performance of the organisation is verified in comparison to the safety policy and objectives.*" (from OMM section 4.9)
- "*The compliance monitoring programme* […] *is tailored to the size, complexity and activity of the organization. It shall be properly implemented, maintained and continuously reviewed and improved. It is strongly recommended that the Compliance Monitoring Programme requires, that all aspects of the organisation are reviewed periodically, within a defined cycle.*" (from OMM section 5.1)
- "*To ensure that all aspects of the organisation are reviewed periodically, it is strongly recommended to specify an interval between audits, covering the same scope and focus. Ideally, all aspects should be reviewed within a period of 12 consecutive months.*" (from OMM section 5.2.3)

It is clear that, rather than providing support for personnel, these unspecific passages in the OMM, as well as inconsistencies, contradictions and illogical structures (see, for example, sections A1.17.1.16.8, A1.17.1.16.9 and A1.17.1.16.10), are confusing. It also seems likely that such inadequacies in compliance with processes, if they are conclusively defined elsewhere, are damaging. Moreover, unspecific passages needlessly increase the size of the operational documentation and thus act as a deterrent for personnel to deal with the stipulated safety-related processes.

A1.17.1.20 System for monitoring compliance with the relevant requirements

A1.17.1.20.1 Background

Ju-Air implemented a compliance monitoring system (also referred to as 'compliance management system' by Ju-Air) to check that business activities conformed with legal standards and self-imposed processes. This system, which was required by rule ORO.GEN.200(a)(6) of Commission Regulation (EU) No. 965/2012 and explained in more detail by European recommendations[59], primarily consisted of a compliance monitoring manger (CMM, see in particular sections A1.17.1.4.6 and A1.17.1.16.6) as well as of internal inspections and internal audits. During the internal inspections, which took place several times a year, the appointed persons reviewed the work processes in their own areas of responsibility. In internal audits, the various areas of responsibility were to be reviewed by a person from another area of responsibility.

A1.17.1.20.2 Internal audits in 2016 and 2017

The following audits were conducted in the autumn of 2016 and 2017:[60]

- Policy and system overview – these areas, which are the responsibility of the accountable manager (ACM), were audited by the SM/CMM.
- Legal requirements for the air operator certificate (AOC) and operations – these areas, which are the responsibility of the accountable manager (ACM), were audited by the SM/CMM.
- Compliance monitoring (also known as compliance management at Ju-Air) – this area, which is the responsibility of the CMM, was audited by the NPFO.

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[59] "*Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex III Organisation requirements for air operations [Part-ORO] of Commission Regulation (EU) 965/2012 on air operations, Consolidated version including Issue 2, Amendment 12, December 2017.*" AMC1 ORO.GEN.200(a)(6) and GM1 ORO.GEN.200(a)(6).

[60] Such audits were also planned for 2018. They took place after the accident on 4 August 2018.

- The safety manager (SM) and the flight safety programme for which he was responsible were audited by the NPFO.
- Flight preparation and flight planning – these areas, which are partly the responsibility of the NPFO and partly the responsibility of the NPGO, were audited by the SM/CMM.
- The processes for aircraft loading as well as the calculations of mass and balance – these areas, which are the responsibility of the NPFO, were audited by the SM/CMM.
- Aircraft performance – this area, which is the responsibility of the NPFO, was audited by the SM/CMM.
- The actual flight operations and flight procedures – these areas, which are the responsibility of the NPFO, were audited by the SM/CMM.

The audit reports primarily consisted of a list of questions that had to be answered by the respective auditor during the audit. When reviewing the audit reports for 2016 and 2017, the following points stood out in particular:

- The question as to whether the operator's procedures and instructions also included the procedures and instructions for a sterile cockpit was answered in the affirmative by the auditor (see section A1.17.1.13).
- The question as to whether there was a system for reporting incidents to the competent state authorities was answered in the affirmative by the auditor. The exact same question was part of the audits of the NPFO, the NPGO and the ACM.
- The question as to whether there was a system for hazard identification and risk management was answered in the affirmative by the auditor. The exact same question was part of the audits of the ACM and CMM.
- The question as to whether the operator ensures that products purchased from a contractor actually meet the requirements was answered in the affirmative by the auditor.
- The question as to whether crew members comply with the requirements of the operator's occurrence reporting system was not answered by the auditor in one audit in 2017, but was answered in the affirmative by another auditor in the same year.
- The question, with reference to rule CAT.OP.MPA.145 (a) of European Regulation 965/2012, as to whether the operator had set minimum flight altitudes for all sections to be flown, was answered by the auditor with "*n/a for Ju-Air*" (see section A1.17.6.3.2.).
- The question as to whether there is a requirement for the commander to ensure that fuel checks are carried out regularly during flight was answered in the affirmative by the auditor in each case (see section A1.17.1.14.).
- Questions with reference to rules CAT.POL.A.205, CAT.POL.A.225 and CAT.POL.A.245 were dealt with and answered by the auditor in each case, although these rules only apply to performance class A aeroplanes, not to performance class C aeroplanes.[61] Questions relating to the rules for performance

[61] Performance class A aeroplanes: multi-engined aeroplanes powered by turbo-propeller engines with an MOPSC of more than nine or a maximum take-off mass exceeding 5,700 kg, and all multi-engined turbo-jet powered aeroplanes; performance class C aeroplanes: aeroplanes powered by reciprocating engines with an MOPSC of

class C were not part of an audit record (see sections A1.17.1.15 and A1.17.6.3.2.).

- The question with reference to rule CAT.POL.MAB.105 (a) of European Regulation 965/2012, as to whether information on mass and balance is available in flight planning documents and systems for determining mass and balance, was answered in the affirmative by the auditor in each case.
- The question as to whether an OFP is prepared for each flight, taking into account the flight performance and based on other requirements, was answered in the affirmative by the auditor in each case (see section A1.17.1.5).
- The question as to whether the operator employs somebody to monitor compliance with the legal standards and the self-imposed processes was answered in the affirmative by the auditor.

These audits were also scheduled to be carried out for 2018. They took place after the accident on 4 August 2018.

A1.17.1.21 Empty weight in planning documents for previous flights

A1.17.1.21.1 Background

As described in section A1.17.1.6, annexes A1.1 and A1.6, the flight planning documents for the accident flight and the outward flight contained inconsistencies in the calculation of the aircraft's mass and balance. Specifically, the operational flight plans (OFPs) for these two flights included, amongst other things, incorrect entries for the aircraft's empty mass and the associated arm, i.e. they did not match the latest values from the "*basic weight and balance record*". In order to determine the origin of these errors and possibly the logic behind them, a sample of 49 additional OFPs from 2018 was assessed with regard to the entry for the empty mass and the associated arm. Nine of these 49 OFPs concerned flights that took place after 4 August 2018. The sample included OFPs for all of the active aircraft in Ju-Air's Ju 52 fleet (HB-HOT, HP-HOP and HP-HOS) and completed by various flight crews; other OFPs filled out by the pilots of the accident flight were also part of the sample. In addition, the following operational flight plans from previous years were also reviewed:

- Two OFPs from 2011;
- Five OFPs from 2014;
- Two OFPs from 2015;
- Four OFPs from 2016;
- Two OFPs from 2017.

Thus, excluding HB-HOT's flights on 3 and 4 August 2018, a total of 64 OFPs were inspected.

The two OFPs from 2011 had been subject to a ramp inspection by FOCA. One of the OFPs from 2014 had also been subject to a FOCA ramp inspection. The other four OFPs from 2014 are for flights that took place as part of the 2014 Ticino adventure tour. The two OFPs from 2015 are for flights that took place as part of the 2015 Ticino adventure tour. One of the OFPs from 2016 had been subject to a FOCA ramp inspection, another had been subject to a FOCA flight inspection, and the two remaining OFPs from 2016 are for flights from the 2016 Ticino adventure

more than nine or a maximum take-off mass exceeding 5,700 kg; Ju-Air's Ju 52/3m fulfilled the criteria for performance class C.

tour. The two OFPs from 2017 are for flights that took place as part of the 2017 Ticino adventure tour. Five of the nine OFPs from after 4 August 2018 had been subject to FOCA ramp inspections (see section A1.17.7.4.7) or to ramp inspections by the German Federal Aviation Authority.

A1.17.1.21.2 Results

All 64 OFPs reviewed had incorrect entries for the empty aircraft mass or the associated arm. This includes ten OFPs that had been subject to an inspection by the Swiss or German supervisory authorities.

In detail:

- Out of the nine OFPs reviewed from flights after 4 August 2018, five OFPs had incorrect entries for the empty mass and the associated arm. One of these five OFPs had been subject to a ramp inspection by the German Federal Aviation Authority. The remaining four OFPs from flights after 4 August 2018 were incorrect regarding the empty mass-related arm. These four OFPs had been subject to a ramp inspection by FOCA. 'Mass and balance calculation' was a check item in each of the ramp inspections conducted by the German Federal Aviation Authority and FOCA.
- All 40 OFPs reviewed from flights between 1 January 2018 and 4 August 2018 and the eight examined OFPs from 2015, 2016 and 2017 had incorrect entries for the empty mass and the associated arm. Two of the OFPs from 2016 had been the subject of inspections by FOCA (see section A1.17.1.21.1).
- All five OFPs reviewed from 2014 were incorrect in terms of the empty mass-related arm. One of these OFPs had been subject to a FOCA inspection.
- The two OFPs reviewed from 2011 had incorrect entries for the empty mass. These two OFPs had been the subject of an inspection by FOCA.

It was noticed that most – but not all – of the incorrectly entered values corresponded to values from previous weight sheets. In some cases, the values for empty mass and arm corresponded to various previous weight sheets. Some of the values entered were identical to values from weight checks carried out in the 1990s. In particular, the OFPs reviewed were equally deficient, irrespective of the aircraft and flight crew.

In addition, similar shortcomings (obviously incorrect values, lack of measurement units) were found in the weight sheets for HB-HOP and HB-HOS, as those already noted in relation to the weight sheet for HB-HOT (see annex A1.6).

A1.17.1.22 Consideration of luggage for the planning of previous flights

A1.17.1.22.1 Background

As already described in annex A1.6, the flight planning documents for the outward flight and accident flight contained inconsistencies in the calculation of the aircraft's mass and balance. Specifically, the operational flight plans (OFPs) for these two flights did not take into account, among other things, the luggage of passengers and crew, specifically that of the ISP, when calculating mass and balance. In order to determine whether this failure to take the luggage into account was an isolated case or a deeper systemic problem at Ju-Air, the OFPs for the following flights were reviewed:

- Locarno adventure tours, 2013 to 2017;
- Bolzano adventure tours, 2013 to 2018.

On these trips, passengers and crew members are likely to have carried as much luggage as on the adventure tour to Locarno in 2018. Sixteen different Ju-Air pilots were involved in the 11 flights reviewed, including several Ju-Air senior managers or pilots from Ju-Air's management team.

A1.17.1.22.2 Results

In all of the OFPs reviewed in this respect, the luggage of passengers and crew had not been included in the calculation of mass and balance.

It was also noticeable that, on the outward flight of the 2015 Locarno adventure tour, which according to the OFP had 17 passengers on board, the mass of the passengers had been included in the calculation of the flight mass but not in the balance calculation because of unfinished handwritten corrections.

During the investigation, Ju-Air stated that, "*with regard to the luggage of passengers and crew, there had been a tendency among Ju-Air pilots for some time, i.e. for several years, not to include the mass of this luggage in the calculation of mass and balance*." The reason for this was assumed to be that "*the Ju-Air pilots find the Ju 52/3m aircraft type to be extremely tested, robust and tolerant. The general opinion was therefore that passenger and crew luggage could be neglected when calculating the mass and balance*."

A1.17.1.23 Required take-off run available for previous flights

A1.17.1.23.1 Background

As described in section A1.17.1.15, the accident flight took off from a runway with a take-off run available (TORA) of 670 m. In order to achieve the desired level of safety in accordance with European Regulation 965/2012, the take-off run available should have been at least 875 m. In order to determine whether this failure to comply with the regulations was an isolated case or a deeper, systemic problem at Ju-Air, the respective minimum take-off run required for the return flights of the Locarno adventure tours from 2013 to 2017 was calculated. In particular, the take-off mass and the departure time according to the respective OFP as well as the prevailing external temperature according to archived aerodrome weather reports were included in the calculations. For the comparison with the actual TORA, the wind direction recorded in the archived aerodrome weather reports was used. Eight different Ju-Air pilots were involved in the five flights reviewed, including several Ju-Air senior managers or pilots from Ju-Air's management team.

A1.17.1.23.2 Results

For all five flights reviewed in this respect, the take-off run available (TORA) should have been more than 900 m due to the aircraft's take-off mass and external temperature. The extreme case was in 2013, when the required TORA should have been at least 990 m due to the aircraft's high take-off mass (9,912 kg) and an external temperature of 31 °C. Due to the direction of the wind, four of the five flights are likely to have taken off from runway 26R featuring a TORA of 670 m, and the remaining flight (2016) from runway 08L featuring a TORA of 750 m.

A1.17.2 Continuing airworthiness management organisation

A1.17.2.1 Legal basis

Annex I (part M) of European Regulation 1321/2014 and section A, subpart G, thereof regulates the continuing airworthiness management organisation (CAMO). M.A.708 of this regulation, 'continuing airworthiness management', lists the essential tasks of the CAMO as follows:

"[…]

(b) For every aircraft managed, the approved continuing airworthiness management organisation shall:

1. *Develop and control a maintenance programme for the aircraft managed including any applicable reliability programme,*
2. *Present the aircraft maintenance programme and its amendments to the competent authority for approval*, […]
3. *Manage the approval of modification and repairs,*
4. *Ensure that all maintenance is carried out in accordance with the approved maintenance programme and released in accordance with Section A, Subpart H of this Annex (Part-M),*
5. *Ensure that all applicable airworthiness directives and operational directives with a continuing airworthiness impact, are applied,*
6. *Ensure that all defects discovered during scheduled maintenance or reported are corrected by an appropriately approved maintenance organisation,*
7. *Ensure that the aircraft is taken to an appropriately approved maintenance organisation whenever necessary,*
8. *Coordinate scheduled maintenance, the application of airworthiness directives, the replacement of service life-limited parts, and component inspection to ensure the work is carried out properly,*
9. *Manage and archive all continuing airworthiness records and/or operator's technical log.*
10. *Ensure that the mass and balance statement reflects the current status of the aircraft.*"

CAMO approval is shown on the approval certificate issued by FOCA and, in the case of commercial transport, is part of the air operator certificate (AOC) issued by FOCA for the aircraft operated.

The accountable manager (ACM) of the air operator nominates a qualified person as the nominated person continuing airworthiness (NPCA) for the air operator's CAMO and applies to the competent authority for approval of this person.

Subsequently, the ACM instructs the NPCA to prepare a continuing airworthiness management exposition (CAME). The ACM then checks the CAME and obtains approval from the competent authority. The CAME must essentially contain or present the following points:

- A declaration signed by the air operator's ACM confirming that the organisation always carries out its work in accordance with annex I (part M) of European Regulation 1321/2014 and the exposition;
- The scope of work of the organisation;
- An organisational chart showing the links between the areas of responsibility of the persons concerned;
- Procedures that prescribe how the continuing airworthiness management organisation ensures compliance with the provisions of annex I (part M) of European Regulation 1321/2014;
- The list of approved aircraft maintenance programmes.

Based on European Regulation 1321/2014, in the case of commercial transport, and if the operator is not duly approved according to part 145, the operator must enter into a written maintenance contract with a part-145-approved maintenance organisation.

A1.17.2.2 Ju-Air CAMO

Ju-Air was first issued an approval certificate as a CAMO on 1 January 2007 and the most recent prior to the accident was issued on 12 June 2012. This approval was included in Ju-Air's AOC operations specifications (see section A1.17.1.1).

The senior staff of the CAMO consisted of the same persons who already formed the senior staff of the Ju-Air maintenance organisation and Naef Flugmotoren AG (see tables 3 and 5).

Ju-Air CAMO
NPCA: person **B**
Deputy NPCA: person **C**
Compliance monitoring manager (CMM): person **D**

Table 3: Management roles within the Ju-Air CAMO and staffing of these roles in accordance with Ju-Air's CAME.

Section 0.3.6 of the CAME states that, in the event that more human resources were required for the work of the CAMO, the volunteers for aircraft maintenance, aircraft preparation and restoration (see sections A1.17.1.3 and A1.17.4.8) could be called upon.

Table 4 lists the proportions of employment for the respective roles within the CAMO and the date when the role was taken on. This is based on information provided by Ju-Air.

Person	Role	Employment	Since
B	NPCA	100 %	12/06/2018
C	Deputy NPCA	30 %	12/06/2018
D	CMM	20 %	10/12/2012

Table 4: Employment and dates when the respective roles were taken on at the CAMO.

In the CAMO, it was noticeable that, since 2005, there has been a high turnover in the NPCA and deputy NPCA roles. In the past 13 years or so, there have been four changes in the role of NPCA, with one person performing this role twice at different times. There were five changes in the role of deputy NPCA. Three people held this position for less than a year each.

Ju-Air's continued airworthiness management activities were barely evident. In particular, the files only contained a few job orders issued by the CAMO addressed to the maintenance organisations.

A1.17.2.3 Evaluation

As a CAMO, Ju-Air was responsible for managing its aircraft's continued airworthiness. Ju-Air's continued airworthiness management activities relating to the maintenance of its Ju 52 aircraft were barely evident. It was therefore unable to fulfil its quality assurance role as intended. If nothing else, this is due to the problem of the CAMO consisting of staff from the two maintenance organisations, which meant that the intended control mechanisms could not be effective. This deficit was not recognised by FOCA.

A1.17.3 Maintenance organisations

A1.17.3.1 General

Maintenance organisations granted approval in line with annex II (part 145) of European Regulation 1321/2014 are permitted to maintain aeronautical products, components or appliances in accordance with approved documentation. The organisation and procedures of a maintenance organisation are to be defined in its maintenance organisation exposition (MOE) and are binding.

The Federal Office of Civil Aviation grants maintenance-organisation approval to the respective organisations, provided that the legal requirements are met. Maintenance organisations are regularly inspected by FOCA. Their approval (as a maintenance organisation) is granted indefinitely. The organisations are obliged to notify FOCA immediately of any changes that may have an influence on their approval. FOCA then lays down conditions or restrictions for continued operation, taking into account the circumstances of each case.

Maintenance of Ju-Air's Ju 52/3m aircraft was carried out by the company's own maintenance organisation. Repairs to and major overhauls of the engines and their components were carried out by Naef Flugmotoren AG, which was a tenant of the Ju-Air premises at Dübendorf Air Base.

The two maintenance organisations Ju-Air and Naef Flugmotoren AG have each employed one or two certifying staff over the years.

A1.17.3.2 Maintenance organisation exposition (MOE)

A1.17.3.2.1 General

Ju-Air and Naef Flugmotoren AG were maintenance organisations according to annex II (part 145) of European Regulation 1321/2014. Both companies had to write a maintenance organisation exposition (MOE) each and have it approved by FOCA. The expositions of the two companies were very similar in content, and in some parts the same.

The content of both expositions had obviously been taken from existing MOEs, which had been adjusted for the maintenance of aircraft with a TC holder. The MOEs of Ju-Air und Naef Flugmotoren AG were partially adapted to suit the needs of Ju 52 aircraft maintenance. Here, too little attention had been paid to the fact that the Ju 52 was a historic aircraft and had no TC holder.

A1.17.3.2.2 Senior management

A total of six persons performed the management roles within the two maintenance organisations (see table 5).

Ju-Air maintenance organisation	Naef Flugmotoren AG
Accountable manager (ACM): person **A**	Accountable manager (ACM): person **F**
Deputy ACM: person **B**	Deputy ACM: person **A**
Operations manager: person **B***	Technical manager: person **B***
Deputy operations manager: person **C**	Deputy technical manager: person **C**
Aircraft maintenance manager: person **B**	Aircraft maintenance manager: person **C**
–	Deputy aircraft maintenance manager: person **B**
Workshop manager: person **B**	–
–	Safety manager (SM): person **D***
Compliance monitoring manager (CMM): person **D***	Compliance monitoring manager (CMM): person **D***
Auditor: person **E***	Auditor: person **E***

Table 5: Management roles within maintenance organisations Ju-Air and Naef Flugmotoren AG as well as staffing of these roles according to the companies' MOEs.

Upon request, FOCA approved the appointment of the designated persons marked with an asterisk (*) in table 5 to their respective roles. A FOCA assessment had to be successfully completed in order to approve a person's appointment as the operations manager of the Ju-Air maintenance organisation or as the technical manager of Naef Flugmotoren AG. For the other roles, however, no such assessment was required.

The following is a list of the proportions of employment for the respective roles and the date when the role was taken on at the two maintenance organisations (see tables 6 and 7). This is based on information provided by the two companies.

Ju-Air maintenance organisation			
Person	**Role**	**Employment**	**Since**
A	Accountable manager (ACM)	No info.	No info.
B	Deputy ACM	No info.	12/06/2018
B	Operations manager	100 %	12/06/2018
B	Aircraft maintenance manager	100 %	12/06/2018
B	Workshop manager	100 %	12/06/2018
C	Deputy operations manager	40 %	12/06/2018
D	Compliance monitoring manager (CMM)	20 %	25/08/2011
E	Auditor	20 %	29/06/2011

Table 6: Proportion of employment for the respective roles within the Ju-Air maintenance organisation and the date when the role was taken on.

Naef Flugmotoren AG			
Person	**Role**	**Employment**	**Since**
F	Accountable manager (ACM)	No info.	No info.
A	Deputy ACM	No info.	No info.
B	Technical manager	100 %	14/06/2018
B	Deputy aircraft maintenance manager	50 %	14/06/2018
C	Deputy technical manager	50 %	14/06/2018
C	Aircraft maintenance manager	100 %	23/02/2017
D	Compliance monitoring manager (CMM)	25 %	12/12/2011
D	Safety manager (SM)	25 %	01/05/2018
E	Auditor	25 %	12/12/2011

Table 7: Proportion of employment for the respective roles at Naef Flugmotoren AG and date when the role was taken on.

Both maintenance organisations showed a high level of fluctuation in the respective roles since 2005. Sometimes a role was only performed by the same person for a few months. This meant that the continuity of management tasks and thus of quality assurance was not guaranteed.

A1.17.3.2.3 Repairs

Repairs are defined as the rectification of damage to an aircraft or the restoration of its airworthiness. When components or parts of equipment are replaced without the need for design or construction work, such repair work may be carried out by the maintenance organisation.

In section 2.9 of Ju-Air's MOE, the procedures for repair work were described as follows:

"*The operations manager is responsible for ensuring that all repair work is carried out as per the applicable procedures stipulated by the authorities and the requirements laid out by the manufacturers of the aircraft or component concerned. Otherwise, the standard procedures and codes of practice used in aviation apply.*

If the organisation is unable to carry out a repair itself, it will award a contract to an organisation approved for this purpose with a clear indication of the applicable regulations.

If the organisation needs to manufacture spare parts for a repair itself, these must fully comply with the applicable airworthiness requirements. The manufacture of such parts and their conformity must be fully documented in each individual case. The competent authority must be informed using a notice of modification.

The operations manager is responsible for ensuring that the rating contained in the organisation's Part-145 approval is not exceeded.

All repairs must be documented and listed separately in work reports."

The content of section 2.9 of Naef Flugmotoren AG's MOE was the same.

A1.17.3.2.4 Storage and tagging of components

The storage and tagging of all components are clearly laid out in the companies' MOEs. Components must be made identifiable at all times using a serviceable or unserviceable tag, or a release-to-service certificate[62].

During FOCA audits of the two maintenance organisations over the past years, findings were made regarding the storage and tagging of components (see section A1.17.7.3).

The STSB also discovered after the accident that, at Ju-Air, the components stored in the hangar were neither marked with a tag nor with a release certificate for identification. Furthermore, the spare parts warehouse did not have identification papers for all components. In Naef Flugmotoren AG's engine workshop, there were engine components which were also unidentifiable (see figure 2).

Figure 2: Unidentifiable engine components stored in a cabinet.

On the issue of components, section 2.3 of the Ju-Air MOE states the following:

"*2.3 Storage and tagging of aircraft components and materials and procedures for dispensing them to personnel*

The operations manager shall ensure that the following conditions regarding the correct storage of aircraft components are met:

[…]

- *Clear tagging of parts as stock items if they have to be stored outside the actual warehouse, with the above conditions also applying for such parts.*

[…]

The operations manager shall ensure that non-airworthy parts are stored in a separate warehouse and that stock items that need to be periodically inspected are recorded in the inventory accordingly. Such parts may only be dispensed by the warehouse for repair, overhaul or inspection/calibration if a corresponding order has been placed for this work."

The content of the relevant section of Naef Flugmotoren AG's MOE was the same.

62 An authorised release certificate (EASA form 1) for a product, part or component shows that this product, part or component was manufactured, repaired or refurbished in accordance with the approved design data and declared airworthy.

A1.17.3.3 Evaluation

A1.17.3.3.1 General

Both Ju-Air and Naef Flugmotoren AG were FOCA-approved maintenance organisations for the continuing airworthiness of Ju 52 aircraft according to annex II (part 145) of European Regulation 1321/2014.

During this safety investigation, both maintenance organisations were found to have some major deficits, such as in the following areas:

- Record keeping (see annex A1.6)
- Adherence to the manufacturer's documentation (see annex A1.6)
- Repairs (see annex A1.6)
- Storage of components (see section A1.17.3.2.4)
- Procurement of spare parts (see annex A1.6)

Maintenance organisations have to apply the currently applicable maintenance documents when performing a task. Interviews with the aircraft mechanics from the two maintenance organisations revealed that, although the manufacturers' documents for the aircraft and engines were available, the aircraft mechanics had little knowledge of their content. This is unusual for people who have been working with aircraft of this type or with components for this aircraft type on a daily basis for several years. This gives the impression that the manufacturers' instructions have been used relatively infrequently during maintenance work.

A1.17.3.3.2 Maintenance organisation exposition

The maintenance company's organisation and procedures are defined in the maintenance organisation exposition (MOE) and are binding whenever work is carried out under the terms of the approval according to annex II (part 145) of European Regulation 1321/2014. The MOE of each of the two maintenance organisations was checked and approved by FOCA.

The MOEs of both maintenance organisations were very extensive and had largely the same content. With regards to the procurement of spare parts and the refurbishment of components, the issues in terms of the Ju 52 aircraft's continued airworthiness had been partially identified and were evident in the companies' MOEs. However, the procedures relating to this were insufficiently described.

During the safety investigation, it became apparent that work had not been carried out as specified in the companies' MOEs.

A1.17.3.3.3 Storage of components

On the premises of Ju-Air and Naef Flugmotoren AG, there were various components which could not be identified. The specifications defined in the MOEs of the two companies regarding the storage and tagging of components were apparently not followed (see section A1.17.3.2.4).

These deficits were identified by the STSB during several visits to the two maintenance organisations as part of the safety investigation. Inspections prior to the accident carried out by FOCA over the past few years also identified and complained some shortcomings. However, the companies did not remedy the majority of these deficits, leading FOCA to again demand an improvement during the subsequent inspection. However, these shortcomings had still not been rectified by the time of the accident.

A1.17.4 Staff of the maintenance organisations

A1.17.4.1 Legal basis

Annex III (part 66) of European Regulation 1321/2014 defines the provisions for the continuing airworthiness of aircraft and aeronautical products as well as parts and equipment, and for the approval of organisations and personnel involved in these activities. This regulation was valid at the time of the accident. Section A, subpart A, defines the aircraft maintenance licence and establishes the requirements for application, issuing and the continuation of its validity. In this respect, definitions cited include the following:

"*66.A.3 Licence categories*

(a) Aircraft maintenance licences include the following categories:

- Category A

- Category B1

- Category B2

- Category B3

- Category C

(b) Categories A and B1 are subdivided into subcategories relative to combinations of aeroplanes, helicopters, turbine and piston engines. These subcategories are:

- A1 and B1.1 Aeroplanes Turbine

- A2 and B1.2 Aeroplanes Piston

- A3 and B1.3 Helicopters Turbine

- A4 and B1.4 Helicopters Piston"

"66.A.10 Application

[...]

(f) Each application shall be supported by documentation to demonstrate compliance with the applicable theoretical knowledge, practical training and experience requirements at the time of application."

"66.A.20 Privileges

(a) The following privileges shall apply:

[...]

2. A category B1 aircraft maintenance licence shall permit the holder to issue certificates of release to service and to act as B1 support staff following:

- maintenance performed on aircraft structure, powerplant and mechanical and electrical systems,

- work on avionic systems requiring only simple tests to prove their serviceability and not requiring troubleshooting.

[…]

5. A category C aircraft maintenance licence shall permit the holder to issue certificates of release to service following base maintenance on aircraft. The privileges apply to the aircraft in its entirety."

As some Ju-Air and Naef Flugmotoren AG staff had acquired an aircraft maintenance licence before European Regulation 1321/2014 came into force, excerpts of the then valid annex III (part 66) of European Regulation 2042/2003 are quoted below:

"*66.A.30 Experience requirements*

(a) An applicant for an aircraft maintenance licence shall have acquired:

1. For category A and subcategories B1.2 and B1.4:

(i) Three years of practical maintenance experience on operating aircraft, if the applicant has no previous relevant technical training; or

(ii) Two years of practical maintenance experience on operating aircraft and completion of training considered relevant by the competent authority as a skilled worker, in a technical trade; or

(iii) One year of practical maintenance experience on operating aircraft and completion of a Part-147 approved basic training course.

[…]

3. For category C with respect to large aircraft:

[…]

(ii) Five years of experience exercising category B1.2 or B1.4 privileges on large aircraft or as Part-145 B1.2 or B1.4 support staff, or a combination of both; or

[…]

5. For category C obtained through the academic route:

An applicant holding an academic degree in a technical discipline, from a university or other higher educational institution recognised by the competent authority, three years of experience working in a civil aircraft maintenance environment on a representative selection of tasks directly associated with aircraft maintenance including six months of observation of base maintenance tasks.

[…]

(c) For category A, B1 and B2, the experience must be practical which means being involved with a representative cross section of maintenance tasks on aircraft.

[…]

(e) Notwithstanding paragraph (a), aircraft maintenance experience gained outside a civil aircraft maintenance environment shall be accepted when such maintenance is equivalent to that required by this part as established by the competent authority. Additional experience of civil aircraft maintenance shall, however, be required to ensure understanding of the civil aircraft maintenance environment."

"66.A.45 Type/task training and ratings

[…]

(e) Category C approved type training shall comply with Appendix III to this part. In the case of a category C person qualified by holding an academic degree as specified in 66.A.30(a), (5), the first relevant aircraft type theoretical training shall be at the category B1 or B2 level. Practical training is not required.

[…]

(h) Notwithstanding paragraph (c), ratings on aircraft other than large aircraft may also be granted, subject to satisfactory completion of the relevant category B1, B2 or C aircraft type examination and demonstration of practical experience on the aircraft type, unless the Agency has determined that the aircraft is complex, where paragraph 3 approved type training is required.

In the case of a category C ratings on aircraft other than large aircraft, for a person qualified by holding an academic degree as specified in 66.A.30 (a), (5), the first relevant aircraft type examination shall be at the category B1 or B2 level.

[…]"

In areas that are exempt from European regulations or have not yet been regulated by the EU, national licences exist, e.g. for the maintenance of components. These are based on the ordinance on aircraft maintenance personnel (VLIp; SR 748.127.2).

In guideline TM 90.001-10, the entries in licences for aircraft maintenance personnel were described. This TM applied to entries in licences according to part 66 of a European regulation under national privileges and national licences for the aircraft mechanic (category M) and technical specialist (category S) categories.

A1.17.4.2 Person A

Information on person A can be found in section A1.17.1.4.2.

A1.17.4.3 Person B

After completing a technical apprenticeship, person B worked for a major Swiss maintenance organisation in the 'base maintenance' department where they were trained as an aircraft mechanic. On 13 April 2012, they received a licence for the A1/B1.1 subcategory according to annex III (part 66) of European Regulation 2042/2003.

From January 2013 to December 2017, person B worked for three different maintenance organisations and attended various courses for obtaining type certificates.

On 4 November 2016, person B received the category C licence extension upon application to FOCA.

From 18 January 2018, person B was employed by Ju-Air and Naef Flugmotoren AG on a full-time basis.

From 15 January to 25 July 2018, person B was trained on the type Ju 52/3m g4e aircraft by persons E and H.

On 23 May 2018, person B was approved by FOCA to act as the NPCA of the Ju-Air CAMO. On 25 May 2018, they were approved for the role of operations manager in the Ju-Air maintenance organisation and for the role of technical manager at Naef Flugmotoren AG.

On 27 July 2018, person B was issued with a subcategory A2/B.1.2 licence and the Ju 52/3m and CASA 352/A3 type rating.

Below is a list of person B's senior roles. This is based on information provided by Ju-Air.

Ju-Air CAMO		
Role	**From**	**To**
Deputy NPCA	02/02/2018	12/06/2018
NPCA	12/06/2018	*
Ju-Air maintenance organisation		
Role	**From**	**To**
Deputy accountable manager (deputy ACM)	01/02/2018	12/06/2018
Operations manager	12/06/2018	*
Deputy ACM	12/06/2018	*
Aircraft maintenance manager	12/06/2018	*
Workshop manager	12/06/2018	*
Naef Flugmotoren AG		
Role	**From**	**To**
Technical manager	14/06/2018	*
Deputy aircraft maintenance manager	14/06/2018	*

Table 8: Person B's senior management roles; an asterisk (*) indicates that this role was held beyond 4 August 2018.

A1.17.4.4 Person D

Information on person D can be found in section A1.17.1.4.6.

A1.17.4.5 Person E

From 1960 to 1974, Person E worked for in a major airline as a mechanic and metal worker in aircraft maintenance and overhaul. They were subsequently self-employed in the non-aviation sector for nine years.

In 1983, person E was hired by Ju-Air as operations manager and trained by mechanics from BAMF[63] on the Ju 52/3m g4e type.

In March 1984, upon application to FOCA, person E obtained the national licence as aircraft mechanic category M with the Ju 52/3m type rating. In 1989, they obtained the national category C licence extension upon application to FOCA.

On 30 September 2004, person E retired, but continued to work as an aircraft mechanic at Ju-Air and Naef Flugmotoren AG on a casual basis with an irregular proportion of employment of 20 to 40 %. During this period, person E performed various roles at both maintenance organisations.

At the beginning of November 2004, an application was submitted to FOCA for the conversion of the national licence for categories M and C into a licence according to JAR (part 66), subcategories A2/B1.2 and C, with the Ju 52/3m type rating. In 2007, the licence according to JAR (part 66) was converted into a licence according to annex III (part 66) of European Regulation 2042/2003.

On 29 June 2011, person E was approved by FOCA for the role of auditor at Ju-Air.

[63] BAMF: Federal Office for Military Airfields, which carried out maintenance on the Ju 52/3m g4e during its time in military service.

On 12 December 2011, person E was approved by FOCA for the role of auditor at Naef Flugmotoren AG. Since then, their responsibility has included auditing the subcontractors.

Person E's licence was last renewed on 29 April 2014.

Below is a list of person E's senior roles. This is based on information provided by Ju-Air.

Ju-Air CAMO		
Role	**From**	**To**
NPCA	01/01/2007	10/07/2012
NPCA	15/12/2017	12/06/2018
Ju-Air maintenance organisation		
Role	**From**	**To**
Compliance monitoring manager (CMM)	04/01/2005	13/02/2006
Compliance monitoring manager (CMM)	27/11/2007	24/08/2011
Auditor	29/06/2011	*
Operations manager	06/01/2004	03/01/2005
Operations manager	29/11/2017	14/06/2018
Deputy operations manager	01/12/2006	01/07/2011
Aircraft maintenance manager	29/11/2017	12/06/2018
Workshop manager	29/11/2017	12/06/2018
Naef Flugmotoren AG		
Role	**From**	**To**
Compliance monitoring manager (CMM)	27/05/2005	*
Auditor	12/12/2011	*
Technical manager	08/12/2017	14/06/2018
Deputy aircraft maintenance manager	08/12/2017	14/06/2018

Table 9: Person E's senior management roles; an asterisk (*) indicates that this role was held beyond 4 August 2018.

A1.17.4.6 Person G

The following information on the training history of person G is based on the curriculum vitae they submitted to FOCA as proof of their practical work in aircraft maintenance. This CV only includes years, but no more precise dates.

After completing a technical apprenticeship with a vocational diploma, person G finished the military recruit school (RS) as a helicopter technical assistant. In this role, they carried out preparation work on helicopters.

Subsequently, person G served their national service as a corporal in the 'Air Force RS' in a single period and was then assigned the rank of sergeant. During this time, person G worked as a helicopter technical assistant on the Alouette III, Super Puma and Cougar helicopter types.

After their national service, person G worked on the system integration production line for an aircraft manufacturer for 15 months.

From 2006 to 2009, person G studied aviation at Zurich University of Applied Sciences (ZHAW), specialising in Technics & Engineering. Person G graduated as a 'Bachelor of Science ZFH' in Aviation.

From 1 January 2010, person G worked for Ju-Air in base maintenance. In April 2010, person G completed a two-day in-house theoretical foundation course on the type Ju 52/3m g4e / CASA 352 aircraft taught by person E and underwent practical training on these aircraft from June 2010 to May 2012.

On 2 February 2011, person G applied to FOCA for a category C aircraft maintenance licence (see section A1.17.4.1). This was issued to them on 29 March 2011.

On 3 May 2011, person G applied for a subcategory A2/B1.2 licence. FOCA found that they did not have the required two years of practical experience. In the end, the licence was issued on 6 June 2012.

On 27 July 2011, person G was approved by FOCA for the role of operations manager in the Ju-Air maintenance organisation. Person G was then also responsible for working on the Ju-Air 'Ageing Aircraft Programme' initiated by FOCA (see annex A1.6). This was later followed by approvals from FOCA for the roles of technical manager at Naef Flugmotoren AG and as the NPCA of Ju-Air.

On 30 May 2017, their licence was renewed upon application to FOCA.

At the end of December 2017, person G resigned from Ju-Air and Naef Flugmotoren AG, and handed over all their roles at Ju-Air and Naef Flugmotoren AG to their successors.

In early 2018, person G returned to Naef Flugmotoren AG where they worked in a non-managerial position in the engine workshop until the accident involving HB-HOT on 4 August 2018.

Below is a list of person G's senior management roles. This is based on information provided by Ju-Air.

Ju-Air CAMO		
Role	**From**	**To**
NPCA	10/07/2012	15/12/2017
Ju-Air maintenance organisation		
Role	**From**	**To**
Operations manager	01/07/2011	29/11/2017
Aircraft maintenance manager	01/07/2011	29/11/2017
Workshop manager	01/07/2011	29/11/2017
Naef Flugmotoren AG		
Role	**From**	**To**
Technical manager	12/12/2011	08/12/2017
Deputy aircraft maintenance manager	23/03/2017	08/12/2017

Table 10: Person G's senior management roles.

A1.17.4.7 Person H

Since 1973, person H carried out major overhauls on aircraft engines at Naef Flugmechanik AG in Fischenthal, including Ju 52 BMW 132 engines for the Swiss air defence corps and, from 1982 onwards, on Ju 52 engines belonging to Ju-Air.

In 1987, person H moved to the newly founded company Naef Flugmotoren AG in Dübendorf and continued their previous work on the Ju 52 engines. In 1988, upon application to FOCA, person H was issued with a national category S licence to work on piston engines and mechanical equipment.

Person H supported the test runs of completely overhauled engines, which were carried out by a company in Germany. Person H carried out the inspection and approval of these test runs and subsequently issued the certificates of release to service.

In 1995, person H was approved by FOCA for the role of technical manager at Naef Flugmotoren AG. In 2002, person H received the national licence as a category M aircraft mechanic.

On 19 May 2003, person H attended a one-day training course on human factors and Joint Aviation Authorities (JAA) rules and regulations.

In 2005, the national category M licence was converted into a licence according to JAR (part 66), subcategory A2/B1.2, with the Ju 52/3m type rating. Category S for performing work on equipment, mechanical components and piston engines of the BMW 132 type series was listed under "*National privilege*". In 2007, the JAR licence was converted into a licence according to annex III (part 66) of European Regulation 2042/2003.

In 2014, person H was granted the category C licence extension category upon application to FOCA. The STSB had no documents available to prove that person H had attended the necessary training module 10 ('Legislation') and passed the required examinations to obtain category C.

Person H retired in 2016, but continued to work part-time in a non-managerial position as an aircraft mechanic for Naef Flugmotoren AG.

Below is a list of person H's senior management roles. This is based on information provided by Ju-Air.

Naef Flugmotoren AG		
Role	**From**	**To**
Deputy technical manager	12/12/2011	20/03/2017
Deputy technical manager	08/12/2017	14/06/2018
Ju-Air maintenance organisation		
Role	**From**	**To**
Deputy operations manager	01/07/2011	16/06/2017
Deputy operations manager	29/11/2017	01/02/2018

Table 11: Person H's roles.

A1.17.4.8 Volunteers

The Ju-Air and Naef Flugmotoren AG maintenance organisations have been working with volunteers since the 1980s. These volunteers were neither employed nor paid for their work. At the time of the accident, 27 people from a wide variety of professions were available to carry out maintenance work on the aircraft or work in the engine workshop. They also prepared the aircraft for take-off and checked them over after landing. The volunteers' work assignments for the following month were planned by the operations manager of the Ju-Air maintenance organisation. During various visits to the site by the STSB, up to a dozen volunteers were encountered carrying out a wide variety of tasks. There was no evidence of direct supervision of these volunteers as defined in the MOEs of the two maintenance organisations. Due to the small number of certifying staff, it was impossible to directly supervise the many volunteers.

The Ju-Air maintenance organisation exposition (MOE) states the following regarding helpers:

"*3.8 Qualification of mechanics*

[…]

Volunteers

Voluntary helpers called in by the operations manager for certain work as required shall work exclusively under the direct supervision of the certifying staff and shall be supervised by them."

The corresponding text in the Naef Flugmotoren AG MOE is similar:

"*3.8 Qualification of mechanics*

[…]

Volunteers

The volunteer helpers, who are assigned to certain jobs by the technical manager for the BMW 132 engine revision department and by the head of aircraft maintenance [i.e. aircraft maintenance manager] *for the area of aircraft maintenance as required, work exclusively under the direct supervision of certifying staff and are supervised by them*."

A1.17.4.9 Evaluation

A1.17.4.9.1 Person B

Person B had no experience with historic aircraft and piston engines when they joined Ju-Air.

At the time of the accident, person B held a total of seven management roles at the two maintenance organisations and the Ju-Air CAMO, which, according to the number of working hours per role declared by the companies, add up to a total employment of at least 550 %. It is obvious that it was impossible for person B to fully perform the respective roles.

A1.17.4.9.2 Person E

Person E had no experience with historic aircraft and piston engines when they joined Ju-Air as their operations manager in 1983. They did not hold an aircraft mechanic licence at that time. They obtained this in March 1984 after a familiarisation training at the BAMF.

After their retirement in 2004, person E continued to work for Ju-Air part-time, corresponding to an employment of 20 to 40 %. From that date onwards, person E had various management roles in both maintenance organisations and the Ju-Air CAMO. It seems impossible to perform these roles comprehensively with such a small proportion of employment.

A1.17.4.9.3 Person G

Person G had never worked in a maintenance organisation before joining Ju-Air and had no experience in aircraft maintenance.

After about one year's practical experience in maintaining the Ju 52 aircraft, person G held four different management roles. At the same time, they were also responsible for the processing of the Ju-Air 'Ageing Aircraft Programme' initiated by FOCA. In the years that followed, person G performed additional roles. During this safety investigation, it became apparent that person G lacked the necessary expertise and experience in aircraft maintenance to perform these roles.

A1.17.4.9.4 Person H

Person H has worked for about 44 years in the maintenance and overhaul of piston engines.

Person H issued the release certificates for various remanufactured and reconditioned components for the engines. The general condition of the engines exhibited numerous deficits in terms of their maintenance, which indicate a lack of expertise or insufficient quality awareness on the part of person H.

Upon application to FOCA, person H obtained the category C licence extension without having completed the necessary theoretical training including a final examination. However, FOCA accepted the one-day course person H attended on 19 May 2003 as a substitute.

A1.17.4.9.5 Volunteers

Ju-Air and Naef Flugmotoren AG worked with volunteers from a wide variety of professions.

During visits to the two maintenance organisations' premises as part of this safety investigation, the STSB was able to establish on several occasions that up to a dozen volunteers were working on the aircraft and in the engine workshop, with only two certifying staff members present to supervise them.

Direct supervision of the volunteers by certifying staff was not possible with these staff numbers.

A1.17.4.9.6 Summary

The Ju-Air and Naef Flugmotoren AG maintenance organisations lacked experienced, competent and licenced personnel for the demanding level of maintenance work required for Ju-Air's Ju 52 aircraft and BMW 132 engines. Thus, the many faults identified on the aircraft and engines during this safety investigation are a logical consequence.

A1.17.5 Pilot A's flying club

According to the syllabus of the flying club in which pilot A was a flight instructor, at least ten landings in different configurations as well as an emergency landing exercise must be carried out as part of the difference training for the Robin DR 400/140 B (Robin DR 401-155 CDI) aircraft type before the flight instructor records the difference training as complete in the pilot's logbook.

The documents found in the wreckage of HB-HOT belonging to pilot A included a checklist for the difference training of one of his trainee pilots, where pilot A – as the flight instructor – confirmed with the date and his signature that this trainee pilot had completed the following training content on the Robin DR 400/140 B:

- Engine operation and air experience – All ground checks, air work, at least three landings. Handwritten date: 1 August 2018.
- Approach training – Traffic patterns in different configurations, emergency landing exercise, at least five landings. Handwritten date: 4 August 2018.
- Full-load flight – At least two traffic patterns with flight weight close to the maximum, at least two landings. Handwritten dates: 3 August 2018, 4 August 2018.

In addition, it was recorded on the training checklist, along with the date and signature of flight instructor, pilot A, that this trainee pilot had completed his difference training on 1 August 2018.

A1.17.6 Flight operations and flying tactics – requirements and practice at Ju-Air

A1.17.6.1 Introduction

Various legally binding rules (primarily two European regulations) as well as non-binding procedures (best practice) that have been tried and tested in aviation influence, or should influence, flying under visual flight rules in or over mountainous terrain. These binding and non-binding rules and procedures as well as their influence on Ju-Air's flight operations are shown below.

A1.17.6.2 Selecting a flight path in the mountains

A1.17.6.2.1 Binding rules on selecting a flight path in the mountains

For motor-powered aeroplanes, the free selection of flight paths in the mountains is primarily restricted by the following rules, which primarily serve to maintain safety:

- Minimum flight altitudes and minimum distances from the ground;
- Minimum achievable flight performance and thus maximum flight altitudes;
- Minimum distances from clouds;
- Minimum visibility;
- Rules regarding evasive manoeuvres when encountering oncoming aircraft close to sloping terrain.

The rules on minimum flight altitudes, minimum distances from the ground, minimum flight performance to be achieved and minimum distances from clouds are listed in sections A1.17.6.3 and A1.17.6.4. The other two limiting factors mentioned are, at the most, of secondary importance for the accident under investigation and are therefore not discussed in detail.

A1.17.6.2.2 Recommendations for selecting a flight path in the mountains

The following procedures are widely accepted as fundamental for VFR flights in the mountains (rules of good mountain flying tactics):

1. Option of a 180-degree turn – In valleys, basins or similar sections of terrain, the flight path should be selected in such a way that a 180-degree turn to reverse course can be executed at any time without encountering any problems. Consequently, flight paths in narrow valleys, where it is not possible to perform a 180-degree turn from the centre to both sides, must not be in the centre but closer to a valley flank, so that it is still possible to execute a 180-degree turn to at least one side. Here, the minimum distance to be maintained from the slope of 150 m is specified by rule SERA.5005 (see section A1.17.6.3.1). To reduce the risk of collision with an oncoming aircraft, the flight path is usually on the

right-hand side of the valley, which enables a left turn. Sections of terrain that do not allow for a safe 180-degree turn to be performed at any time should be avoided.

2. Generous distance from the ground – Due to vertical air movements, which are generally stronger in the mountains than above flat terrain, due to the ways topography affects air flow, and due to the associated effects (turbulence, lee rotors, wind shear, etc.), flying over passes and ridges at a generous distance from the ground is recommended. The desired altitude should be reached significantly before the pass, when entering the route section (see 'Principle of key points' in the following section). A minimum safety margin of 300 m (1,000 ft) above ground, which is also suggested in the official Swiss VFR-Guide and other recognised sources, is generally considered good practice. Especially in stronger winds, 600 m (2,000 ft) or more is recommended in some places. The ICAO 1:500,000 aeronautical chart of Switzerland mentions "*recommended minimum altitudes* [...] *to fly over passes*", stating that the minimum flight altitude corresponds to the elevation of the respective pass, plus the height of any obstacles on the pass, plus 300 m.
3. Lateral approach to passes and ridges – Hazards such as clouds, oncoming motor-powered aircraft, circling hang-gliders or gliders on the other side of passes or ridges can occasionally only be detected shortly before flying over the pass or ridge. In order to allow the overflight to be safely aborted for as long as possible, approaching passes and ridges laterally diagonally at approximately 45 degrees between the ridge and flight path is recommended. This enables pilots to still be able to perform a turn-around until shortly before flying over the ridge or pass, or to decide to remain on the front of the ridge or pass respectively.

On the topic of 'mountain flying', the VFR-Guide, which was published by air navigation service provider Skyguide on behalf of FOCA and was part of the Swiss Aeronautical Information Publication (AIP), states that: "[...] *Vertical air currents are much stronger in the mountains than in the lowlands. Passes should therefore be approached with a safety margin of at least 1,000 ft AGL (300 m) and from the side in a manner that allows a 180-degree turn to be executed without any risk, should the terrain behind the pass be covered in clouds. A pass should not be flown over when climbing, but whilst in horizontal flight or when descending and with sufficient airspeed so that areas of downdraught can be crossed quickly*. [...]"

A1.17.6.2.3 'Flying in the mountains' lecture by pilot A

The 'Flying in the mountains' lecture given by pilot A in his role as a flight instructor at his flying club as part of a refresher course in spring 2018 had the following aims for the participants:

- "*Recognising the dangers of flying in the mountains;*
- *Knowing the principles for correct tactical behaviour in the mountains*."

In particular, the lecture included the following content – partly supported by visuals:

- In a valley, there was "*generally right-hand traffic*". In a valley, one should fly at a sufficient altitude and offset to one side of the valley so that a 180-degree turn to reverse course was possible.

- "*Tactical approach to a mountain pass*" – Approach at 45 degrees to the pass axis with the option of a turn-around before flying over the pass, "*situation assessment with view over the pass*" before flying over, above the pass elevation, a flight altitude of at least 1,000 ft (about 300 m) above ground.
- "*Tactical overflight of a ridge*" – *"A ridge should never be flown over at 90 degrees*", but at 45 degrees to the ridge with the "*option of changing course*". When flying over the ridge, the flight altitude should be at least 1,000 ft (about 300 m) higher than the ridge.
- Distance from slope and minimum height – "*According to the law, the distance from the slope and the ground is 150 m (300 m above a populated area).* […] *Sufficient distance from the slope is crucial. 150 m or 300 m is not always enough as a safe altitude to fly into a valley.*"
- In a practical example, pilot A proposed a flight altitude of "*approx. 9,000 ft*" (approx. 2,750 m) for crossing the Julier pass (2,284 m AMSL), i.e. a ground clearance of more than 450 m at the pass.
- Flight planning and flight execution – "*Key points principle: Divide a valley into individual sections of terrain that are easy to survey.* [...] *The entire section of the valley must be visible.* [There is a key point at each transition from section to section.] *A key point must meet the following requirements:* [1.] *Sufficient free space is available to turn around at the current altitude without any problems.* [2.] *The next section of the terrain is perfectly visible.* [3.] *Flight altitude is sufficient for the entire section of terrain.* [4.] [Next] *key point is visible and identified.* [5.] *Alternative route selection is possible*." And: "*Define key points and apply them consistently*."
- 180-degree turn – "*Always fly in such a way that there is enough space for a 180-degree turn at any time. Decide to turn around in good time. If the decision to turn around is made too late, there is a risk of a stall and a tendency to climb, for speed and altitude to drop and this results in a crash.*"

A1.17.6.2.4 Selecting a flight path at Ju-Air

In most cases, at Ju-Air, selecting the flight path was the responsibility of the respective operating pilots. In particular, Ju-Air did not have any fixed sightseeing flight routes that could be booked by customers, as is often the case with tourist sightseeing flights from small Swiss airfields. Usually, Ju-Air only specified the starting point, destination and the flight duration. Whenever groups of customers requested flying over or past specific locations or areas, this was taken into account wherever possible, depending on the weather and airspace situation. For sightseeing flights from Dübendorf in good weather, a route through the foothills (pre-Alps) and Alps of Central or Eastern Switzerland was generally chosen, while a route over the Central Plateau was chosen for lower cloud cover. Frequent destinations or waypoints were Mount Rigi, Gross Mythen, Hüfifirn, Claridenfirn, Limmernsee, Martinsloch (north side) and Glärnisch.

At Ju-Air, the selection of the flight path in terms of flying tactics was entirely the responsibility of the operating pilots. Ju-Air did not give its pilots any instructions or recommendations as to selecting a flight path for specific individual valleys, passes or other sections of terrain. Ju-Air assumed that its experienced pilots did not need relevant guidance.

All Ju-Air pilots interviewed on the subject during this investigation emphasised that the option of a steep turn was very important and was to be available at all times. The pilot who had carried out sightseeing flights from Dübendorf together with pilot B on the morning of 4 August 2018 testified that pilot B had emphasised the importance of the option of a steep turn in conversation that morning.

Information regarding the selection of the route and flight path for the HB-HOT flights on 3 and 4 August 2018 can be found in section 1.1 of the main body and in annex A1.1.

Information regarding the selection of the flight path for other flights on Ju-Air Ju 52 aircraft can be found in annex A1.18.

A1.17.6.3 Selecting flight altitudes and distances from the terrain

A1.17.6.3.1 Minimum flight altitudes and minimum distances from the terrain for VFR flights

For flights operated under visual flight rules (VFR), rule SERA.5005 of the binding 'Standardised European Rules of the Air' (SERA) applies in European airspace, which includes Swiss airspace.[64] Rule SERA.5005 (f) regulates the minimum height above and lateral distance from obstacles as follows:

"*Except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown:*

(1) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300 m (1 000 ft) above the highest obstacle within a radius of 600 m from the aircraft;

(2) elsewhere than as specified in (1), at a height less than 150 m (500 ft) above the ground or water, or 150 m (500 ft) above the highest obstacle within a radius of 150 m (500 ft) from the aircraft."

In the case of the basin south-west of Piz Segnas, the values referred to in point 2 were clearly applicable at the time of the accident.

Ju-Air was of the opinion that there was no legally established minimum lateral distance from terrain and obstacles. In this respect, Ju-Air would apply "*reason and common sense*".

According to FOCA and EASA[65], the rule specified in (2) is essentially to be understood as follows: A pilot must constantly imagine a horizontal circle with a radius of at least 150 m around their aircraft. They must constantly check whether there is any obstacle in this circle – be it natural (terrain, vegetation) or man-made. If there is, the pilot's aircraft must be at least 150 m above this obstacle. Consequently, the protective space that must be kept free of obstacles at all times is a cylinder shape with a radius of 150 m, which extends vertically downwards for 150 m with the aircraft as the centre point (see figure 3).

[64] The Standardised European Rules of the Air (SERA) are governed by the Commission Implementing Regulation (EU) No 923/2012 of 26 September 2012 laying down the common rules of the air and operational provisions regarding services and procedures in air navigation and amending Implementing Regulation (EU) No 1035/2011 and Regulations (EC) No 1265/2007, (EC) No 1794/2006, (EC) No 730/2006, (EC) No 1033/2006 and (EU) No 255/2010, and in particular by its annex. The Swiss DETEC Ordinance on Traffic Regulations for Aircraft (SR 748.121.11) refers to this European regulation.

[65] EASA drafted the 'Standardised European Rules of the Air' (SERA) on the basis of the guidelines and recommendations of the 'International Civil Aviation Organisation' (ICAO) on behalf of and for the attention of the European Commission.

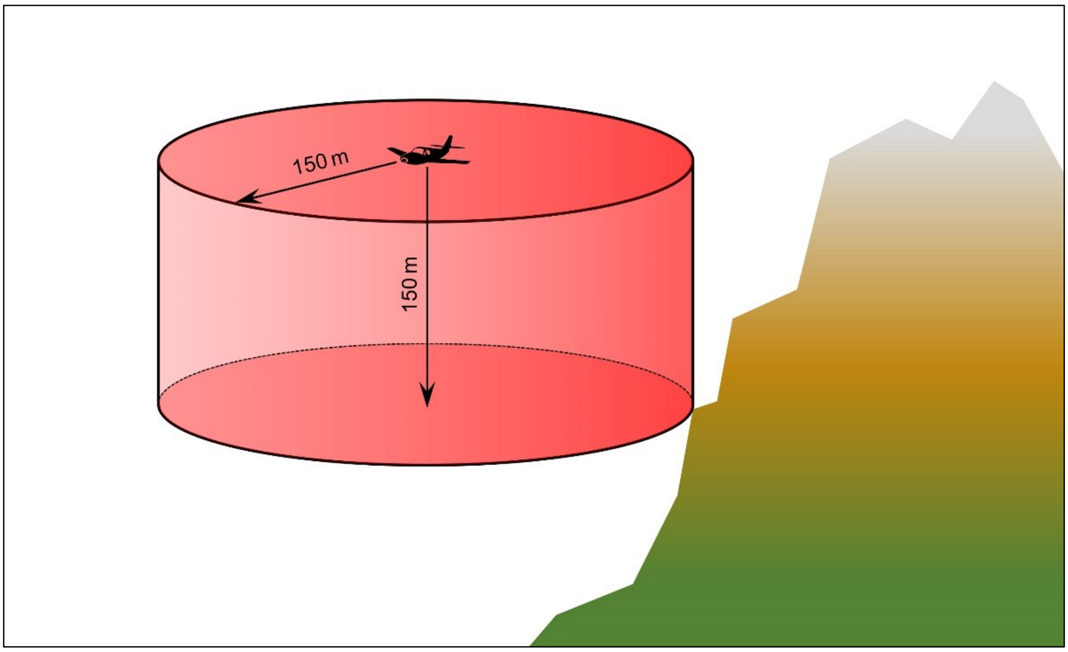

Figure 3: Visual representation of the protective space (red cylinder), which according to SERA.5005 (f) must be kept free of obstacles (shown in green/brown/grey) during cruise flight; the official Swiss VFR-Guide for 2018 contains a similar illustration.

A1.17.6.3.2 Minimum flight altitudes for commercial air transport operations

Commercial air transport operation (CAT) is subject to the binding regulations for Switzerland from annexes III (part ORO) and IV (part CAT) of European Regulation 965/2012[66]. These sections establish a number of rules concerning minimum flight altitudes for commercial air transport operations[67] .

Rule CAT.OP.MPA.135 concerning flight routes and areas of operation from European Regulation 965/2012 states that "*the operator shall ensure that operations are only conducted along routes, or within areas, for which:* [...] *the performance of the aircraft is adequate to comply with minimum flight altitude requirements*;*"*

Rule CAT.OP.MPA.145 concerning the establishment of minimum flight altitudes from European Regulation 965/2012 states the following:

"(*a) The operator shall establish for all route segments to be flown:*

(1) minimum flight altitudes that provide the required terrain clearance, taking into account the requirements of Subpart C [see below]; *and*

(2) a method for the flight crew to determine those altitudes.

(b) The method for establishing minimum flight altitudes shall be approved by the competent authority. […]"

66 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. The applicability for Switzerland results from the DETEC Ordinance on the Implementation of Flight Operations Regulations in accordance with Regulation (EU) No 965/2012 of 17 December 2013 ('*Verordnung des UVEK über die Umsetzung der Vorschriften über den Flugbetrieb nach der Verordnung (EU) Nr. 965/2012 vom 17. Dezember 2013*', SR 748.127.7). The rules of European Regulation 965/2012 are also known as 'EASA-OPS' or 'AIR OPS'.

67 European Regulation 965/2012 defines "*commercial air transport operation (CAT) operation*" as follows: "*aircraft operation to transport passengers, cargo or mail for remuneration or other valuable consideration*."

Regarding rules CAT.OP.MPA.135 and CAT.OP.MPA.145:

- According to FOCA, Ju-Air implemented rules CAT.OP.MPA.135 and CAT.OP.MPA.145 by means of the Swiss Aeronautical Information Publication (AIP) and the AFM.
- According to FOCA, Ju-Air carried these documents on the aircraft as this was stipulated in Ju-Air's OM-A.
- In reality, Ju-Air did not carry the Swiss AIP or parts thereof (VFR Manual, VFR-Guide) on board its aircraft.

Rule CAT.OP.MPA.270 concerning minimum flight altitudes from European Regulation 965/2012 states the following:

"*The commander or the pilot to whom conduct of the flight has been delegated shall not fly below specified minimum altitudes except when:*

(a) necessary for take-off and landing; or

(b) descending in accordance with procedures approved by the competent authority."

Regarding rule CAT.OP.MPA.270:

- Ju-Air had not had any descent procedures under letter (b) approved by FOCA as the competent authority.

Subpart C, to which rule CAT.OP.MPA.145 refers (see above), concerns aircraft performance and operating limitations. This subpart C includes all of the rules set out below.

Rule CAT.POL.A.100 of European Regulation 965/2012 states that aeroplanes used in commercial air transport operations "*shall be operated in accordance with the applicable performance class requirements*".

Regarding rule CAT.POL.A.100:

- FOCA and Ju-Air assumed that rule CAT.POL.A.100 was applicable to Ju-Air. Ju-Air noted in its OM-A that empirical flight performance data would be used instead of the manufacturer's data for compliance with the rules applicable to performance class C aeroplanes.

Ju-Air's Ju 52 aircraft were performance class C aeroplanes.[68] The following rules from European Regulation 965/2012 apply to performance class C aeroplanes: [69]

"*CAT.POL.A.410 En-route – all engines operating*

(a) In the meteorological conditions expected for the flight, at any point on its route [...] *the aeroplane shall be capable of a rate of climb of at least 300 ft per minute with all engines operating within the maximum continuous power conditions specified at:*

(1) the minimum altitudes [...] *specified in or calculated from the information contained in the operations manual relating to the aeroplane; and*

(*2) the minimum altitudes necessary for compliance with the conditions prescribed in CAT.POL.A.415* [...]"

[68] According to European Regulation 965/2012, performance class C aeroplanes are: "*Aeroplanes powered by reciprocating engines with an MOPSC of more than nine or a maximum take-off mass exceeding 5,700 kg.*" HB-HOT had an MOPSC (maximum operational passenger seating configuration) of 17 or 18 (see annex A1.6) and a maximum take-off mass of 10,500 kg (see annex A1.6). The fact that Ju-Air's Ju 52 aircraft are performance class C aeroplanes is also implied in various places in Ju-Air's operations manual (OM-A).

[69] Similar rules to cover single or double engine failure are known as 'drift down procedures' in classic commercial aviation, which is normally – but not exclusively – performed under instrument flight rules.

"*CAT.POL.A.415 En-route – OEI* [one-engine-inoperative]

(a) In the meteorological conditions expected for the flight, in the event of any one engine becoming inoperative at any point on its route [...] *and with the other engine(s) operating within the maximum continuous power conditions specified, the aeroplane shall be capable of continuing the flight from the cruising altitude to an aerodrome where a landing can be made* [...]. *The aeroplane shall clear obstacles within 9,3 km (5 NM) either side of the intended track by a vertical interval of at least:*

(1) 1 000 ft, when the rate of climb is zero or greater; or

(2) 2 000 ft, when the rate of climb is less than zero.

(b) The flight path shall have a positive slope at an altitude of 450 m (1 500 ft) above the aerodrome where the landing is assumed to be made after the failure of one engine.

(c) The available rate of climb of the aeroplane shall be taken to be 150 ft per minute less than the gross rate of climb specified. […]."

Regarding rules CAT.POL.A.410 and CAT.POL.A.415:

- The current AFM does not specify maximum climb rates for defined altitudes when all engines are working. Likewise, no service ceiling and no absolute ceiling are given for this case. OM-B does not contain any credible and comprehensible information on this either.[70] The AFM only implies an average climb rate of 365 ft per minute for an altitude between 2,000 and 3,000 m AMSL; Ju-Air estimates a maximum rate of climb of between 100 and 300 ft per minute at an altitude of 3,000 m AMSL in summer temperatures. Ju-Air was unable to provide corresponding evidence or measurement data.
- In relation to the accident flight involving HB-HOT on 4 August 2018, the corridor of 9.3 km on both sides of the flight path from leaving the TMA LSZL is shown in figure 4. Within this corridor, the following mountain peaks in particular are located (from south to north): Torent Alto (2,952 m AMSL), Rheinwaldhorn (3,402 m AMSL), Piz Terri (3,149 m AMSL), Bifertenstock (3,419 m AMSL), Bündner Vorab (3,028 m AMSL) and Ringelspitz (3,247 m AMSL).
- The operational inspectors responsible for Ju-Air over the past few years and also some of FOCA's senior managers were of the opinion that the rules CAT.POL.A.410 and CAT.POL.A.415 of European Regulation 965/2012 only applied to air operations under instrument flight rules (IFR) and not to operations under visual flight rules (VFR), as practised by Ju-Air. Furthermore, as argued by said persons, these rules would contradict rule SERA.5005 (f) if they were assumed to be applicable. This interpretation led the FOCA inspectors concerned to believe that – in the context of their licensing and supervisory activities concerning Ju-Air – the minimum required flight altitudes for commercial air transport operations in accordance with European Regulation 965/2012 in particular were not applicable and as a result they tolerated Ju-Air's non-compliance with these rules.
- Other FOCA officers, however, took the view that the rules CAT.POL.A.410 and CAT.POL.A.415 of European Regulation 965/2012 apply to all forms of commercial air transport (therefore also to operations under visual flight rules), but

[70] A table in section 5.2 of OM-B suggests consistent climb performance between sea level and 4,000 m AMSL, and thus contradicts the AFM data and basic laws of physics. In addition, numerous conditions for the validity of the values in the table are not explained. Ju-Air could not explain how the values in this table were arrived at. FOCA could not retrace whether, when and how it had approved this table.

that Switzerland was entitled to a certain degree of flexibility in applying these provisions. The background for this view was FOCA's assessment that the regulations applicable to commercial air transport do not adequately cover VFR operations of large and historic aircraft. Nevertheless, as stated by FOCA, their permitting derogation from these rules, "*did not sufficiently comply with the requirements"* to satisfy the European authorities *"regarding documentation and the provision of information*". The officers went on to explain that FOCA had "*failed to document the derogation in the forms provided for this purpose and to notify EASA*". With this, they mean, in particular, that FOCA did not request Ju-Air to provide evidence for an 'equivalent level of safety' and did not provide such evidence themselves. The European authorities were not advised of any intended derogation. Consequently, EASA did not assess the viability of such derogation in terms of equivalent level of safety.

- The wording of the European regulations does not indicate that rules CAT.POL.A.410 and CAT.POL.A.415 are to apply only to instrument flight. EASA takes the view that these rules are equally applicable to instrument and visual flight (see section A1.17.8).
- At the time of the accident and subsequently, Ju-Air was of the opinion that rules CAT.POL.A.410 and CAT.POL.A.415 do not apply to flights under visual flight rules, and therefore not to Ju-Air. Thus, corresponding procedures and minimum flight altitudes were not stated in the OM-A valid at the time of the accident (valid as of 1 April 2018). Section 8.1.2.4, "*Performance Considerations*", of the 1998 edition of OM-A had however stated that, "*En-route: Class C aeroplanes shall only be operated at altitudes where an all engine rate of climb of at least 300 ft per minute can be achieved. Aeroplanes shall not be operated on routes where – within 5 NM of the intended track – a vertical obstacle clearance of 1,000 ft can* [not][71] *be maintained with one engine out with the residual gross rate of climb of 150 ft per minute as per OM Part B.*" However, in OM-B of that time, there was no information on the altitude at which a rate of climb of 300 or 150 ft per minute could still be achieved. In the same year, Ju-Air declared in an official document (compliance list) that it complied with JAR-OPS 1.575 and JAR-OPS 1.580 through the quoted explanations in section 8.1.2.4 of OM-A. In 1998, these two rules presented the almost identical predecessors of CAT.POL.A.410 and CAT.POL.A.415 of European Regulation 965/2012. The declarations concerning compliance with JAR-OPS 1.575 and JAR-OPS 1.580 were then signed by the FOCA inspector responsible.

The AFM only provides the following flight performance data for a two-engine flight (i.e. one engine failure):

- Service ceiling: "*approx. 1,900*" m AMSL
- Absolute ceiling: "*approx. 2,500*" m AMSL

Rules with almost the same wording as CAT.OP.MPA.135, CAT.OP.MPA.145, CAT.OP.MPA.270, CAT.POL.A.100, CAT.POL.A.410 and CAT.POL.A.415 of European Regulation 965/2012 mentioned above had been part of preceding binding regulations (JAR-OPS, later European Regulation 3922/91[72] amended by European Regulation 859/2008[73] ['EU-OPS']) since the end of the 1990s.

[71] The word 'not' is missing in the original wording. This is an obvious error.

[72] 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.

[73] Commission Regulation (EC) No 859/2008 of 20 August 2008 amending Council Regulation (EEC) No 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane.

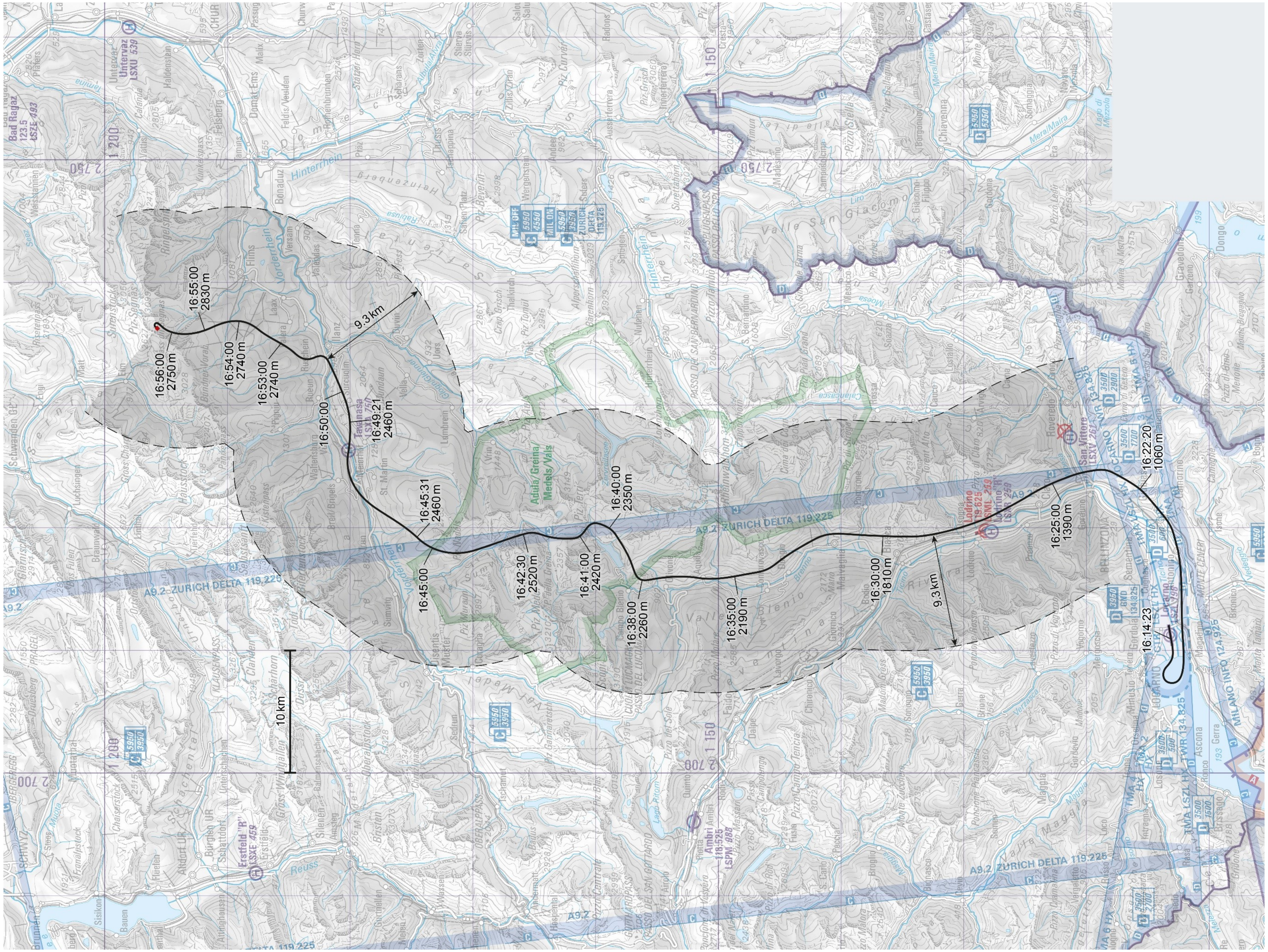

Figure 4: 9.3-km corridor on either side of HB-HOT's flight path on 4 August 2018;
all altitudes are given in altitude above mean sea level; base map: glider chart from the Swiss Federal Office of Topography; reworked

A1.17.6.3.3 Ju-Air's selection of flight altitudes and lateral separation from obstacles

Pilots from Ju-Air's management team stated that, in accordance with rule SERA.5005 (f), a minimum height of 300 m above ground was aimed for and usually adhered to for flights over towns, other densely populated areas or crowds of people, and a minimum height of 150 m for flights over other areas (sparsely populated areas, fields, forests, mountains). According to a Ju-Air Ju 52 TRI[74] and Ju 52 TRE[75] who was interviewed, ridges, on the other hand, had sometimes been flown over at a height of only approximately 50 m above ground, and for training purposes, they had also occasionally practised 180-degree turns at only 100 m above ground.

The accountable manager (ACM) and the NPFO stated that, in their opinion, the rules on minimum flight altitudes in European Regulation 965/2012 did not apply to Ju-Air. The justification for this stance was that these rules would not apply to VFR traffic and that Ju-Air, since it was moving "*within the topography*", could not comply with them anyway. The CMM did not comment on this matter and instead advised consulting the NPFO.

Regarding lateral distances to obstacles, the NPFO stated on record that obstacles, such as the Gross Mythen or the Fronalpstock (canton of Schwyz), were passed at a "*reasonable*" distance. This was quantified as 50 to 100 m.

Information on the flight altitudes actually selected by Ju-Air pilots and lateral distances to obstacles can be found in annex A1.1 and annex A1.18.

A1.17.6.4 Minimum distances from clouds

In class G[76] airspace, there is no minimum distance from clouds, but flights must be flown "*outside clouds and with a constant view of the ground*" (article 23 of the Swiss DETEC Ordinance on Traffic Regulations for Aircraft (SR 748.121.11)).

In class E[77] airspace, a minimum distance from clouds of 1,500 m horizontally and 300 m (1,000 ft) vertically (rule SERA.5001) applies.

A1.17.7 National supervision

A1.17.7.1 General

The Federal Office of Civil Aviation (FOCA) is responsible for aviation approvals, supervising civil aviation and developing aviation in Switzerland. 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.

[74] Type rating instructor

[75] Type rating examiner (referred to by FOCA as 'examiners for pilot examinations' or just 'examiners') are appointed by FOCA after they have successfully passed a series of selection processes and completed a multi-stage training and examination programme with FOCA. In particular, examiners perform a pilot examination after the pilot has completed the relevant training with a flight instructor or type rating instructor, be this their initial training or professional development. According to FOCA, the office monitors the activities of the appointed examiners.

[76] The airspace within a 20-km radius of the accident site between the surface of the earth (ground) and a height of 600 m (2,000 ft) above ground was class G airspace.

[77] The airspace within a 20-km radius of the accident site between the upper limit of class G airspace, i.e. 600 m (2,000 ft) above ground and flight level 150 (approximately 4,570 m AMSL in ISA conditions) was class E airspace.

A1.17.7.2 Organisation

FOCA's organisational structure ensures that divisions dealing with aviation safety (yellow in figure 5) are strictly separated from those dealing with aviation policy (blue in figure 5). This structure is to enable FOCA to fulfil its duties as a certification and supervisory authority and to perform its role as a regulatory body in a national and international context.

The current organisational structure is based on the recommendations by the Royal Netherlands Aerospace Centre (NLR), which conducted a study on safety in Swiss civil aviation in 2003. The authority officially completed its re-structure in 2005 and is now split into five divisions, which are divided into departments (see figure 5).

For this safety investigation, the 'Safety Division – Aircraft' is mainly relevant with regards to technology and will thus be discussed in more detail in the next section. The 'Safety Division – Flight Operations', as the name suggests, is important in terms of operations. This division will also be discussed below.

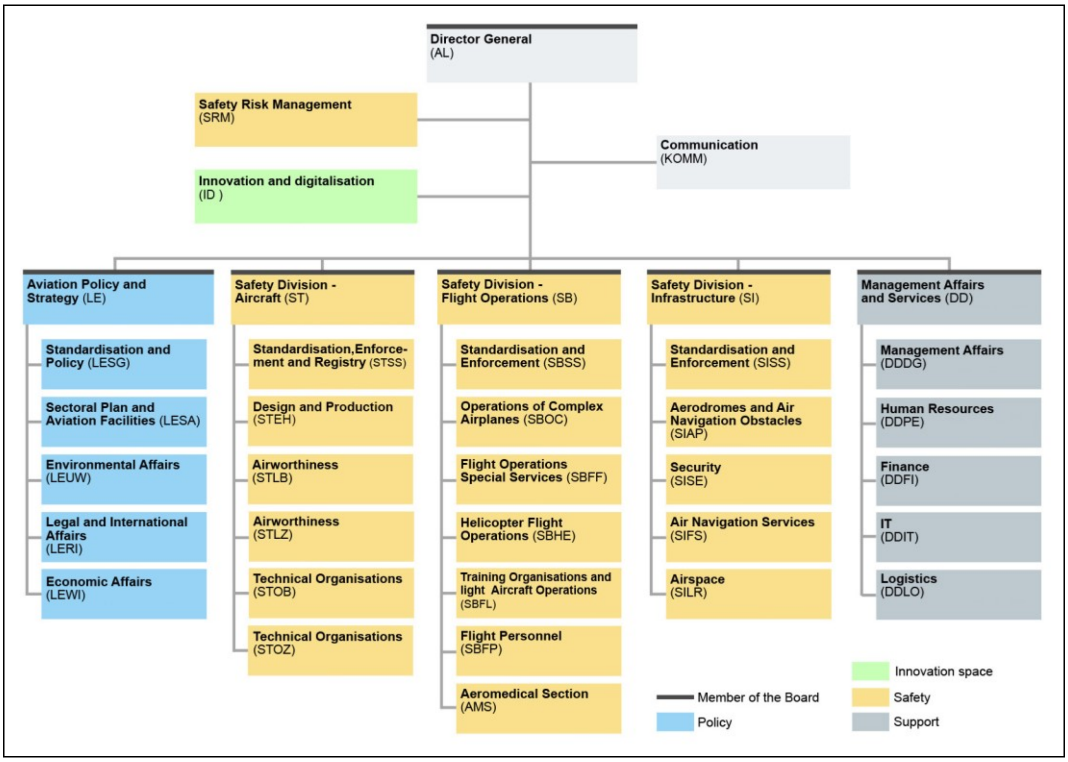

Figure 5: FOCA organisational chart, as at 1 January 2019.

A1.17.7.2.1 'Safety Division – Aircraft'

The 'Safety Division – Aircraft' (ST) is responsible for the type approval and continuing airworthiness of aircraft, the approval and supervision of designers and manufacturers as well as maintenance organisations including the training and qualification of technical personnel. The division ensures the implementation of both national and international safety regulations in the Swiss aviation industry.

The 'Safety Division – Aircraft' is divided into six departments.

A1.17.7.2.2 Design and Production department

Design and Production (STEH) is responsible for the type approval of aircraft including their components and equipment and the approval and supervision of design and manufacturing companies in Switzerland. Its activities are based on national law as well as on European Aviation Safety Agency (EASA) regulations. Furthermore, this department is responsible for the publication of airworthiness directives (AD) from FOCA and other aviation authorities.

As a matter of principle, it would have been mandatory for all modification and repair work on the Ju 52 aircraft as well as newly created or amended service bulletins to be checked and approved by FOCA. As of 2005, this had been the responsibility of STEH. Since 2000, FOCA had received and approved five notices of modification for Ju-Air's entire Ju 52 fleet (see annex A1.6).

For several years, this department did not have an expert on piston engines.

This department was responsible for approving aircraft flight manuals (AFM).

The 'Ageing Aircraft Programme' for aircraft under annex II of European Regulation 216/2008 was initiated and led by this department (see annex A1.6).

A1.17.7.2.3 Aircraft Airworthiness Zurich department

Aircraft Airworthiness Zurich (STLZ) oversees the airworthiness of complex aircraft. In addition, as a higher authority, it is tasked with aircraft continuing airworthiness monitoring (ACAM). To this end, it carries out ACAM inspections in addition to the annual airworthiness inspections.

Inspectors from this department carried out the airworthiness review certificate inspections (ARC) on Ju-Air's Ju 52 aircraft (see section A1.17.7.3). Service bulletin no. 1005 (see annex A1.6) from 2018 was approved by an inspector from this department. This would have been the responsibility of STEH. The same inspector also approved changes to the AFM.

A1.17.7.2.4 Technical Organisations Zurich department

Technical Organisations Zurich (STOZ) is responsible for the approval and supervision of Swiss continuing airworthiness management organisations (CAMOs). In addition, it is responsible for approving and overseeing maintenance organisations for aeroplanes.

Inspections of the two maintenance organisations, i.e. the Ju-Air maintenance organisation and Naef Flugmotoren AG, and the Ju-Air CAMO were carried out by inspectors from this department. The MOE and CAME manuals were also approved by this department.

A1.17.7.2.5 'Safety Division – Flight Operations'

The 'Safety Division – Flight Operations' is responsible for the supervision of private and commercial aircraft operations in Switzerland. More specifically, it grants all operational approvals, issues the necessary certificates and, by its own account, ensures that flight operations are constantly monitored. The 'Safety Division – Flight Operations' is divided into six departments and one special services unit.

A1.17.7.2.6 Flight Operations Special Services department

By its own account, Flight Operations Special Services monitors and analyses all operational developments in aviation, in particular those in international regulations and safety standards for flight operations. It draws up recommendations for action to be taken, leads projects regarding the preparation of working materials and manages them for the division.

A1.17.7.2.7 Operations of Complex Aircraft department

Operations of Complex Aircraft is responsible for overseeing flight operations of complex aeroplanes. It certifies and approves operators and, by its own account, ensures that flight operations are continuously monitored. By its own account, it monitors the companies' compliance with the applicable standards for their flight operations and training through audits and inspections. Another tool being used is random checks of aircraft and crews (ramp inspections).

A1.17.7.3 Supervision of technical aspects

A1.17.7.3.1 General

Annex II (part 145) of European Regulation 1321/2014 regulates the supervisory duties of the competent authority towards maintenance organisations. The action to be taken by the authority is regulated under 145.B.50 'Findings'.

"145.B.50 Findings

a) When during audits or by other means evidence is found showing non-compliance with the requirements of this Annex (Part-145), the competent authority shall take the following actions:

1. For level 1 findings, immediate action shall be taken by the competent authority to revoke, limit or suspend in whole or in part, depending upon the extent of the level 1 finding, the maintenance organisation approval, until successful corrective action has been taken by the organisation.

2. For level 2 findings, the corrective action period granted by the competent authority must be appropriate to the nature of the finding but in any case initially must not be more than three months. In certain circumstances and subject to the nature of the finding the competent authority may extend the three month period subject to a satisfactory corrective action plan agreed by the competent authority.

b) Action shall be taken by the competent authority to suspend in whole or part the approval in case of failure to comply within the timescale granted by the competent authority."

A1.17.7.3.2 Preparation of audits and inspections

A standard checklist containing the items to be assessed was available to the inspectors from STOZ and STLZ for the respective audits and inspections. The specific requirements for the maintenance of a historic aircraft such as Ju-Air's Ju 52 aeroplanes were not taken into account. Inspectors routinely planned the audits and inspections. No preparations for the specific circumstances were made. The same checklist as for maintenance organisations responsible for aircraft with a TC holder was used for audits at Ju-Air and Naef Flugmotoren AG.

The entire checklist, including all items, was generally processed within a supervisory cycle of 24 months. It was up to the respective inspectors to decide whether the audits or inspections should be annual or biennial. The same inspector from STLZ was responsible for inspections of the Ju 52 fleet for many years. There was no systematic exchange of information about the respective organisations between inspectors from STOZ and STLZ, who were responsible for the same organisations.[78] The respective inspectors carried out supervisory activities within their relevant areas of expertise.

[78] There was, however, a regular exchange of information between the heads of these departments regarding the organisations supervised. This exchange took the form of a quarterly meeting with other heads of departments.

A1.17.7.3.3 Airworthiness review certificate inspection

Between 2010 and 2018, HB-HOT underwent its airworthiness review certificate (ARC) inspection every two years. During the five inspections carried out in this period, no complaints or comments were recorded in the corresponding reports.

A1.17.7.3.4 Audits at the Ju-Air maintenance organisation

FOCA carried out seven audits of the Ju-Air maintenance organisation between 2010 and 2017. Similar organisational deficits were repeatedly identified. Complaints included the following:

Date	**Complaint level 2**
25 September 2012	*"In the workshop, there are general tools in a drawer for which there is no actual inventory. There is no overview of possibly 'missing' tools, nor a monitored approach to handing out tools."*
25 September 2012	*"The contents (hardware) of the drawer racks in the workshop are not consistently separated and labelled according to 'aviation or non-aviation' criteria.* *Exclusive access to the various materials by authorised personnel only is not guaranteed."*
16 April 2015	"*In the spare parts warehouse, non-usable parts are not consistently separated from usable parts. The storage management procedures shall be reviewed, taking into account parts 145.A.25 (d), 145.A.42 and 145.A.65 (b)."*
16 April 2015	"*Various parts were found in the spare parts warehouse, which had not been labelled in terms of their usability."*
16 April 2015	*"The procedures established in the organisation for the use of tools do not ensure that, after completion of work on aircraft, the tools used for this purpose are all available again. (Tool trolley in the workshop not complete)."*

A1.17.7.3.5 Audits at the Naef Flugmotoren AG maintenance organisation

During six audits at the Naef Flugmotoren AG maintenance organisation between 2010 and 2018, organisational deficits were found several times. During the audit in 2014, it was pointed out that there is no information in the MOE on incidents that must be reported. In 2017, an unscheduled post-audit was considered to verify planned improvements. Complaints included the following:

Date	**Complaint level 2**
20 April 2010	*"The procedure for locking the spare parts warehouse executed in the organisation does not ensure that only authorised personnel have access to it."*
28 January 2014	"*A micrometer was found in the engine workshop which is obviously used for measurements, although it is marked as 'not calibrated'.*"
2 December 2015	*"The engine parts (cylinders) found in the hangar had no protection from damage by external influences. (Ref. AMC 145.A.25 (d)(3)."*
2 December 2015	*"An engine with a release to service certificate is stored on the gallery on the upper floor, unprotected from external influences. Information on measures potentially required to preserve the engine could not be provided."*
2 December 2015	*"The MOE does not include a procedure which specifically considers maintenance work on components and, in this context, the requirements of part 145.A.50 (d), and the AMC's 145.A.50 (d)."*
19 April 2014	*"All tools allocated to a toolbox aren't properly marked yet, as well as tools stored on the shelves."*
19 April 2014	*"Maintenance data, although available, shall be sorted out in order to have a good overview and rapid access to the latter."*
13 February 2018	*"No process is established to ensure that a general verification is carried out on the aircraft or component to ensure that it is clear of all tools, equipment and any extraneous part or material after completion of maintenance."*
13 February 2018	"*The Safety Manager's position is not mentioned on the organisational chart neither his duties and responsibilities are described in the MOE.*"

A1.17.7.3.6 Audits at the continuing airworthiness management organisation

Between 2013 and 2017, three audits were carried out at the Ju-Air continuing airworthiness management organisation (CAMO). Among other things, the CAMO was directed in 2013 to introduce a corrosion control programme by 2 October 2013. The CAMO had not complied with this requirement by the time of the accident. Organisational deficits were also pointed out. Complaints included the following:

Date	**Complaint level 2**
4 July 2013	*“The procedure Maintenance Program periodical review revealed, that the review was not performed and documented (at least annually the Maintenance Program shall be reviewed). The AMP is still the first issue and references to the MME and the JAA and applicability of AD shall be corrected (CAME and EASA). A procedure on how JU Air is performing a corrosion control program shall be added.”*
4 July 2013	*“A review of the procedure personnel training revealed that there was no evidence of a training plan for the CAMO personnel. A training plan shall be established or the CAMO personnel shall be integrated in the part 145 org. training plan.”*
4 July 2013	*“A review of the requirement on how the organization control the competence of personnel involved in continuing airworthiness shall be described in a procedure. Guidance can be found in GM2 145.A.30 (e).”*
4 July 2013	*“A review of the quality procedure revealed that the product audit in 2012 was not performed. The sampled audit plan did not list the whole requirement to be checked. Product audit shall be performed and the audit plan shall be reviewed.”*
16 May 2017	“*Reviewing the work order HB-HOS, 781 dated 06.04.2017, it has been found that the actual number of parts in the store doesn’t match with the number of parts in the computerised inventory system. (for example, instance Bremsschlauch & Bremsventil* [brake hose & brake valve] *(Junker)).”*
16 May 2017	*“No control of the competence of the personnel involved in the continuing airworthiness management and/or quality audit could be presented.”*

A1.17.7.3.7 Evaluation

The Federal Office of Civil Aviation is responsible for the supervision of civil aviation in Switzerland and for aviation development.

Over the years, no findings were recorded during inspections of HB-HOT's airworthiness carried out by FOCA.

The investigation revealed that the technical files of HB-HOT were kept in an unclear manner, were incomplete and for the most part not transparent. The files were neither kept in accordance with the specifications in FOCA's technical communications, nor with the specifications in the MOE of the respective maintenance organisations. FOCA did not question this in the period from 2010 to 2018.

The inspections at the Ju-Air and Naef Flugmotoren AG maintenance organisations and the continuing airworthiness management organisation (CAMO) did not uncover the many serious deficits over the years either. Repeated findings during inspections of the maintenance organisations and the CAMO did not result in any consequences.

Examples of such findings at the Ju-Air maintenance organisation:

- Procedure for using tools in the workshop;
- Management of the spare parts warehouse;
- No training plan for staff;
- No checking of staff skills.

Examples of such findings at Naef Flugmotoren AG:

- Procedure for using tools in the workshop;
- Management of the spare parts warehouse;
- Use of non-calibrated measuring tools.

Improvement measures required by FOCA, such as a corrosion protection programme or supplemental structural inspection documents (SSIDs), were never implemented by Ju-Air. FOCA did not assert itself.

Furthermore, FOCA did not pay enough attention to the problem of people simultaneously performing different management roles in both the Ju-Air maintenance organisation and Naef Flugmotoren AG as well as in the Ju-Air CAMO.

The fact that a person stayed in a role for only a very short time was not critically questioned. It is hardly feasible that one person can become fully acquainted with the complex tasks in the CAMO within half a year.

There was no piston engine expert working in Design and Production at FOCA. Moreover, this department was barely involved in Ju-Air's repair and modification projects. Only five notices of modification were submitted to FOCA for approval between 2000 and the time of the accident. Many projects were not known to this department as Ju-Air had not submitted them to FOCA for approval. As a result, the department was unable to fulfil its role in this field.

Among the inspectors of FOCA's 'Safety Division – Aircraft' department, there was no systematic exchange of information on the organisations supervised. The respective inspectors carried out their supervisory activities predominantly within their respective areas of expertise. There was no apparent specific preparation of the audits and inspections taking the situation at Ju-Air into account.

The many deficits that remained undetected for a long time show that FOCA's audits and inspections did not provide a realistic picture of the two maintenance organisations and the CAMO.

In summary, the following can be said about FOCA's supervisory activities in relation to Ju-Air:

- There was no effective supervision;
- There was no effective risk management;
- The authority was dependent on experts from the maintenance organisations due to a lack of expert knowledge within the authority;
- There was no complaint about the inadequate aircraft maintenance programme;
- There was a lack of exchange of information within the authority;
- Deficits regarding the CAMO remained undetected.

A1.17.7.4 Supervision in the field of operations

A1.17.7.4.1 Legal basis

State supervision of commercial aircraft operators is regulated by European Regulation 965/2012, which is binding for Switzerland. Rule ARO.GEN.305 defines how an oversight programme[79] must be designed by the state supervisory body. More specifically, according to rule ARO.GEN.305 (b), the oversight programme must be based on an assessment of the risks associated with, or arising from, the following factors:

- The "*specific nature*" of the air operator;
- The "*complexity of its activities*" and
- The "*results of past certification and/or oversight activities*".

Consequently, the development of an oversight programme must be preceded by an assessment of the safety risks associated with the specific characteristics ("*specific nature*") of the air operator concerned. In actual fact, a safety risk assessment of the air operator concerned must be carried out before an oversight programme is established. A safety risk assessment requires the prior identification of hazards and risks.

The Swiss Federal Office of Civil Aviation (FOCA), which is responsible for the state supervision of Ju-Air and regularly developed the oversight programme for its own supervision of Ju-Air, had never carried out such a safety risk assessment itself or demanded one from Ju-Air. As justification for this approach, FOCA stated that it considered the operation of Ju-Air to be a 'standard VFR operation'.

The operation of Ju-Air, however, was characterised by the following peculiarities:

- Commercial air operator performing VFR flights in close proximity to the terrain in mountainous areas;
- Historic commercial aircraft without type certificate holder;
- Several derogations granted by FOCA or the European Commission;
- No flight data monitoring;

[79] The oversight programme contains the planning of the audits and inspections to be carried out by the supervisory authority in relation to an air operation within an oversight planning period.

- The composition of the cohort of pilots with regard to the pilots' aeronautical background was exceptional;
- Unusual personnel situation with numerous volunteers;
- Flight operations and aircraft equipment which, according to FOCA inspectors, was barely in line with European regulations (see section A1.17.7.4.4).

Instead, FOCA relied on an evaluation system specifically developed by FOCA for the supervision of air operators. This system took into account the results of previous licensing and/or supervisory activities, but not the hazards or risks associated with the specific characteristics of Ju-Air. Therefore, the risks arising from Ju-Air's characteristics were not taken into account for many years when structuring the supervision of Ju-Air.

A1.17.7.4.2 General understanding of the regulations at FOCA

With regard to the rules concerning minimum required flight performance and minimum required flight altitude for commercial air transport operations (CAT.POL.A.410 and CAT.POL.A.415) in accordance with European Regulation 965/2012, the Federal Office of Civil Aviation had the following different opinions (see section A1.17.6.3.2):

- The operational inspectors responsible for Ju-Air over the past few years and also some of FOCA's senior managers were of the opinion that the rules CAT.POL.A.410 and CAT.POL.A.415 only applied to air operations under instrument flight rules (IFR) and not to operations under visual flight rules (VFR), as practised by Ju-Air. Furthermore, as argued by said persons, these rules would contradict rule SERA.5005 (f) if they were assumed to be applicable. This interpretation led the FOCA inspectors concerned to believe that – in the context of their licensing and supervisory activities concerning Ju-Air – the minimum required flight altitudes for commercial air transport operations in accordance with European Regulation 965/2012 in particular were not applicable and as a result they tolerated Ju-Air's non-compliance with these rules.
- Other FOCA officers, however, took the view that the rules CAT.POL.A.410 and CAT.POL.A.415 apply to all forms of commercial air transport (therefore also to operations under visual flight rules), but that Switzerland was entitled to a certain degree of flexibility in applying these provisions. The background for this view was FOCA's assessment that the regulations applicable to commercial air transport do not adequately cover VFR operations of large and historic aircraft. Nevertheless, as stated by FOCA, their permitting derogation from these rules, "*did not sufficiently comply with the requirements"* to satisfy the European authorities *"regarding documentation and the provision of information*". The officers went on to explain that FOCA had "*failed to document the derogation in the forms provided for this purpose and to notify EASA*". With this, they mean, in particular, that FOCA did not request Ju-Air to provide evidence for an 'equivalent level of safety' and did not provide such evidence themselves. The European authorities were not advised of any intended derogation. Consequently, EASA did not assess the viability of such derogation in terms of equivalent levels of safety.

With regard to the rules concerning aircraft equipment for commercial air transport operations in accordance with European Regulation 965/2012, the Federal Office of Civil Aviation had the following different opinions (see sections A1.6.4.2 and A1.6.5): The Office had understood a letter from the European Commission "*as covering all derogations from the operational rules resulting from the design of the JU-52 without additional specific exemption approval (for each individual deroga-*

tion)." In its letter, however, the European Commission approved of Ju-Air's commercial air operations with Ju 52 aircraft based on its understanding that these operations would be conducted in full compliance with the operational rules, including the rules regarding equipment, with the exception of OPS 1.180 (a)(1). This interpretation led FOCA to believe that – in the context of its licensing and supervisory activities concerning Ju-Air – the requirement for the aircraft to be equipped with a terrain awareness warning system (CAT.IDE.A.150 (b)) in accordance with European Regulation 965/2012 in particular was not applicable and as a result they tolerated Ju-Air's non-compliance with this rule.

A1.17.7.4.3 Intensity of supervision

Rule ARO.GEN.305 of European Regulation 965/2012 mentioned in section A1.17.7.4.1 specifies that the oversight planning cycle, which determines the intensity of supervision, is usually 24 months. However, the oversight planning cycle may be extended to a maximum of 36 months and the intensity of supervision may thus be relaxed if[80]:

- "[the air operator] *has demonstrated an effective identification of aviation safety hazards and management of associated risks;*
- [the air operator] *has continuously demonstrated* […] *that it has full control of all changes*;
- *no level 1 findings have been issued; and*
- *all corrective actions have been implemented* […]."

The intensity of FOCA's supervision of Ju-Air since 2015 has been as follows:

- In 2015, the oversight planning cycle was 24 months
- In 2016, the oversight planning cycle was 24 months.
- In 2017, the oversight planning cycle was 36 months. FOCA justified this relaxation of the intensity of supervision by stating that Ju-Air had met all four of the above criteria during the last 24 months. However, FOCA was unable to provide details on how in particular the first criterion, i.e. effective identification of aviation safety hazards and management of associated risks, was met.
- In 2018, the oversight planning cycle was 24 months. The oversight planning cycle had been reduced again compared to the previous year "*due to provocative flying and many reports on* [low-level flights]".

Prior to 2015, intensity of supervision was regulated by a different set of rules to European Regulation 965/2012, but the relaxation of intensity of supervision depended on similar criteria. One of the criteria was that the operator's *"internal control loops are fully implemented and used".* The intensity of supervision had also been relaxed and tightened again on various occasions before 2015. Below is a selection of FOCA's arguments for the respective relaxations from the annual reports[81] of that time.

Relaxation from 2008 to 2009:

[80] Conversely, the oversight planning cycle can also be reduced and the intensity of supervision thus increased "*if there is evidence that the safety performance of the organisation has decreased*."

[81] For FOCA, an annual report is a report on a specific operator prepared each year by the FOCA inspector responsible for said operator. It contains summarised information on the supervisory activities in the previous year as well as personal opinions.

- *“No major problems during 2008 in Ju-Air’s flight operation.”*
- “*Very small operation for friends of historic aircraft.*”[82]

Relaxation from 2012 to 2013:

- “[…] *no CRM issues*.”[83]
- “*The majority of the pilots are ex Swiss Air Force with a distinctive experience in VFR low-level flying*.”
- “*The risk assessments documented for the various operational issues (e.g. USA trip, Rundflüge Pistenfest Birrfeld* [sightseeing flights at Birrfeld air show] *etc.) are exemplary.*”[84]
- “*Same equipment operated by same management and pilots gives opportunity for minimum oversight activities.*”

Maintaining the relaxation from 2013 to 2014:

- “*The risk assessments documented for the various operational issues (e.g. USA trip, Rundflüge Flugplatz Amlikon* [sightseeing flights at Amlikon airfield] *etc.) are exemplary*.”[85]
- “*The majority of the pilots are ex Swiss Air Force with a distinctive experience in VFR low-level flying.*”
- “[Ju-Air has] *highly motivated staff in a well-established, stable operation.*”

In the annual report from 2014, the superior of the inspector responsible for Ju-Air stated that Ju-Air carried out “*Very special operations (risk profile) but handled by very experienced management/pilots”*.

The annual reports determining the intensity of supervision for a particular operator were prepared by the FOCA inspector responsible for the operator. The inspector’s supervisor subsequently added his assessment to this report and proposed or determined the level of intensity of supervision for the following year. The responsible head of department then confirmed this new level of intensity with his signature.

A1.17.7.4.4 Doubts regarding the compliance of Ju-Air operations

When reviewing the annual reports[86] on Ju-Air prepared by FOCA, several passages were found for 2006 to 2011, in which the responsible FOCA inspectors or their superiors commented on issues involving Ju-Air’s compliance with standards.

Autumn 2006 and 2007:

- “*Operating these old aircraft types represents certain problems concerning the implementations of JAR-OPS 1.*”

Autumn 2008:

- “*Ju Air is still a small to medium size VFR operator with their ‘special vintage aircraft’ Ju-52. Operating these old aircraft types represents certain problems*

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[82] See also the characteristics of Ju-Air’s operations and those of the passengers in section A1.17.1.2.

[83] CRM: Crew resource management; see the incident of 5 May 2012 described in section A1.17.1.18.2.

[84] See section A1.17.1.16.15.

[85] See section A1.17.1.16.15.

[86] For FOCA, an annual report is a report prepared each year by the FOCA inspector responsible for a specific operator on the operator in question. This report contains summarised information on the supervisory activities in the previous year as well as personal opinions.

concerning the implementations of EU-OPS 1, requiring a CAMO which is not possible under EASA for historical aircraft."

Autumn 2009:

- "*EU-OPS status has to be reviewed (exemptions: which, when, how long, needed, etc.). The 'vintage' type of aircraft does not really fit into the 'modern' regulations* [...]"
- "*Operating these old aircraft types still represents certain problems concerning the implementations of EU-OPS 1.*"
- "[...] *Last year it first seemed that operations would stop within the next 2 to 3 years. Today Ju air is again speaking of a 'brighter' future and thinks that operations will be possible until the year 2025. This also means, that the special situation has to be set onto a 'new' EASA and EU-OPS compatible basis.*"
- *"I strongly recommend that FOCA invites the Ju-Air responsibles before the end of this year to start the process of setting up proper legal bases for the Ju operation."* [87]

Autumn 2010:

- "*Operating these old aircraft types represents certain problems concerning the implementations of EU-OPS 1.*"

Autumn 2011:

- "*An equipment that fits hardly into EU-OPS rules makes this company special.*"

The annual reports were prepared by the FOCA inspector responsible for the operator. The inspector's superior subsequently added their assessment to this report. At the end of the process, the annual report was formally approved by the responsible head of section.

A1.17.7.4.5 Base audits

Ju-Air was regularly audited by FOCA auditors through one-day base audits depending on the currently valid regulations and the currently defined intensity of supervision (see section A1.17.7.4.3). The focus was on the descriptions of the processes and the documentation of the operator. The base audit reports for 2012, 2013, 2014 and 2015 were available for the investigation. In 2016 and 2017, no base audits took place for the following reasons: In 2016, no base audit took place as no base audit was planned due to the prevailing oversight planning cycle of 24 months. No base audit took place in 2017 as the base audit originally planned for 2017 could be postponed until autumn 2018 due to the relaxed intensity of supervision (oversight planning cycle extended to 36 months).

Findings made by FOCA auditors from the base audit of 2014 included:

- "*All operation manuals are up to date and EASA compliant.*"
- "*The checked flight documents made a complete and properly used impression.*"

With regard to Ju-Air's internal audits (see section A1.17.1.20), FOCA explained the following practice: The base audits check whether the operator has an internal audit plan and whether this plan is adhered to. The subject of internal audits is, however, not dealt with in any more depth as part of the base audits. In particular, base audits do not check the extent to which the internal audit system's scope is adequate and its content correct.

[87] I = the signing FOCA inspector

A1.17.7.4.6 Flight inspections

From 2003 to 2018 (before the accident on 4 August 2018), ten flight inspections were carried out on the Ju 52/3m aircraft type by FOCA at Ju-Air. Nine of these concerned proficiency check[88] flights without passengers on board. One of the ten flight inspections concerned a standard flight to the Alps with passengers on board. FOCA's inspections covered flight preparation, the flight itself and the follow-up. Whilst inspections of standard flights primarily assessed the work of the pilots carrying out the flight, inspections of proficiency check flights primarily assessed the work of the examiner.

The ten flight inspections between 2003 and 2018 mentioned above took place as follows:

- 4 April 2005 – Inspection of a proficiency check flight on HB-HOY, without passengers on board;
- 1 March 2006 – Inspection of a proficiency check flight from and to Dübendorf Air Base, without passengers on board;
- 19 March 2009 – Inspection of a proficiency check flight from and to Dübendorf Air Base via Emmen, without passengers on board;
- 2 April 2012 – Inspection of a proficiency check flight to and from Dübendorf Air Base with air work in the Greifensee region, without passengers on board;
- 4 April 2013 – Inspection of a proficiency check flight on HB-HOP from and to Dübendorf Air Base with air work in the Greifensee region, without passengers on board;
- 23 April 2014 – Inspection of a proficiency check flight on HB-HOS from and to Dübendorf Air Base with air work in the Greifensee region, without passengers on board;
- 10 March 2015 – Inspection of proficiency check flight on HB-HOY from and to Dübendorf Air Base via Emmen with air work in the Greifensee/Zurichsee region, without passengers on board;
- 13 September 2016 – Inspection of a standard sightseeing flight on HB-HOS from Dübendorf into high alpine terrain (Hüfifirn, Limmerensee) and back to Dübendorf with 11 regular passengers on board (total of 15 people on board);
- 18 April 2017 – Inspection of a proficiency check flight on HB-HOP from and to Dübendorf Air Base via Emmen Air Base, without passengers on board;
- 14 March 2018 – Inspection of a proficiency check flight on HB-HOS from and to the Bremgarten Airport (EDTG) with air work in the Bremgarten im Breisgau region, without passengers on board.

Items checked by inspectors as part of the inspections of proficiency check flights include the following (extract from the inspection report of the inspection on 18 April 2017):

- "*Aircraft;* [...]
- *Examiner's briefing;*

[88] During a proficiency check, an examiner – usually appointed by the air operator, but qualified and accepted by the supervisory authority – assesses the skills of the air operator's pilots. When such a flight is subject to a flight inspection, this is *not* carried out by the examiner who is qualified and accepted by the supervisory authority. In such a case, the inspection is carried out by an inspector from FOCA.

- *Candidate's briefing;* [...]
- *Check program content;*
- *Conduct of the session;*
- *Debriefing;*
- *Airman compliance and performance*."

No inspection items were listed, which indicated that the inspection was tailored to the specific nature of the air operator Ju-Air or the historic Ju 52/3m aircraft type.

Items checked by the inspector as part of the inspection of the standard sightseeing flight include the following (extract from the inspection report of the inspection on 13 September 2016):

- "[...] *Flight planning;*
- *Flight preparation (airworthiness aspects);*
- *Flight preparation (operational aspects);*
- *Mass and balance;*
- *Cockpit preparation/performance;* [...]
- *Departure/en-route flight phase;*
- *Approach and landing;* [...]
- *Specific approvals for LVP* [...]*;*
- *TCAS, EGPWS, wind shear;*
- *RVSM/MNPS/RNAV/RNP* [...]."[89]

No inspection items were listed, which indicated that the inspection was tailored to the specific nature of air operator Ju-Air or the historic Ju 52/3m aircraft type.

The five flight inspections since 2014 were examined more closely: All five of these had been announced to Ju-Air in advance. As part of these inspections, FOCA issued a total of two written non-compliance notices. One concerned a wrong date on a checklist, and the other a missing form. In the inspection reports of these five inspections, the persons audited and their work were exclusively attested as having good qualities (samples taken from inspection reports: "*highly professional work*", "*very good flying skills, good airmanship and professional work*", "*professional flight operation*", "*good CRM*[90] *was present at all the time*", "*all paperwork was done accurate and correct*", "*motivated crew, performing a professional work, to guarantee a safe operation of the aircraft*"). During these five flight inspections, the authority's inspectors did not identify and document any problems concerning in particular the calculation of mass and balance, flying tactics, lateral flight path selection or altitude selection.

This is remarkable in view of the following facts:

- During the HB-HOS flight on 13 September 2016, which was inspected by FOCA, the fundamental rules for safe mountain flying, as set out by FOCA itself in the Swiss AIP, were not complied with (see annex A1.18).
- The operational flight plan for HB-HOS flight on 13 September 2016, which was inspected by FOCA, included several mistakes in the calculation of mass and balance (see section A1.17.1.21).

[89] The terms LVP, TCAS, EGPWS, RVSM, MNPS, RNAV and RNP describe procedures, rules or systems in commercial aviation usually performed by large turbine-powered aircraft under instrument flight rules.

[90] CRM: Crew resource management

A1.17.7.4.7 Ramp inspections

From 2003 to 2018 (before the accident on 4 August 2018), a total of six ramp inspections were carried out by FOCA on five days at Ju-Air.

These six ramp inspections were:

- 24 September 2003 – Ramp inspections of HB-HOP and HB-HOT at Dübendorf Air Base;
- 4 March 2011 – Ramp inspection of HB-HOS at Dübendorf Air Base;
- 15 October 2014 – Ramp inspection of HB-HOP at Dübendorf Air Base;
- 10 March 2015 – Ramp inspection of HB-HOY at Dübendorf Air Base;
- 26 October 2016 – Ramp inspection of HB-HOS at Dübendorf Air Base.

In addition to flight crew identification cards and aircraft documents, items checked by inspectors as part of the ramp inspections included the following (extract from the inspection report of the inspection on 26 October 2016):

- "[...] *Flight preparation*[91]*;*
- *Mass and balance calculation*[92]*;* [...]
- *General external condition* [of the aircraft]*;* [...]
- *Flight controls;* [...]
- *Powerplant and pylon.* […]"

Two of the three FOCA inspectors interviewed as part of the investigation, who had been entrusted with the supervision of Ju-Air in recent years, stated that the basic aircraft values from the OFP and the basic aircraft values from the current weight sheet were usually checked for consistency during ramp inspections. The third inspector interviewed argued that such an inspection was not required as there was no corresponding item in the "*list of pre-defined findings*"[93] from EASA that was being used. The inspectors' superiors disagreed on this issue. FOCA management took the view that the calculations of mass and centre of gravity were checked on a random basis during ramp inspections. Furthermore, they stated that it was not standard to inspect that the calculations and values were correct but only that such calculations existed. FOCA used the EASA Inspection Instructions on the Categorisation of Ramp Inspection (SAFA/SACA) Findings for ramp inspections of Swiss aircraft – SANA[94]. These inspection instructions set out the following requirements and definitions on this subject:

- *"Inspection instructions: Check for presence of a completed mass and balance sheet (either paper or digital format) and accuracy of the mass and balance calculations.* […] *Check if the crew has sufficient data available (in the OPS manual or AFM) to verify the mass and balance calculations."*
- In the event of an erroneous mass or balance calculation, there are different pre-described findings depending on the various effects of the error.[95]

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[91] See in particular section A1.17.1.4.2

[92] See in particular section A1.17.1.21.

[93] Detailed list of possible, defined findings.

[94] SANA: Safety Assessment of National Aircraft

[95] "*Incorrect mass and/or balance calculations, within* [aircraft] *limits, and having minor effect on the performance calculations.*" "*Incorrect mass and/or balance calculations, within* [aircraft] *limits, but significantly affecting the performance calculations*." "*Mass and balance outside operational limits*."

- In addition: "*The list of PDFs* [pre-described findings] *is not exhaustive since it cannot cover all possible deviations that may occur – as a consequence, other findings may be raised by the inspector.*"

A total of nine findings were recorded during the two ramp inspections performed in 2003. No findings were recorded on the issue of mass and balance.

No findings were recorded by FOCA during the ramp inspections of 2011, 2014, 2015 and 2016.

A1.17.8 Supranational supervision

In accordance with articles 17 and 24 of European Regulation 216/2008, the European Aviation Safety Agency (EASA) had in particular the task of carrying out "*standardisation inspections*" of member states to monitor "*the application by national competent authorities of this Regulation and of its implementing rules*".[96]

The last inspection of FOCA by EASA, during which the application of the standards relating to flight operations (in particular European Regulation 965/2012) was assessed, took place from 20 to 24 April 2015. The following conclusions from the EASA inspection report are relevant here:

- EASA concluded that FOCA was thoroughly reviewing the operators' operations manuals.[97] This formally represented an inspection result.
- EASA concluded that FOCA did not systematically plan flight inspections of operators of aeroplanes for all operators to be supervised.[98] This formally represented an inspection result, and was included in EASA finding CH #18916.
- EASA concluded that although FOCA's supervisory activities with regard to operators of aeroplanes covered the relevant areas, the scope of these activities did not ensure an in-depth verification of compliance. This concerned in particular base audits and flight inspections.[99] This formally represented an inspection result, and was also included in EASA finding CH #18916.
- EASA concluded that FOCA did not include the specific characteristics of helicopter operators in the planning of the supervisory activities of these operators.[100] This formally represented an inspection result, and was also included in EASA finding CH #18917.
- EASA concluded that the approval of take-offs during ground fog or low stratus, which FOCA had granted to several commercial helicopter operators, was not

[96] When the successor regulation to European Regulation 216/2008, European Regulation 2018/1139, came into force in September 2018, the European Aviation Safety Agency (EASA) became the European Union Aviation Safety Agency. The abbreviation EASA was retained.

[97] "*The review of operations manuals was found to be thorough.*"

[98] "*With regard to the oversight of aeroplane operators, FOCA has established an oversight programme in compliance with the authority requirements, with the exception of flight inspections, which are not planned systematically for all operators.*"

[99] "*The review of the oversight files has shown that, although all relevant areas are covered, the man-hours spent on the yearly base audit cannot systematically allow for an in-depth verification of all the requirements included in the audit scope.*" Extract from the executive summary of EASA's inspection report: "*The extent of the oversight activities for aeroplane operators, although documented and implemented, did not ensure an in-depth verification of continued compliance with some requirements, mainly related to base audits and flight inspections.*"

[100] "*With regard to the oversight of helicopter operators, FOCA has not yet formally established an oversight programme compliant with the Part-ARO requirements. Several issues have been identified:* […] *the schedule of oversight activities does not apply risk-based criteria, as the specific nature of the operators and the complexity of their activities have not been taken into account,* […]."

permitted under European law in commercial air transport operation (CAT).[101] This formally represented an inspection result.

It should be noted that at the time FOCA did not accept the invitation to comment on the draft inspection report cited and did not send any comments to EASA.[102]

Following the inspection, FOCA agreed with EASA on various measures to increase the effectiveness of the supervision of commercial operators. EASA documents show that, at least in 2016, FOCA was not able to implement some of the supervisory objectives set and asked EASA to postpone the deadline for several of the measures that had been agreed – in some cases several times and in total by up to more than one year. In the end, EASA accepted FOCA's response and concluded their processing of the findings. During the investigation of the accident concerning HB-HOT, it could not be established that the measures had any effect.

According to EASA, the rules CAT.OP.MPA.135, CAT.OP.MPA.145, CAT.OP.MPA.270, CAT.POL.A.100 and CAT.POL.A.410 (concerning minimum climb rate for cruise) as well as rule CAT.POL.A.415 (concerning minimum cruising altitudes) of European Regulation 965/2012 apply to all commercial air operations with complex motor-powered aeroplanes, such as Ju 52 aircraft, regardless of whether these operations are performed under visual flight rules or instrument flight rules.

A1.17.9 Obligation to report incidents to the STSB

According to the Swiss Ordinance on the Safety Investigation of Transport Incidents (OSITI) of 17 December 2014, parties required to report civil aviation incidents (accidents and serious incidents) to the STSB include for example:

- The owners of the aircraft;
- The operator of the aircraft;
- The airlines involved;
- The aviation personnel involved;
- The Federal Office of Civil Aviation.

Until OSITI came into force on 1 February 2015, the Ordinance on the Investigation of Aircraft Accidents and Serious Incidents (VFU) of 23 November 1994 regulated the obligation to report civil aviation incidents. The scope of the persons and organisations subject to reporting requirements is identical in the VFU and OSITI. However, the VFU explicitly stated that air accidents and serious incidents involving Swiss aircraft abroad must also be reported to the Swiss safety investigation authorities (formerly the AAIB, later the STSB).

[101] *"The team also investigated a specific approval process (helicopter departure in fog – HDF), which is based on national law and not compliant with EU requirements. The HDF approval was granted to several helicopter operators and included on the AOC operations specifications. After an extensive review, it was determined that such approval was not allowed in CAT operations*."

[102] *"FOCA did not provide comments to this report."*

Contents

A1. Factual information

A1.18 Additional information

A1.18.1 Flight over the Segnespass in 2013

Three photographs taken from HB-HOP were available from a flight over the Segnespass on 6 July 2013. Figure 1 shows a flight past the Martinsloch. On board HB-HOP for this flight was the same crew as on the accident flight in HB-HOT on 4 August 2018.

Figure 1: The second of three photographs taken from HB-HOP on 6 July 2013 during a flight past the Martinsloch (red circle).

By photogrammetrically analysing these three images, the geographical position with the corresponding flight altitude was recorded as a data point (P) and the respective pitch attitude (PA) and bank attitude (BA) of the aircraft relative to a horizontal reference line were determined. The straight segments of the red line between the points represent the reconstructed flight path. The blue extension of the flight path was drawn starting from point P 3 based on the bank attitude at this position and assuming a constant flight altitude (see figures 2 and 3).

There are striking parallels between the flight past the Martinsloch on 6 July 2013 and the accident flight (see figure 4).

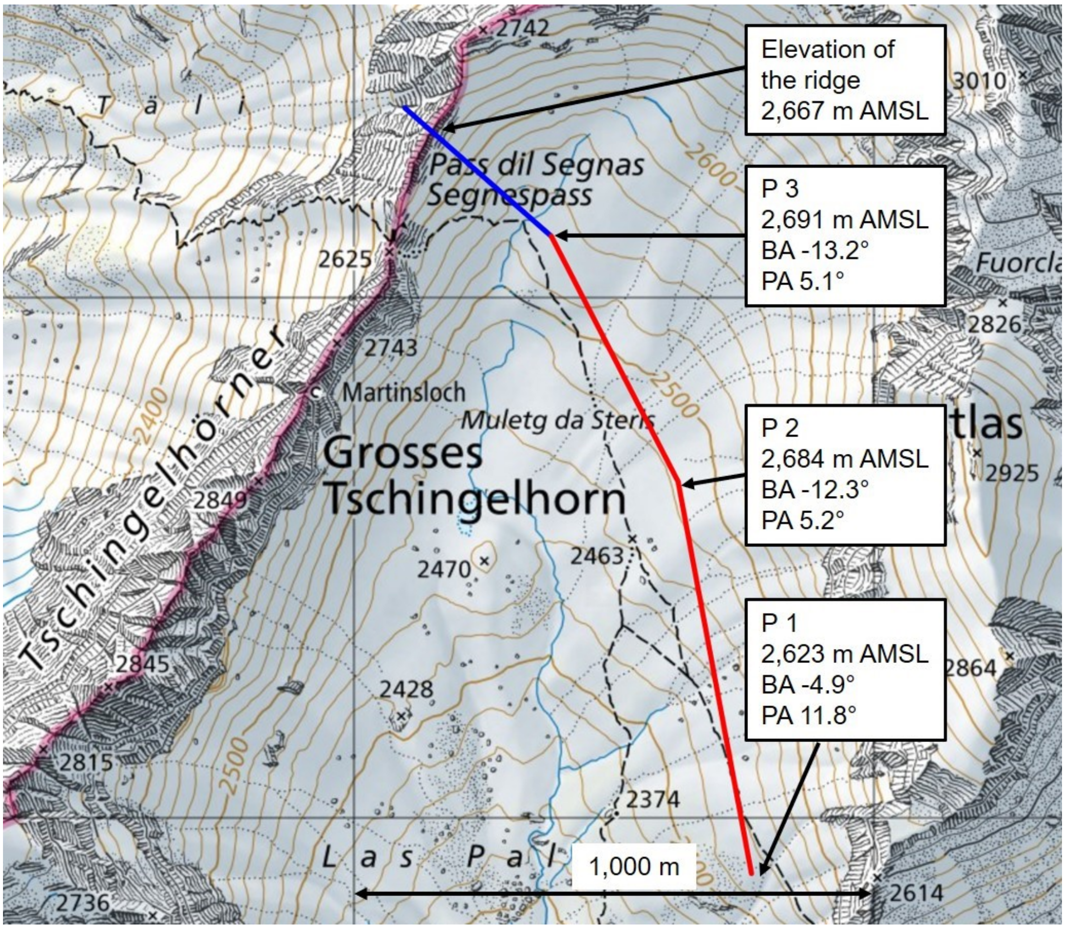

Figure 2: The flight path (red) and extension of the flight path (blue) reconstructed from data points P 1 to P 3 for the flight on 6 July 2013. Assuming the altitude of P 3 was to be maintained, the difference in height between the extension of the flight path (blue) and the elevation of the ridge is 24 m. Source of base map: Swiss Federal Office of Topography.

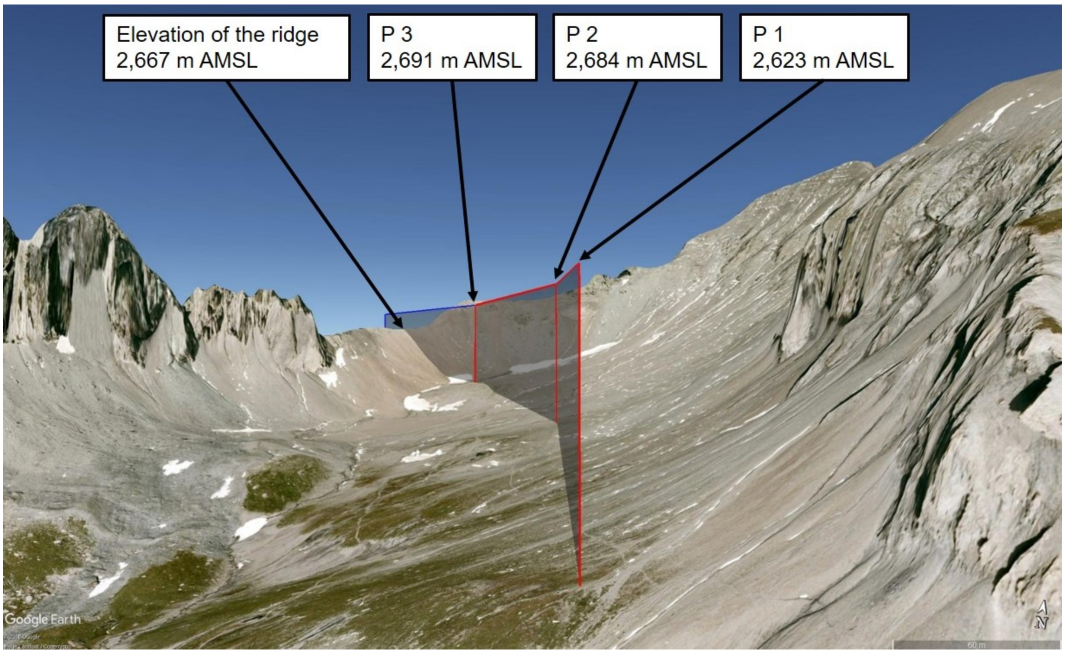

Figure 3: Flight path (red) of 6 July 2013 reconstructed from data points P 1 to P 3 and extension of the flight path (blue) shown in the direction of the flight. Shown on Google Earth.

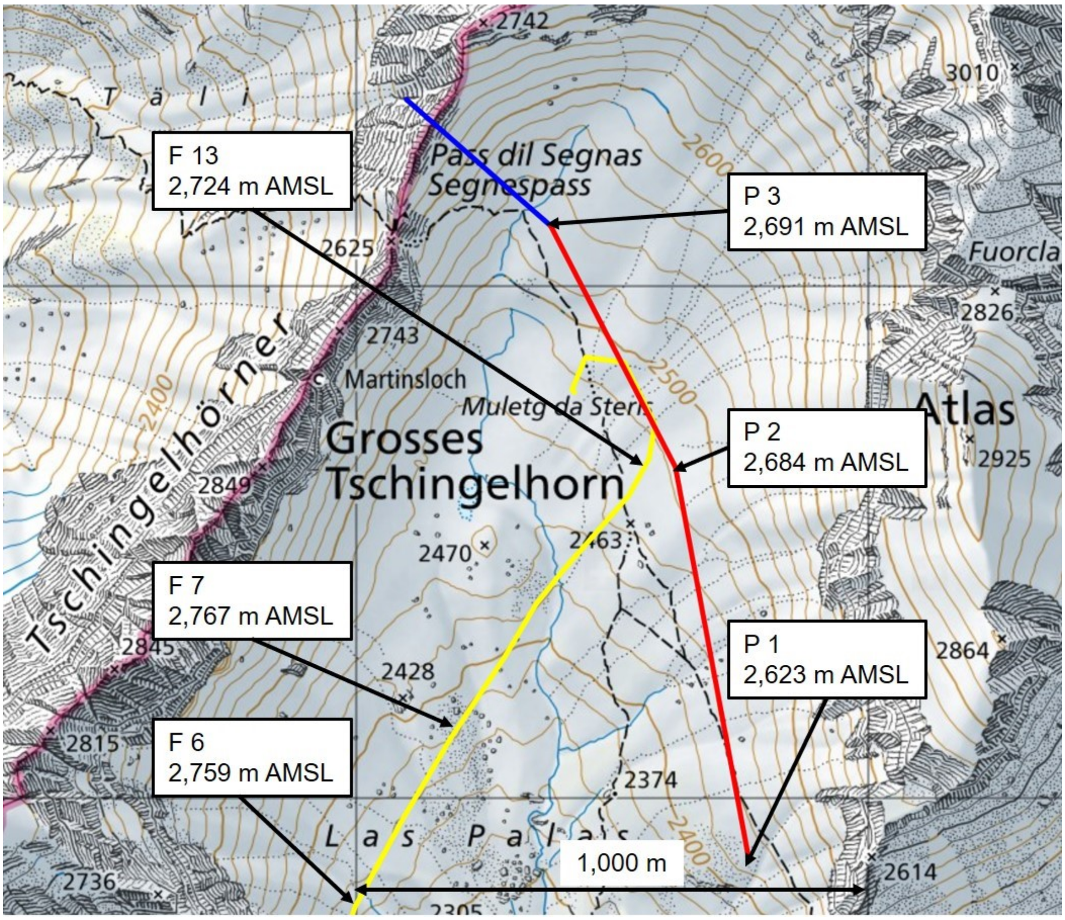

Figure 4: Comparison between the reconstructed flight paths of 6 July 2013 (red) and the accident flight of 4 August 2018 (yellow). On 6 July 2013, the section of terrain in front of the Segnespass was entered along the western flank of the mountain called Atlas, approximately 150 m lower than during the accident flight. Source of the base map: Swiss Federal Office of Topography.

A1.18.2 Comparison of photogrammetric and radar data with GPS data

At noon of 4 August 2018, the day of the accident involving HB-HOT, HB-HOP flew west of the Segnespass towards the Kistenpass, where it was photographed from the ground (see red circle in figure 5). This flight was carried out by another flight crew approximately three hours before the accident flight. It was possible to determine five data points by photogrammetrically analysing the images. Using GPS data of the flight path, the data points could be validated at an accuracy of 2 to 16 m (laterally) and 6 to 13 m (vertically).

As only radar data were available for the analysis of numerous flights before 4 August 2018, the GPS and radar flight paths of the HB-HOP flight on 4 August 2018 were compared at certain positions by way of example, and deviations in positions and flight altitudes were examined.

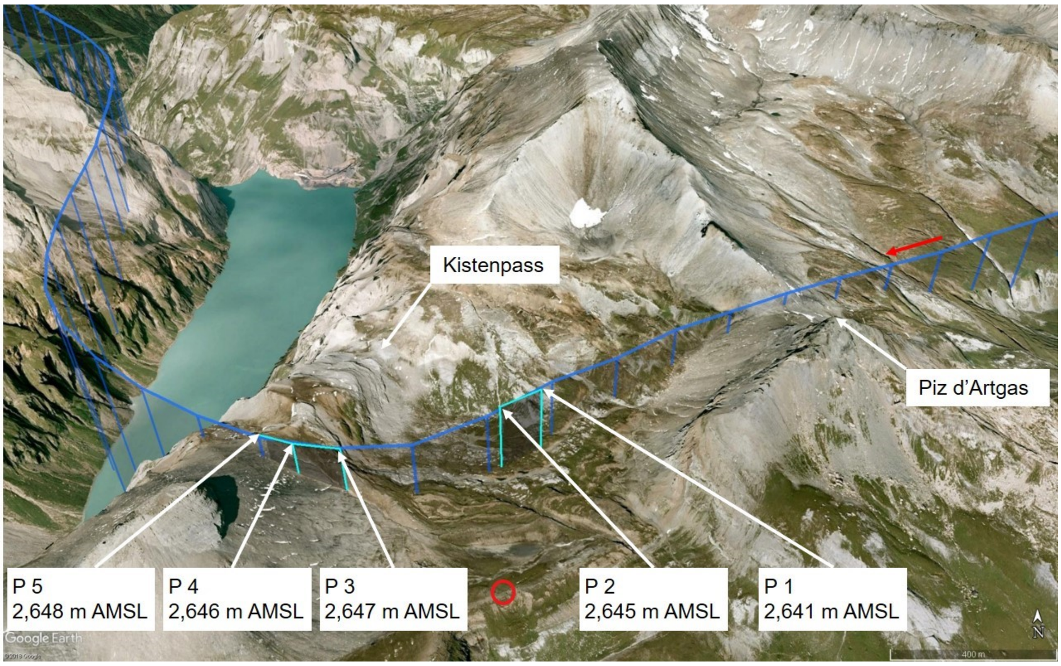

Figure 5: Flight path of HB-HOP on 4 August 2018, flight path segments reconstructed from GPS data (blue) and from data points P 1 to P 5 (light blue), including an arrow pointing in the direction of flight (red arrow) and the photographer's location (red circle). Shown on Google Earth.

The radar data originate from a multi-radar tracker (MRT), which compiles the data of several radar systems from different locations. The flight altitudes relating to the radar positions are transmitted as pressure altitudes based on the ICAO standard atmosphere; they have been corrected for the following examinations based on the actual pressure conditions (see section A1.19.5).

Due to topography, the flight path positions ascertained from radar data vary in accuracy, particularly for flights in mountainous areas, and can deviate considerably from the actual positions. Several positions in a row may be missing, resulting in gaps in a radar flight path. If the radar signal is lost, the MRT extrapolates data points (see figure 6, A and C). These isolated extrapolations and errors were taken into account during further flight path review. The radar data are usually sufficiently accurate to assess the flight path (see figure 6, B). In addition, the flight path between two radar data points located apart can also be estimated using topography. The area marked in red, bordered by the turquoise lines highlighting a zone at the same altitude as the flight path up to 800 m[1] either side of the GPS recording, is required for further comparisons in section A1.18.3. Detailed information on the methodology for the assessment of radar data is given in section A1.19.3.

[1] The 800 m mentioned here represents the space required to perform a 180-degree turn as per the information provided in the aircraft flight manual (AFM).

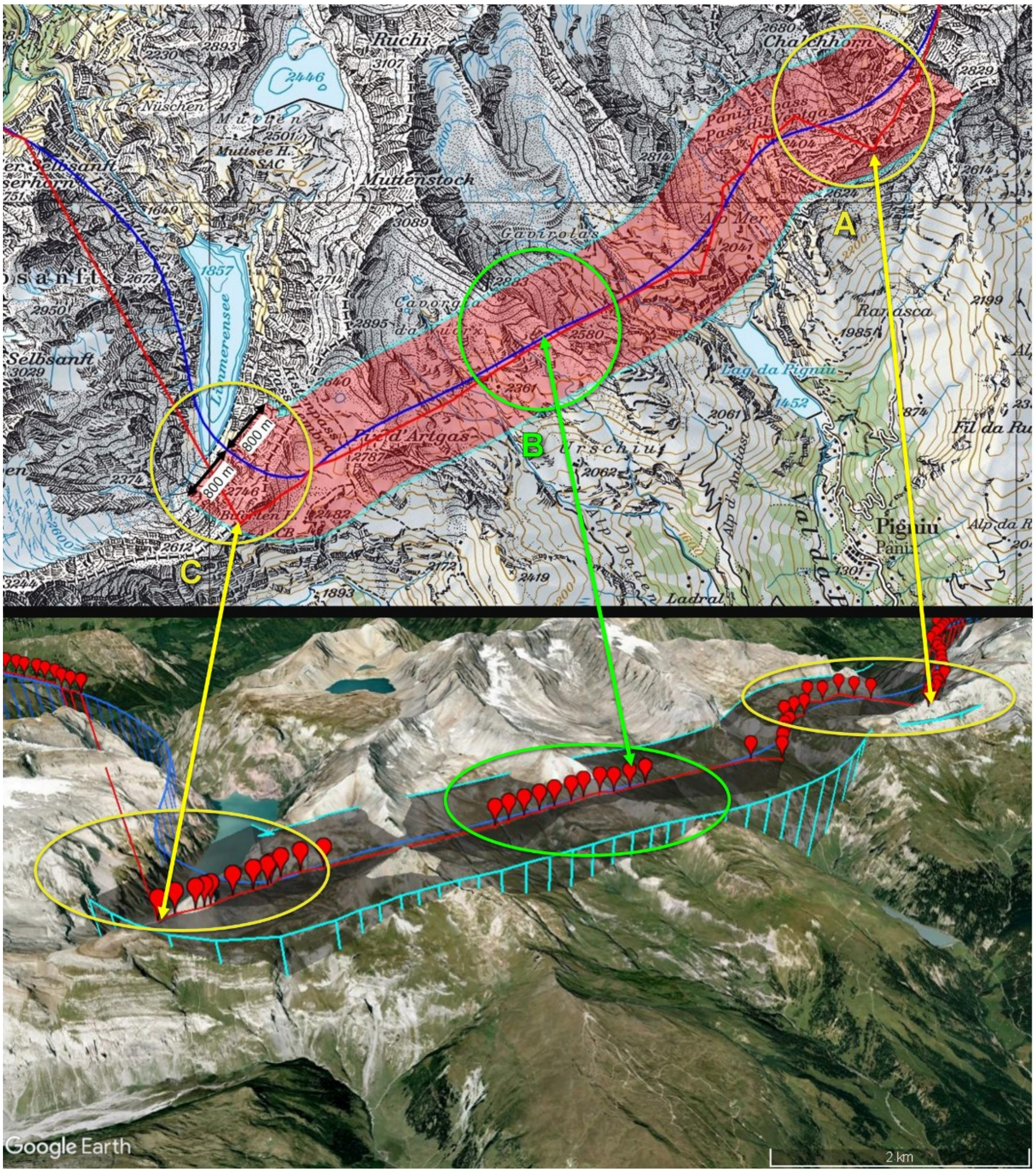

Figure 6: Above – flight path of HB-HOP on 4 August 2018, ascertained from GPS data (blue) and radar data (red). Source of the base map: Swiss Federal Office of Topography. Below – shown on Google Earth.

Deviations between the corrected radar flight altitudes and the flight altitudes from the GPS data are within ± 30 m. This approximately equates to the transponder altitude increments as recorded by the MRT.

A1.18.3 Review of flight paths

Based on the GPS data of HB-HOP's flight path on 4 August 2018 (see section A1.18.2), the flight crews' handling of mountain flying principles was analysed using two example positions. At position A, the flight path led into a rising V-shaped valley and, at position B, it ran vertically towards a ridge, which was flown over at a low level.

When assessing the options for mountain flying tactics – for example, in the event of a loss of engine power or unforeseen downdraughts – the following assumptions were made for the scenarios used based on information in the aircraft flight manual (AFM): a very small margin of 30 % on the stall speed, a 30-degree bank attitude and a turn radius of 400 m, i.e. a 180-degree turn with a diameter of 800 m (see figure 7). It should be noted that this is a theoretical consideration assuming optimal conditions. In particular, the margin on the stall speed does not represent a large enough safety margin for flying in the mountains. Furthermore, no minimum distance from the terrain was taken into account, which would of course also have to be respected in reality.

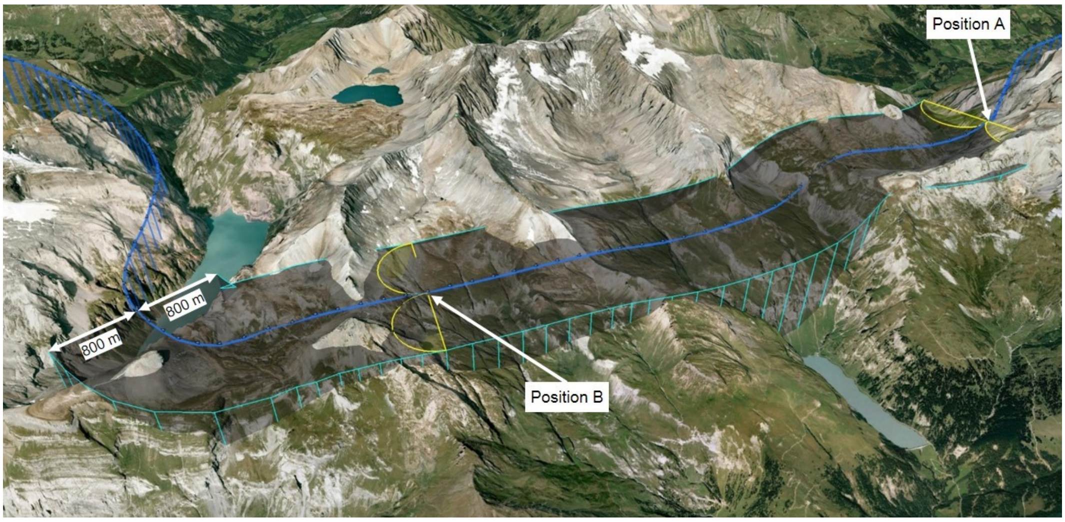

Figure 7: Flight path of HB-HOP on 4 August 2018, ascertained from GPS data (blue) and 180-degree turns (yellow) at a constant flight altitude at positions A and B. Shown on Google Earth.

Assuming a rate of descent of 2 m/s (approx. 400 ft/min), as may result from entering an area of slight downdraught or due to a loss of engine power, the potential options become even more limited.

The approach over the V-shaped valley to the Panixerpass, which was flown over at approximately 140 m above ground, was made along a slightly climbing flight path. A 180-degree turn to the right would still have been possible at position A, assuming the parameters described above, i.e. if flown at a turn radius of 400 m and a rate of descent of 2 m/s. Just before the end of the semicircle (red arrow in figure 8) the hypothetical flight path runs approximately 100 m above the terrain. Had the flight hypothetically continued (marked in yellow in figure 8), also at a rate of descent of 2 m/s, the flight path would have run over the Panixerpass at a height above ground of approximately 43 m.

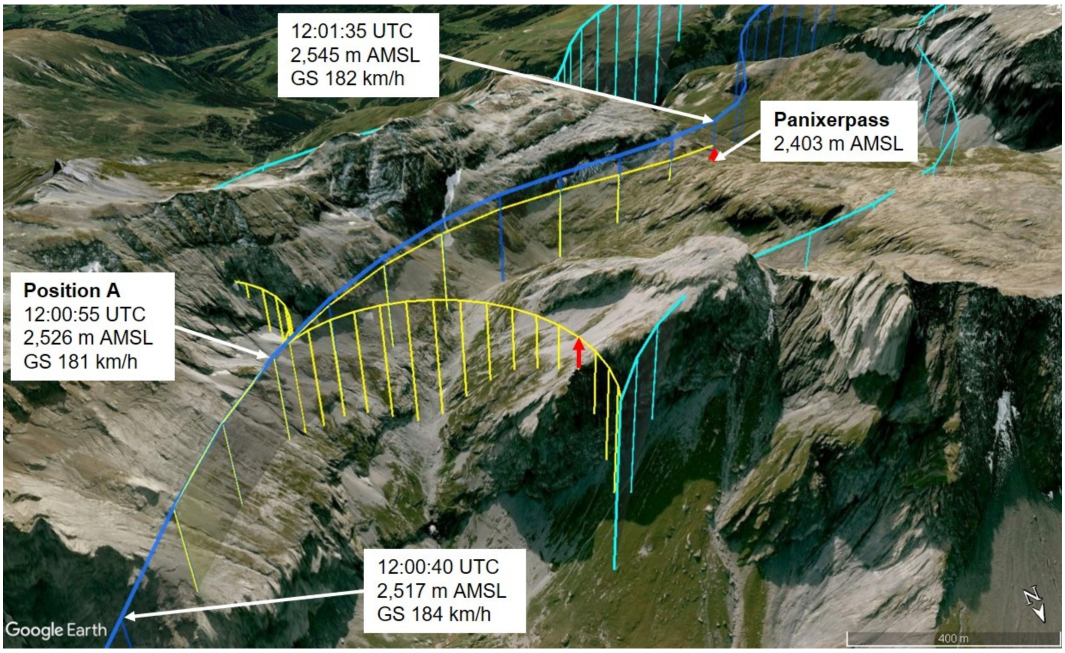

Figure 8: Flight path of HB-HOP on 4 August 2018, ascertained from GPS data (blue), including a zone 800 m either side and hypothetical flight paths at position A (yellow) assuming the sink rates described. Shown on Google Earth.

The saddle of the Piz d'Artgas mountain was flown over at 90 degrees to the saddle ridge at an altitude of less than 50 m above ground (red arrow in figure 9). A 180-degree turn was not possible from position B onwards, approximately 690 m or 17 seconds before the overflight. Had the flight hypothetically continued at a rate of descent of 2 m/s, it would have flown over the saddle of the mountain at a clearance of less than 10 m.

During the right turn south-west of the Kistenpass, the altitude when flying over the ridge at 90 degrees was approximately 60 m (orange arrow in figure 9).

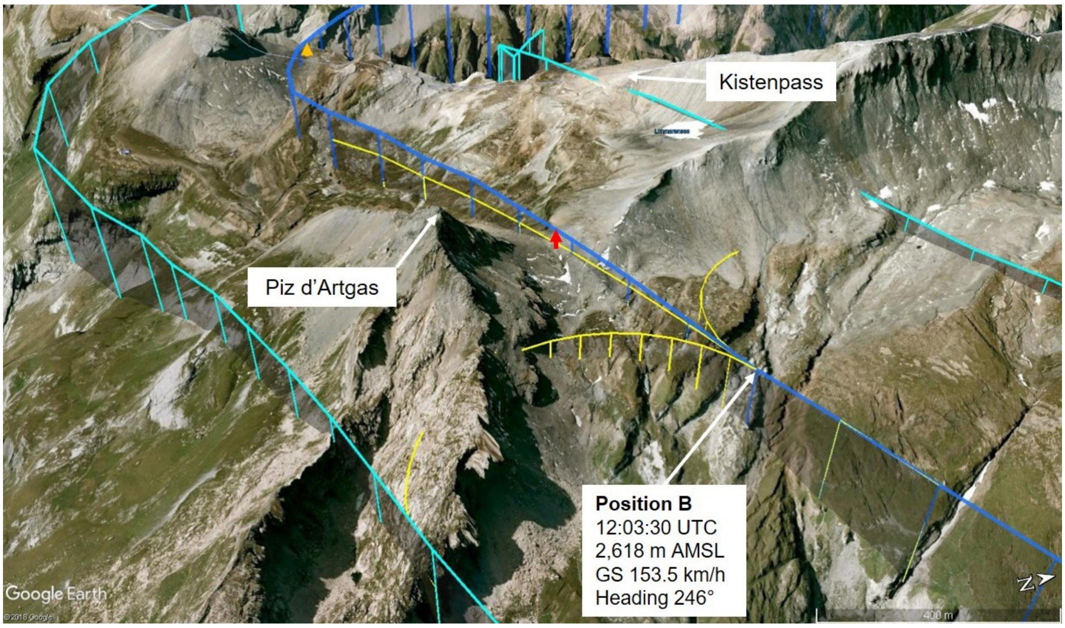

Figure 9: Flight path of HB-HOP on 4 August 2018, ascertained from GPS data (blue), including a zone 800 m either side and hypothetical flight paths at position B (yellow) assuming the sink rates described. Shown on Google Earth.

The comparison between the GPS and radar data (see section A1.18.2) shows that – in terms of quality – the above considerations at example positions A and B could have been determined in the same way using radar data only as the flight path sections inevitably had to pass through the V-shaped valley (figure 8 at position A) and over the ridge (figure 9 at position B), and as the available flight altitudes are sufficiently accurate.

A1.18.4 Analysis of flights in summer 2018

A1.18.4.1 General

Ju-Air did not have any systematic record of its flights' data. This meant that it was not possible to obtain data on previous flights from the aviation company. Radar data were used for analysis of the flights.

A1.18.4.2 Procedure and analysis of flights in summer 2018

In order to assess previous Ju-Air flights with regard to flying tactics in the mountains and general flight procedures, as well as for an exemplary presentation of flight data monitoring (FDM) (see section A1.18.4.4), radar data from flights between 6 April 2018 and 4 August 2018 were processed. During this period of around four months, Ju-Air carried out 406 flights. As flights from Dübendorf to the mountains further afield were of particular interest, the radar data for a total of 216 flights (over 50 % of all flights carried out) were obtained and analysed by the STSB based on flight duration and flight programme. For each flight, the choice of flight path in the mountains was assessed by two specialists. As with positions A and B of the flight involving HB-HOP on 4 August 2018 (see section A1.18.3), the flight path options in the event of any disruptions, for example loss of engine power or downdraughts, which do not represent an abnormal phenomenon in the mountains, were examined in detail.

As Ju-Air's operating manuals did not contain any instructions for flying in the mountains, generally accepted principles regarding the choice of flight path in the mountains were used as criteria, as are also taught to trainee pilots during their basic training. A selection of these analysed flights is presented in section A1.18.6.

The first round of flight assessment served to roughly filter notable flights; the radar data of all 216 available flights were only provisionally corrected in terms of altitude in this round. These data were then used for basic analysis. Particularly notable flights were examined in detail during the second round (see section A1.18.4.3).

The flight paths were analysed in 3D using cartographic tools from the Swiss Federal Office of Topography (Swisstopo) and Google Earth. Hazardous situations on the flight path were identified and independently assessed by two specialists. These hazardous situations are referred to as hotspots in the pages that follow. Each flight was given points ranging from 1 to 5. Here, 1 point means 'unremarkable', whilst 5 denotes 'extremely notable and very high-risk'. The two independently awarded points were added to a score for each flight. This resulted in a scale of scores ranging from 2 (considered unremarkable by both specialists) to 10 (considered extremely notable and very high-risk by both specialists). The results of this analysis, including the distribution of flights according to their score, are shown in figure 10.

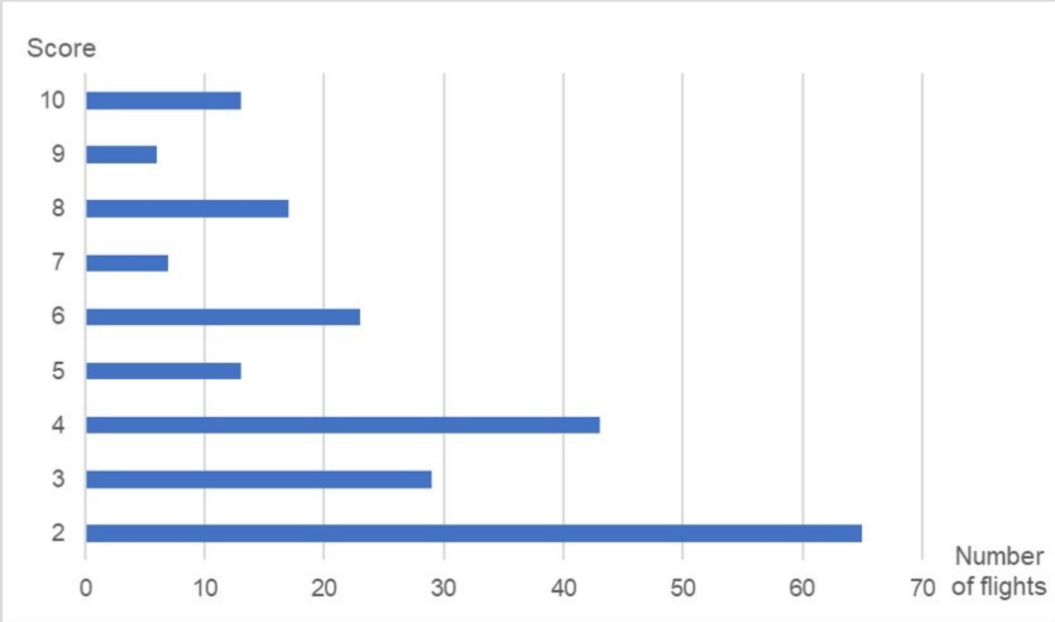

Figure 10: Evaluation of the 216 flights with a score ranging from 2 (unremarkable) to 10 (extremely notable and very high-risk).

It is striking that 79 flights (36.6 % of the 216 flights evaluated) were assessed as having medium and high scores, i.e. risk scores of 5 to 10. These deviations from the principles of safe flying in the mountains will henceforth be referred to as infractions. Flights with scores of 5 to 7 involve major infractions. Flights with a score of 8 to 10 involve massive infractions. This category comprises 36 (16.7 %) of the flights analysed.

In figure 11, infractions with a score of 5 to 10 are shown individually for each pilot. 16 out of a total 27 pilots exhibit major or massive infractions (score 5 to 10). The purpose of such analyses is to ascertain whether the infractions occurred with individual pilots or whether undesired conduct extended across the entire cohort of pilots.

The overall analysis shows that there were certainly pilots who were not listed at all as, not having caused any infractions, their flights had not been provided with scores of 5 to 10 or their flights, with few infractions only classified as minor, were barely noteworthy.

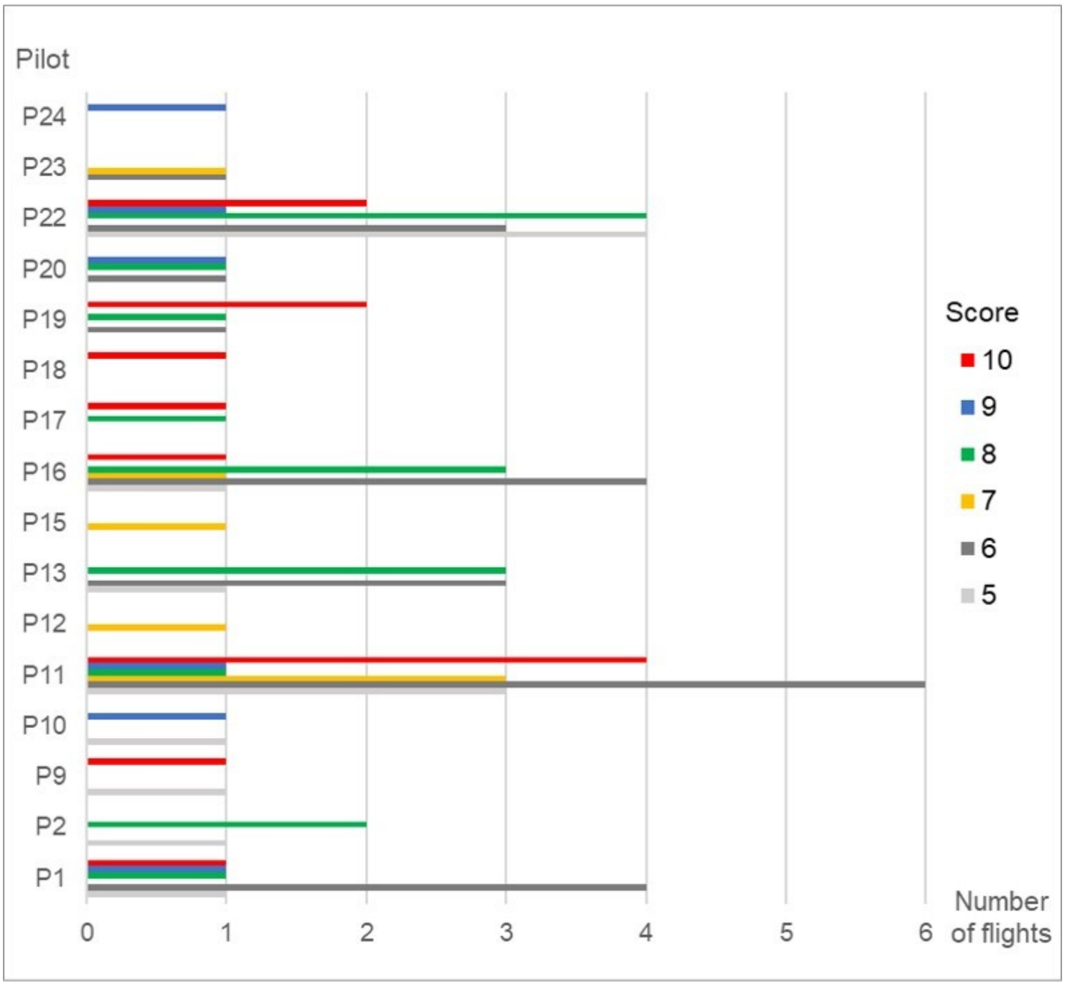

Figure 11: Analysis of the number of major and massive infractions with scores of 5 to 10 (x-axis) per pilot in command (y-axis).

Out of the 23 flights (10.6 % of the 216 flights evaluated) conducted by crews with a purely civilian background, five flights (21.7 %) exhibit infractions with a score of 5 to 10; one flight (4.3 %) had a score of 8 to 10. The flights evaluated included 193 flights that had been conducted by a crew with at least one member trained as an Air Force pilot. 74 flights of these flights (38.8 %) were given a score of 5 to 10 and 35 flights (18.1 %) a score of 8 to 10.

These figures show that in many instances, major and massive infractions involved pilots who had been trained as Air Force pilots[2] and then went on to have a career in civil aviation. This also applies to the pilots of the accident flight on 4 August 2018. Flights considered unremarkable (scores of 2 to 4) were predominantly carried out by crews with a purely civilian background.

It was also of interest as to whether and to what extent it was individual pilots or combinations of two pilots who caused the infractions with high scores. Out of the total of 216 flights evaluated, the pilots of the accident flight on 4 August 2018 performed 11 flights together acting as the cockpit crew. Four of these flights (36.4 %)

[2] Most of these pilots had 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.

were provided with a score of 8 to 10 – which is above the average of 16.7 % of all flights.

A1.18.4.3 Detailed investigation of notable flights

36 flights (16.7 % of the flights analysed) were identified as extremely notable and very high-risk with a score of 8 to 10. For these flights, single radar station data were collected. These tables were used to validate and verify the MRT data obtained and to estimate the radar accuracy on the relevant flight paths and in particular at the hotspots. These data tables can hold approximately 10 times more data than MRT tracks, which each consist of approximately 1,000 data points.

In addition, each data point of each of these MRT flight paths was corrected in terms of altitude using the method described in section A1.19.5.1. Deviations from the provisional estimates ranged between 30 and 50 m. The earlier, provisional estimate of the flight altitudes was higher than the more precise detailed calculation, apart from a few exceptions. This means that, on closer inspection, the majority of the flights analysed were carried out slightly lower and thus even closer to the terrain than originally assumed. Nevertheless, none of the flights was subsequently given a higher score than originally marked.

Apart from the evaluation for the scores, transponder altitudes of seven other flights as well as flights of the motor-powered Robin DR 400/140 B aircraft and sections of the flight path of a Cessna 152 which happened to fly past the Segnespass up ahead were also corrected. The altitudes of the Robin DR 400/140 B could also be compared with the aircraft's GPS data of the same flights on 3 and 4 August 2018, confirming the accuracy of the corrected altitudes.

The transponders from the Ju-Air fleet were not regularly checked for accuracy of pressure measurement and thus altitude transmission at various altitudes. This is also not a legal requirement. In order to assess the precision and potential device inaccuracies of the transponders of the inspected aircraft (HB-HOT, HB-HOP, HB-HOS), transmitted altitudes were compared with known actual altitudes. In addition to existing comparison altitudes from individual GPS data, the transmitted as well as corrected transponder altitudes on the taxiways and on the runway in Dübendorf were compared with the aerodrome's elevation.

The transponders of HB-HOT and HB-HOS displayed the readings correctly within the transponder's discrete accuracy of 100 ft. The transponder altitudes of HB-HOP were regularly too high by approximately 60 ft (2 hPa). It can therefore be assumed that all of the HB-HOP flights analysed were carried out approximately 60 ft lower than calculated. This deviation did not result in an increased score either.

An excerpt covering 10 flights and 27 hotspots of all of these 36 flights analysed in detail is provided in section A1.18.6.

A1.18.4.4 Flight data monitoring

A1.18.4.4.1 Preventive possibilities in relation to the accident

Ju-Air did not carry out any flight data monitoring (FDM)[3]. Nevertheless, it was of interest to assess to what extent an actively managed FDM system with clear

[3] Since 1 January 2005, FDM has been made mandatory in ICAO annex 6, section 3.6.3 for aviation companies operating aircraft with a maximum take-off mass (MTOM) that exceeds 27,000 kg. Since as early as 1 January 2002, ICAO annex 6 has recommended running a voluntary FDM programme for aircraft exceeding 20,000 kg MTOM. As part of a safety management system, flight data is to be monitored continuously to reduce the number of incidents and accidents. Frequently, FDM is also used voluntarily for lighter aircraft.

guidelines in the operating manuals and on flying in the mountains could have identified abnormalities at an early stage.

A1.18.4.4.2 Flight data monitoring in general

FDM, also very aptly referred to as flight operations quality assurance (FOQA) in the USA, is a system in which as many flights as possible are recorded, analysed and compared against a standard benchmark for parameters such as position, altitude, speed, bank attitude, etc. The standard benchmarks and thus the acceptable limits are defined in an aviation company's operating manuals. FDM is considered part of the safety management system (SMS) and is intended to make aviation safety measurable within a company. The aim is to assess compliance with the defined parameters. The effectiveness of changes in flight crew operating manuals involving improved procedures and regulations as well as the effect of additional safety-related instructions can often be directly gauged using FDM.

Each individual flight is typically compared against defined criteria by computer programmes, and deviations are marked. The flight safety manager checks, investigates and classifies these deviations. In the event of infractions, they contact the crew or, depending on severity, even conduct an internal investigation. The aim is not to punish the crews, but to learn from mistakes and to prevent unwanted situations in flight operations from occurring. The flight data are then anonymised and used for statistical trend and risk analysis in the SMS.

The system can be designed in a variety of ways depending on the aviation company. The following is an example of one possible approach, which is quite common for smaller aviation companies nowadays.

These days, classification usually involves three exceedance levels or FDM levels. The severity of deviations is assessed for each individual flight. Statistical distribution and clusters are then important for risk assessment in flight operations.

An actively managed FDM system endeavours to reduce the number and severity of infractions by taking appropriate measures such as the introduction of additional instructions, training programmes and changes to procedures.

A1.18.4.4.3 Example FDM representation for the flights in summer 2018

The score analyses outlined in section A1.18.4.2 cover approximately 50 % of the flights that took place in the 2018 flight season, which lasted around four months.

These flights can also be illustrated within an FDM system using common criteria for flying in the mountains.

When applying the example approach described above for an assessment in line with FDM principles and assigning the scores to FDM levels, the data can be presented as in table 1, for example. This enables a flight safety manager and the head of flight operations to form an opinion on their own flight operations and make the necessary risk assessments.

If FDM analyses are presented more elaborately and the development of the individual figures is examined over time, undesired tendencies can be identified and corrected at an early stage.

When introducing measures, their effect can then be evaluated in the next analysis period. The effectiveness of an SMS with regard to flight safety can therefore be gauged using FDM.

As there were no instructions for flying in the mountains in the operating manuals and FDM was not carried out, such analyses of previous flights can only be conducted using examples and based on the assumption of acceptable critical values.

Score	FDM level		Description	Number of flights	Percentage [%]
2	0		Normal operation	65	30.1 %
3–4	1		Minor infraction	72	33.3 %
5–7	2		Major infraction	43	19.9 %
8–10	3		Massive infraction	36	16.7 %

Table 1: Table of the various exceedance levels and the distribution of the number of flights (216 in total) according to FDM classification with the assigned scores from figure 10.

In commercial aviation, a typical pattern in the annual statistical analysis of an actively managed and mature FDM system would include over 90 % of flights with no abnormalities (FDM level 0) and a high number of flights at FDM level 1. Only a few flights would be registered at FDM level 2. Flights at FDM level 3 should be an absolute exception.

A1.18.5 Methodology and definition of variables of the detailed flight path review

The detailed flight path review is based on the analysis of the flights in summer 2018 (see section A1.18.4). The definitions of variables and tolerances regarding GPS and radar position accuracy are outlined in section A1.18.2 and section A1.19.5.

The choice of flight path was qualitatively reviewed. The sister aircraft HB-HOT, HB-HOP and HB-HOS were examined equally, and no focus was placed on HB-HOT. The flights were assessed in the context of a sightseeing flight involving maximum bank attitudes of 30 degrees during turns with no wind. The prevailing general weather conditions, the extent of any cloud cover and the prevailing level of visibility along the route were not taken into account in this assessment.

The entire flight path for each flight is displayed in an overview. The identified risky situations (hotspots) are marked with a yellow circle (see figure 12). Each hotspot is shown in a separate figure. The screenshots do not include an indication of North. A red arrow indicating the direction of flight aids orientation (see figure 13).

Due to leeway in the lateral position, the radar flight path occasionally intersects the terrain (negative height, < 0 m above ground, see figure 40). The difference in altitude between the radar flight path and the terrain profile was determined at two different points. Height 1 is the difference in altitude between the radar flight path and the terrain profile. Height 2 is the difference in altitude at the lowest point of the terrain profile within 150 m either side of the centre line of the radar flight path. The heights were displayed graphically and rounded down to the nearest whole metre. In some cases, the differences in altitude of heights 1 and 2 are equal (see figures 14 and 15).

The following definitions have been used for the systematic breakdown of height 1:

- ≥ 75 m to < 150 m : low-level flight over the terrain
- < 0 m to < 75 m : very low-level flight over the terrain

The identified hotspots were assessed based on safety-related features. The overall assessment of the choice of flight path results from a combination of the individual features. The total points constitute the sum of the points of the individual safety-related features (see table 2):

Safety-related features		Points
Turning towards an obstacle	:	0.5
Rising terrain in the direction of flight	:	0.5
Low-level flight over the terrain	:	0.5
Restricted view of the following section of terrain	:	0.5
Limited possibility of an alternative flight path	:	1
Approaching an obstacle whilst climbing	:	1
Very low-level flight over the terrain	:	1
No possibility of an alternative flight path for a prolonged period of time	:	3

Evaluation categories		
0.5 to < 2 points	2 to < 3 points	3 or more points
Moderate-risk choice of flight path	High-risk choice of flight path	Very high-risk choice of flight path

Table 2: Overview of safety-related features and evaluation categories.

An overview of flights involving a risky flight path, classified as ‘moderate-risk’, ‘high-risk’ or ‘very high-risk’, are listed in section A1.18.6. Other flights, such as line checks assessing the pilots during regular flight operations, are listed separately in section A1.18.7.

A1.18.6 Representative selection of risky Ju-Air flights and hotspots

A1.18.6.1 General

The following selection of 10 risky flights with a total of 27 rated hotspots, which have been classified as either 'moderate-risk', 'high-risk' or 'very high-risk', are described in detail on the upcoming pages.

A1.18.6.2 Flight_0525_01_HOT

A1.18.6.2.1 Overview of the flight path

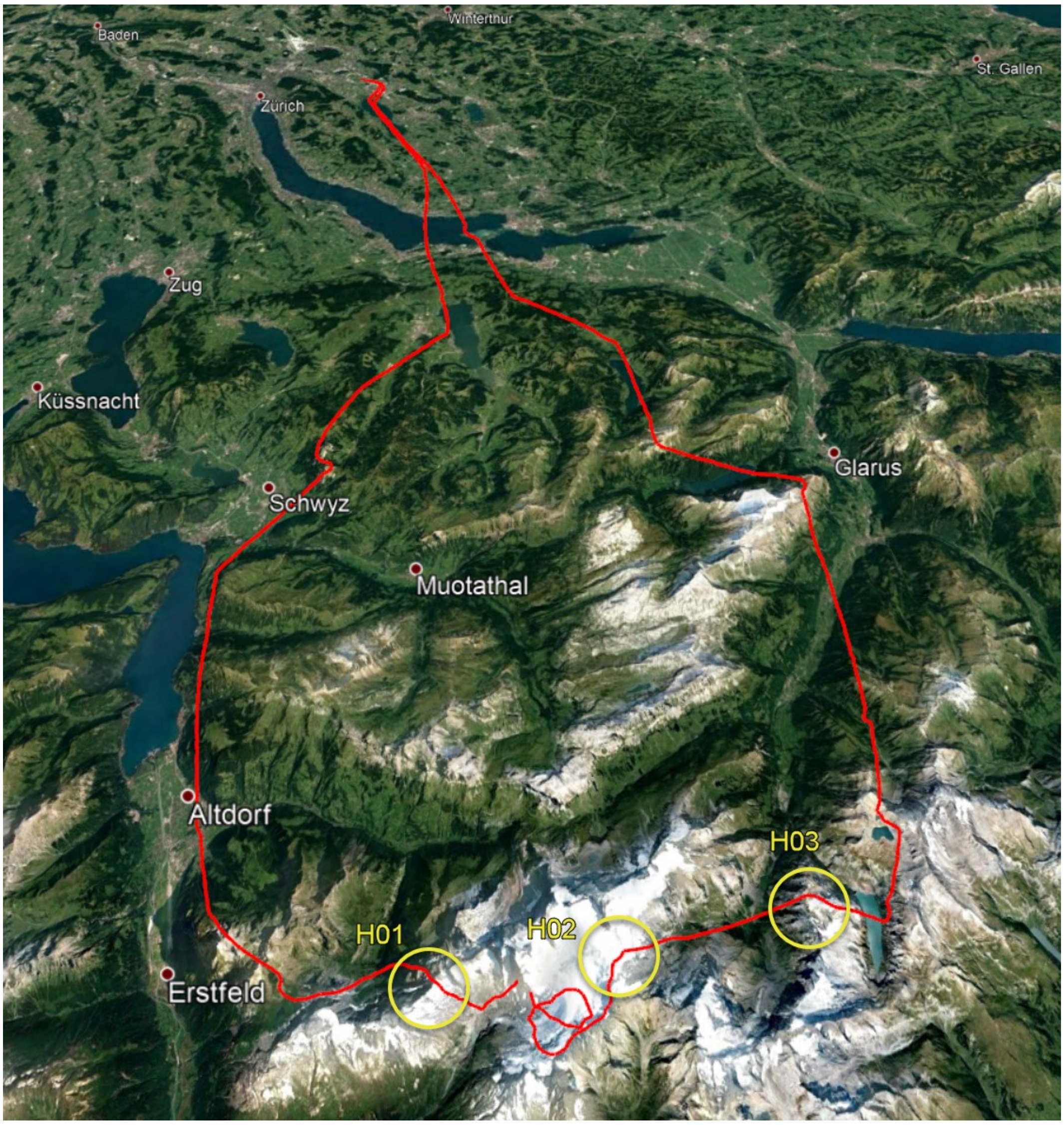

Figure 12: Overview of the flight path including hotspots H01 to H03 (yellow circles). Shown on Google Earth.

A1.18.6.2.2 Hotspot H01

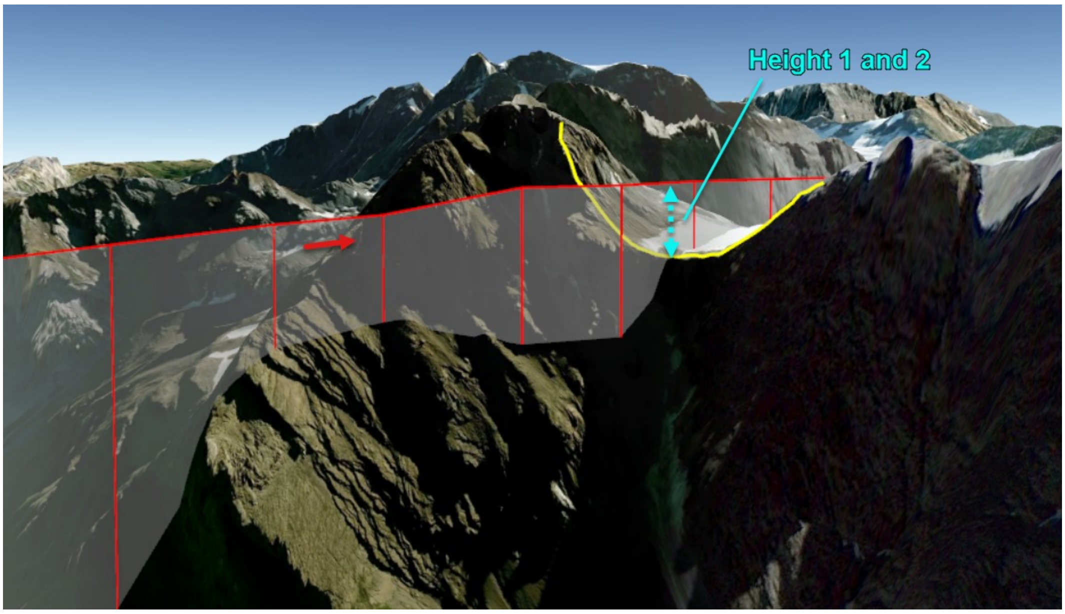

Figure 13: Climbing overflight at 90 degrees to the saddle of the mountain ridge at an altitude of 2,732 m AMSL with a height of 122 m above ground directly below the radar flight path (height 1) and 122 m above ground with respect to the lowest point of the terrain profile (height 2). Shown on Google Earth.

Figure 13 shows a choice of flight path classified as ‘very high-risk’, which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Approaching an obstacle whilst climbing;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.2.2.1 Height 1

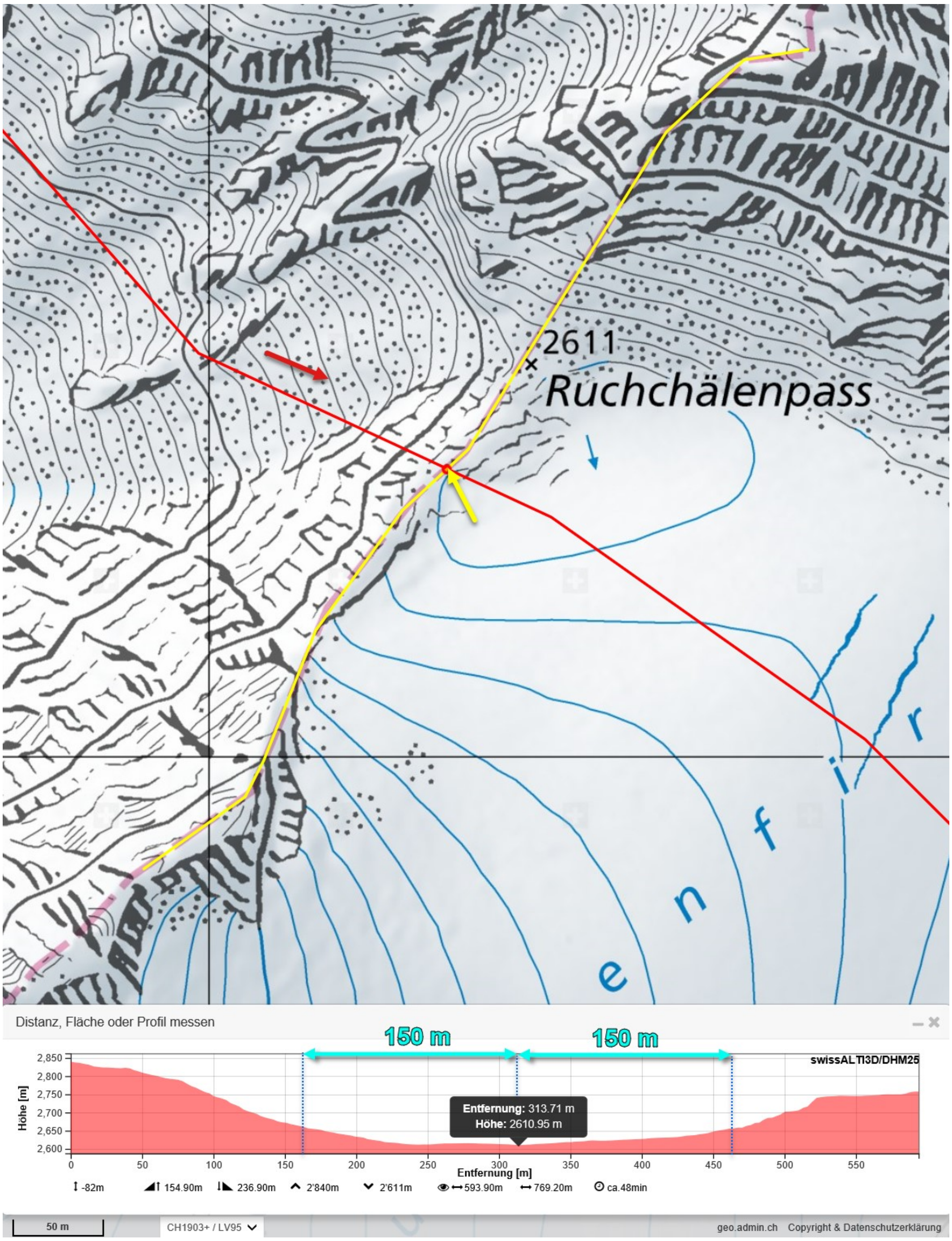

Figure 14: Depiction of the radar flight path (red line) in the direction of flight (red arrow) and the terrain profile (yellow line) with a height of 122 m above ground (2,610 m AMSL) directly below the radar flight path (yellow arrow) as well as a cross-section of the terrain 150 m to either side of the flight path (turquoise). Source of the base map: Swiss Federal Office of Topography.

A1.18.6.2.2.2 Height 2

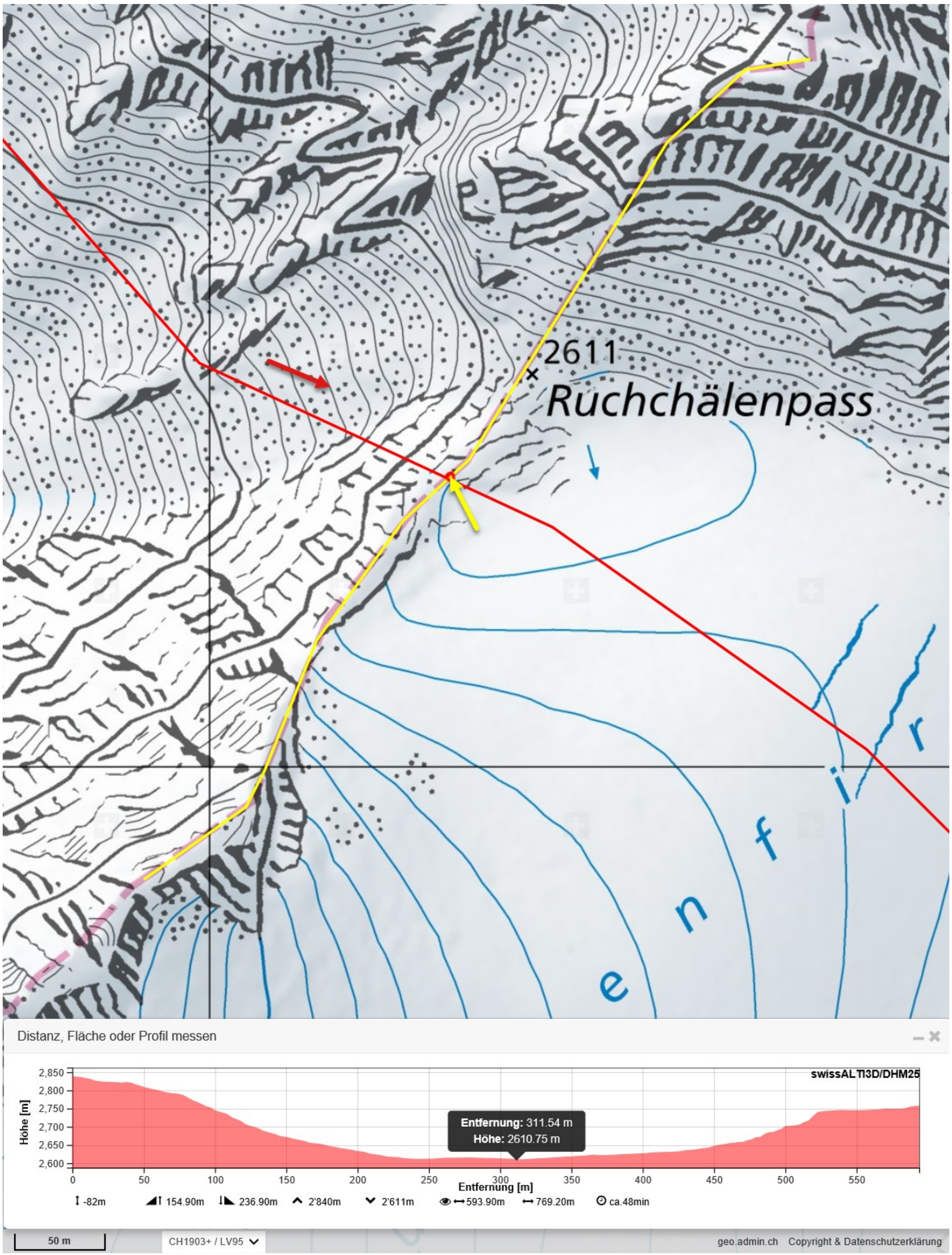

Figure 15: Depiction of the radar flight path (red line) in the direction of flight (red arrow) and the terrain profile (yellow line) with a height of 122 m above ground (2,610 m AMSL) at the lowest point of the terrain profile (yellow arrow). Source of the base map: Swiss Federal Office of Topography.

A1.18.6.2.3 Hotspot H02

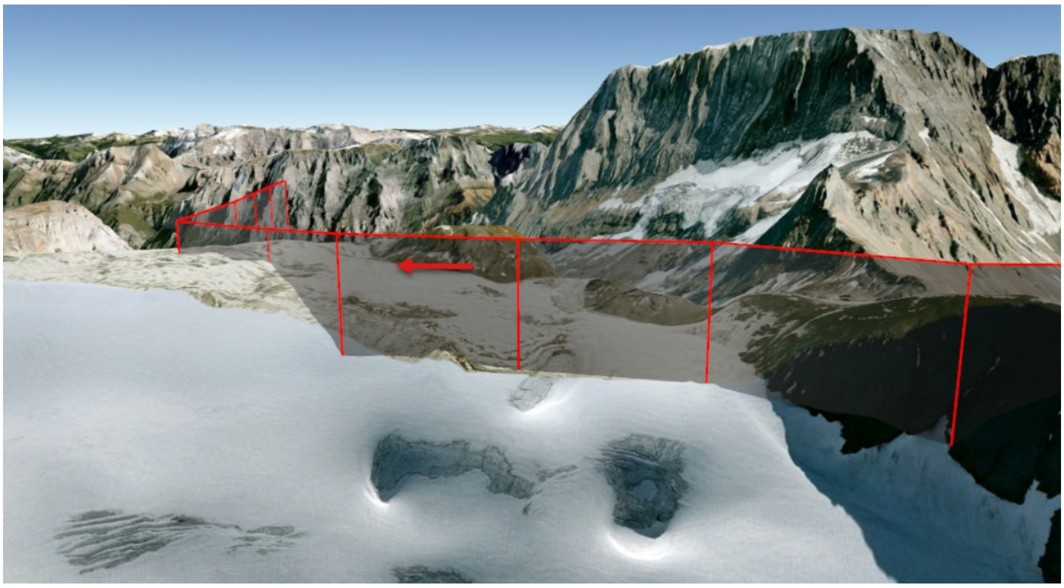

Figure 16: Descending flight over the terrain at an altitude of 3,014 m AMSL with a height of 73 m above ground directly below the radar flight path and 78 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 16 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Restricted view of the following section of terrain;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.2.4 Hotspot H03

Figure 17: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,982 m AMSL with a height of 88 m above ground directly below the radar flight path and 96 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 17 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path.

A1.18.6.3 Flight_0526_05_HOT

A1.18.6.3.1 Overview of the flight path

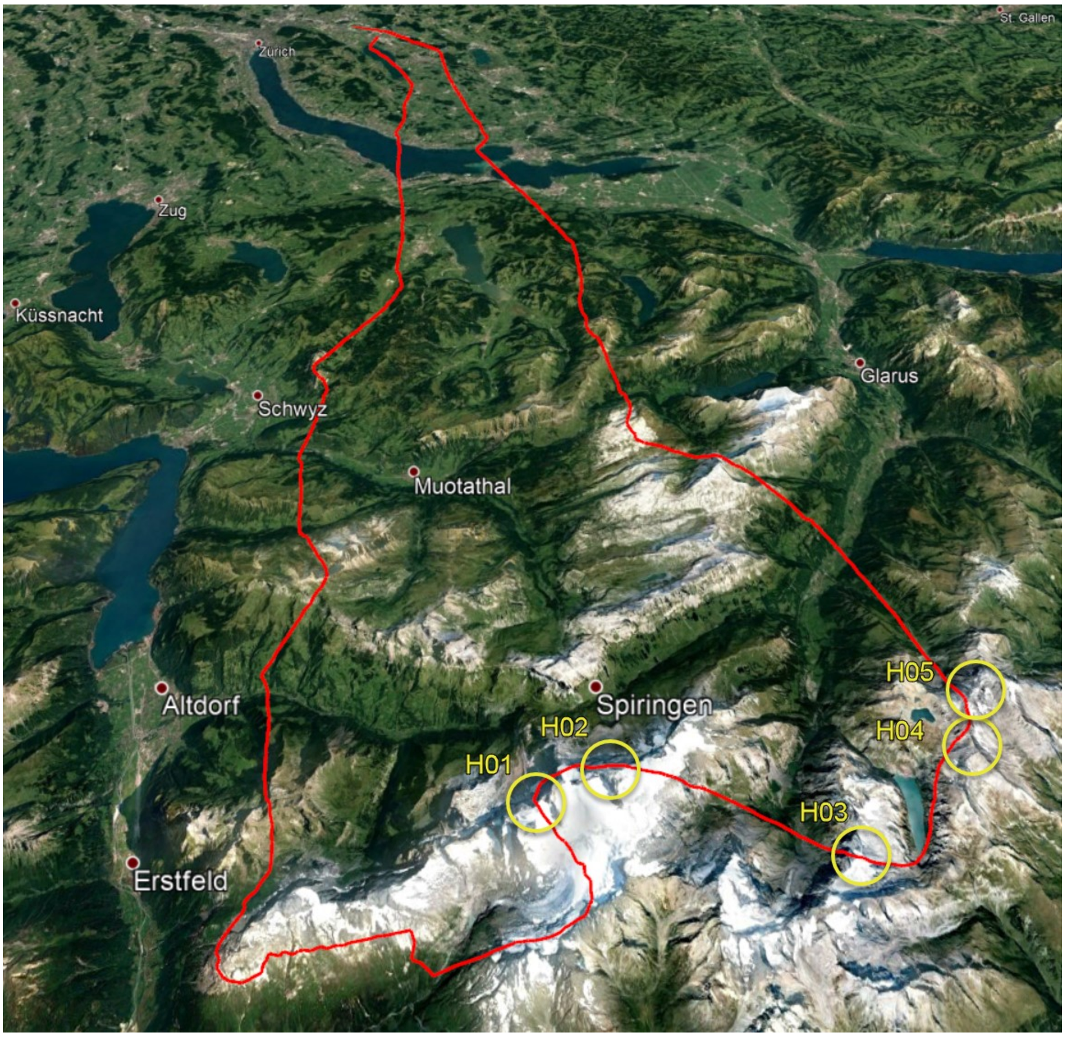

Figure 18: Overview of the flight path including hotspots H01 to H05 (yellow circles). Shown on Google Earth.

A1.18.6.3.2 Hotspot H01

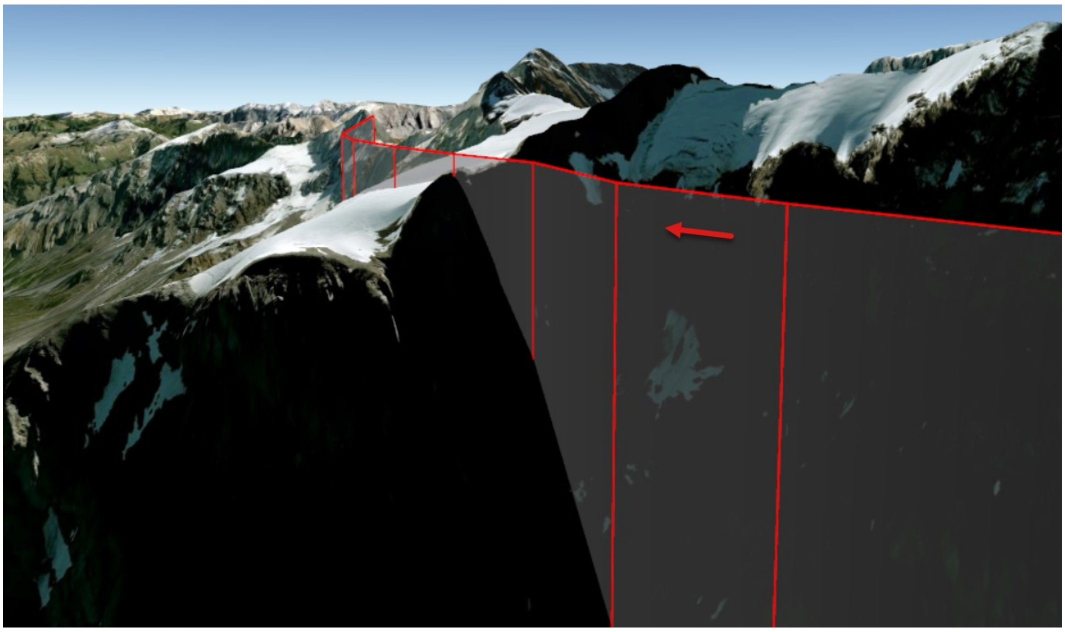

Figure 19: Horizontal flight over the crest of the mountain ridge at an altitude of 3,053 m AMSL with a height of 40 m above ground directly below the radar flight path and 101 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 19 shows a choice of flight path classified as ‘high-risk’, which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.3.3 Hotspot H02

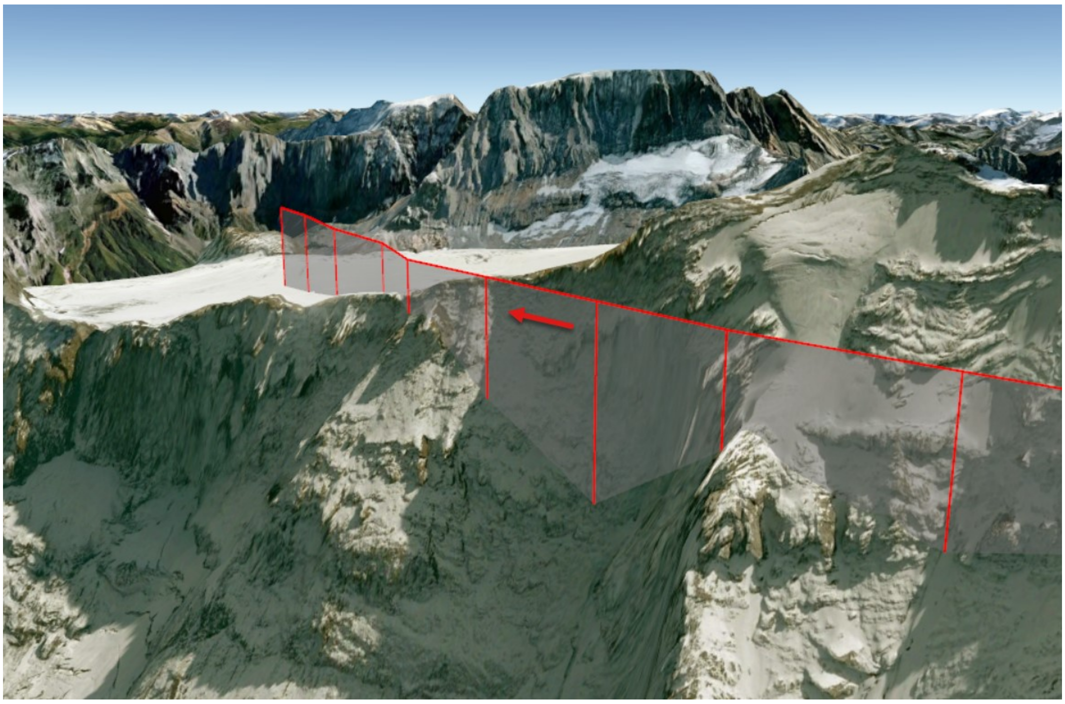

Figure 20: Horizontal flight over the crest of the mountain ridge at an altitude of 3,084 m AMSL with a height of 69 m above ground directly below the radar flight path and 92 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 20 shows a choice of flight path classified as ‘high-risk’, which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.3.4 Hotspot H03

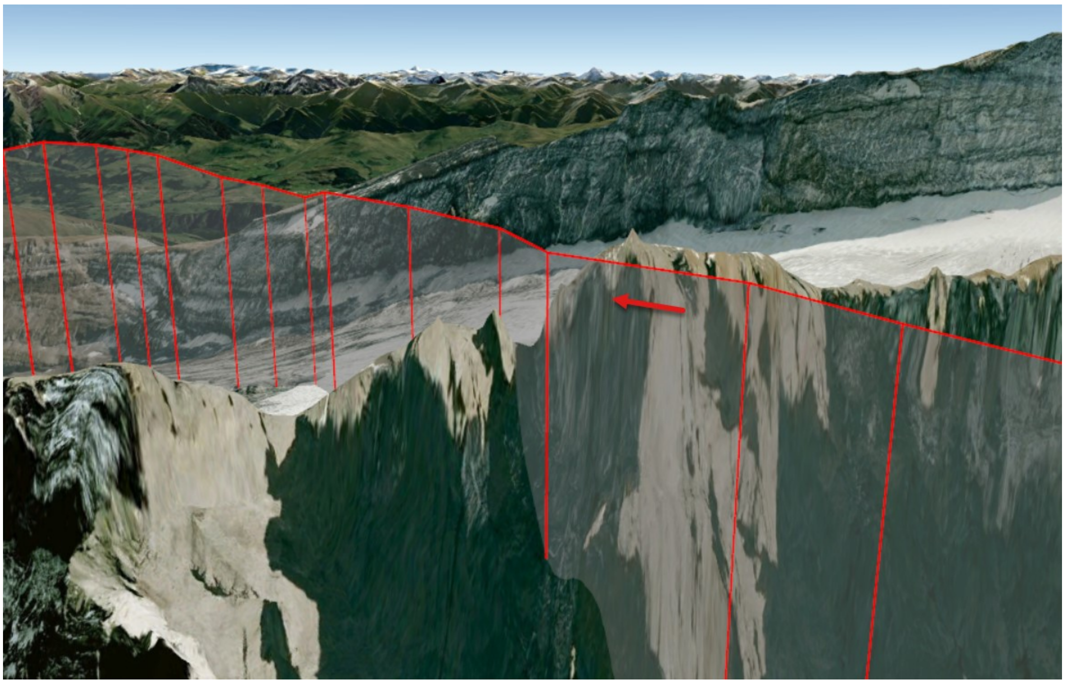

Figure 21: Horizontal overflight at almost 90 degrees to the crest of the mountain ridge at an altitude of 3,084 m AMSL with a height of 116 m above ground directly below the radar flight path and 187 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 21 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path.

A1.18.6.3.5 Hotspot H04

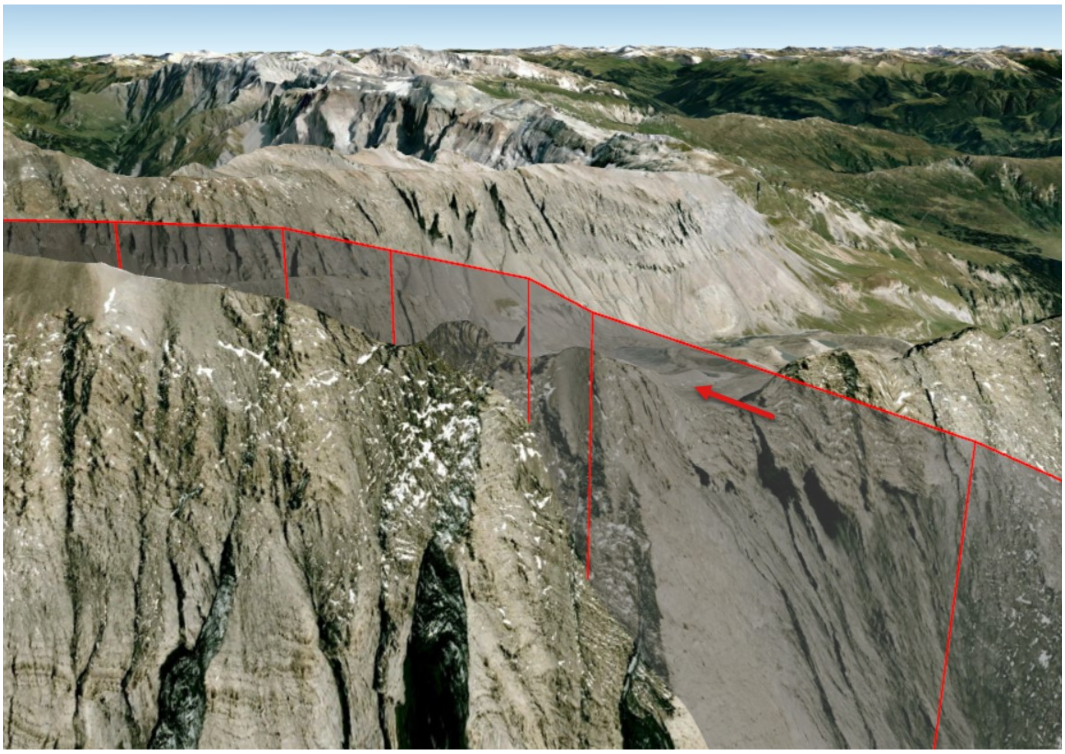

Figure 22: Horizontal flight over the crest of the mountain ridge at an altitude of 3,112 m AMSL with a height of 85 m above ground directly below the radar flight path and 96 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 22 shows a choice of flight path classified as ‘high-risk’, which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path.

A1.18.6.3.6 Hotspot H05

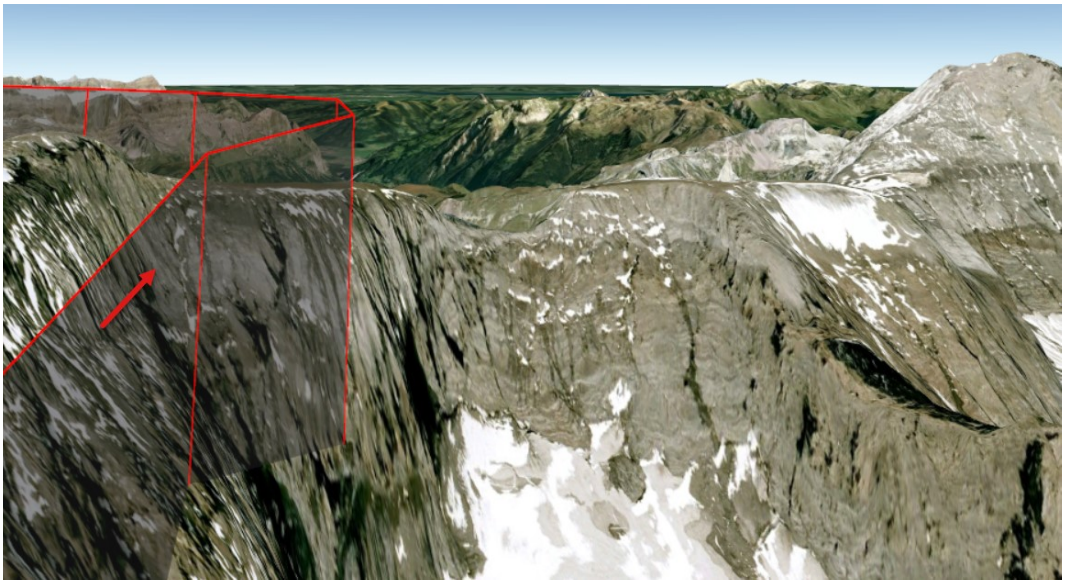

Figure 23: Horizontal overflight at an altitude of 3,112 m AMSL with a height of 62 m above ground directly below the radar flight path and 106 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 23 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.4 Flight_0602_01_HOS

A1.18.6.4.1 Overview of the flight path

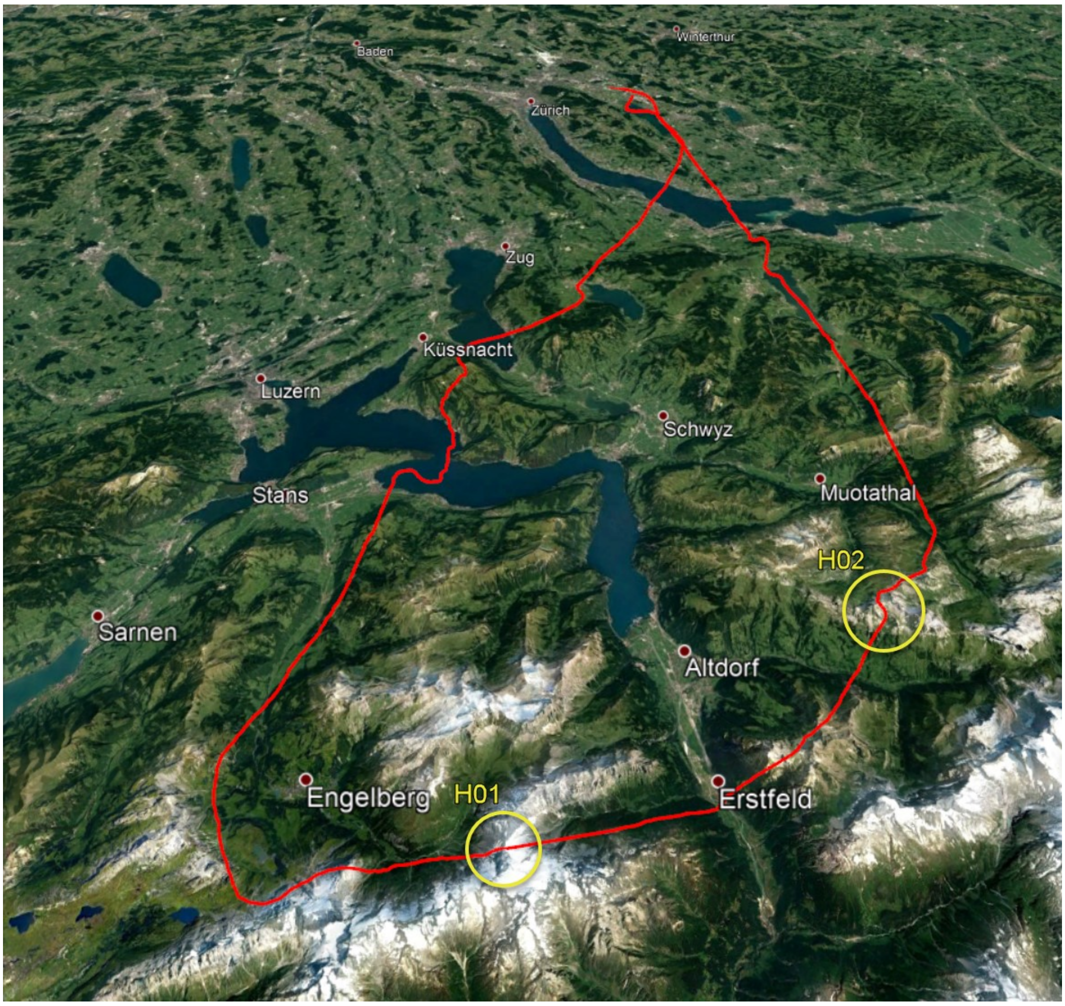

Figure 24: Overview of the flight path including hotspots H01 and H02 (yellow circles). Shown on Google Earth.

A1.18.6.4.2 Hotspot H01

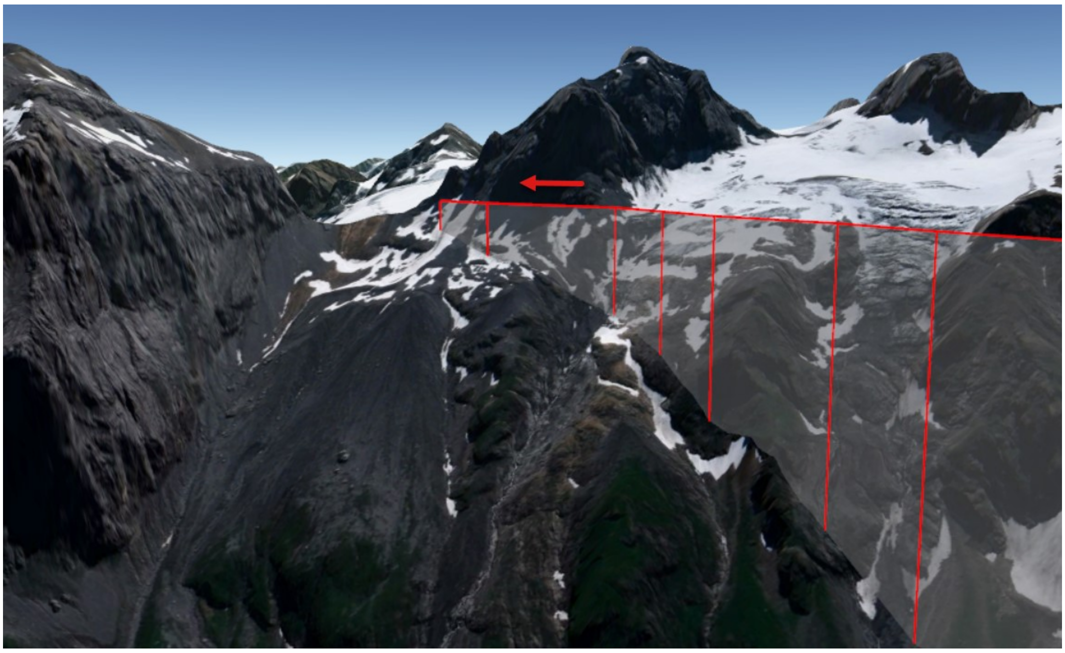

Figure 25: Horizontal flight over the crest of the mountain ridge at an altitude of 2,704 m AMSL with a resulting height at a constant flying altitude of 46 m above ground directly below the radar flight path and 75 m above ground with respect to the lowest point of the terrain profile. Data extrapolated by the radar system were omitted. Shown on Google Earth.

Figure 25 shows a choice of flight path classified as ‘very high-risk’, which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Restricted view of the following section of terrain;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.4.3 Hotspot H02

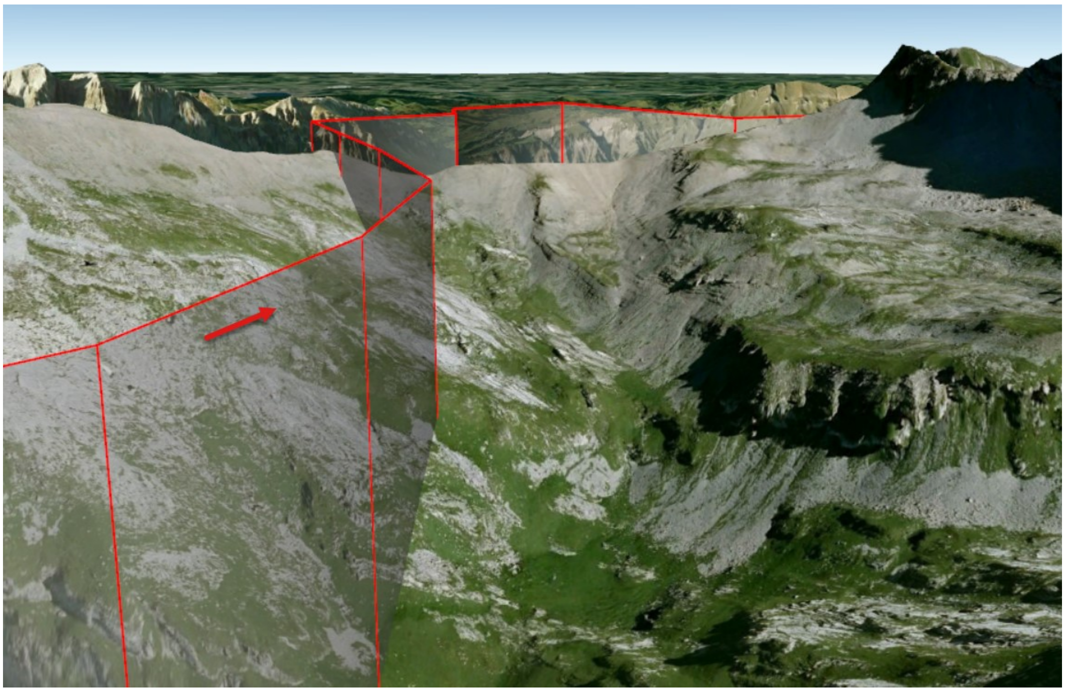

Figure 26: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,418 m AMSL with a height of 26 m above ground directly below the radar flight path and 59 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 26 shows a choice of flight path classified as ‘very high-risk’, which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Restricted view of the following section of terrain;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.5 Flight_0606_01_HOP

A1.18.6.5.1 Overview of the flight path

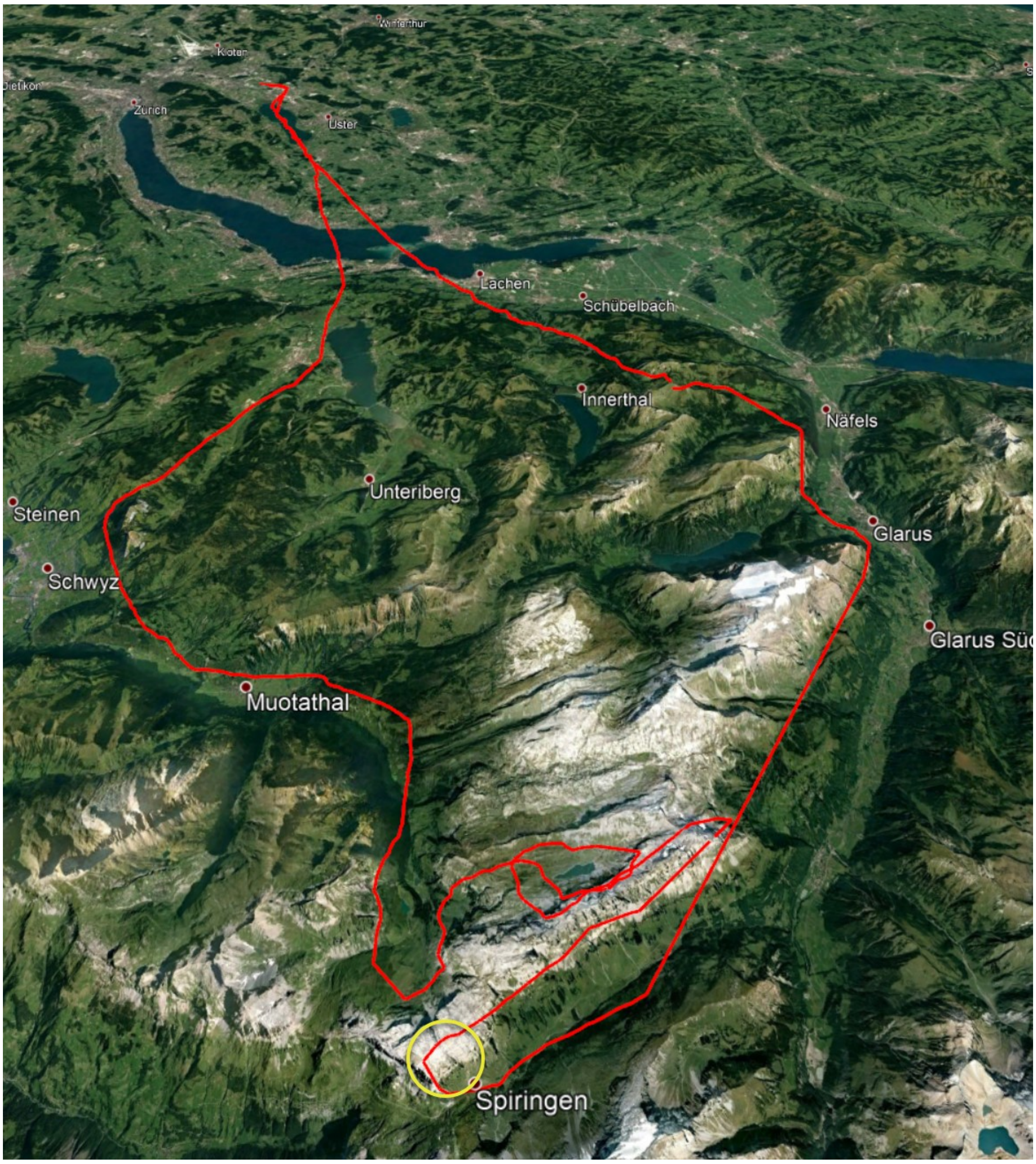

Figure 27: Overview of the flight path including hotspot (yellow circle). Shown on Google Earth.

A1.18.6.5.2 Hotspot

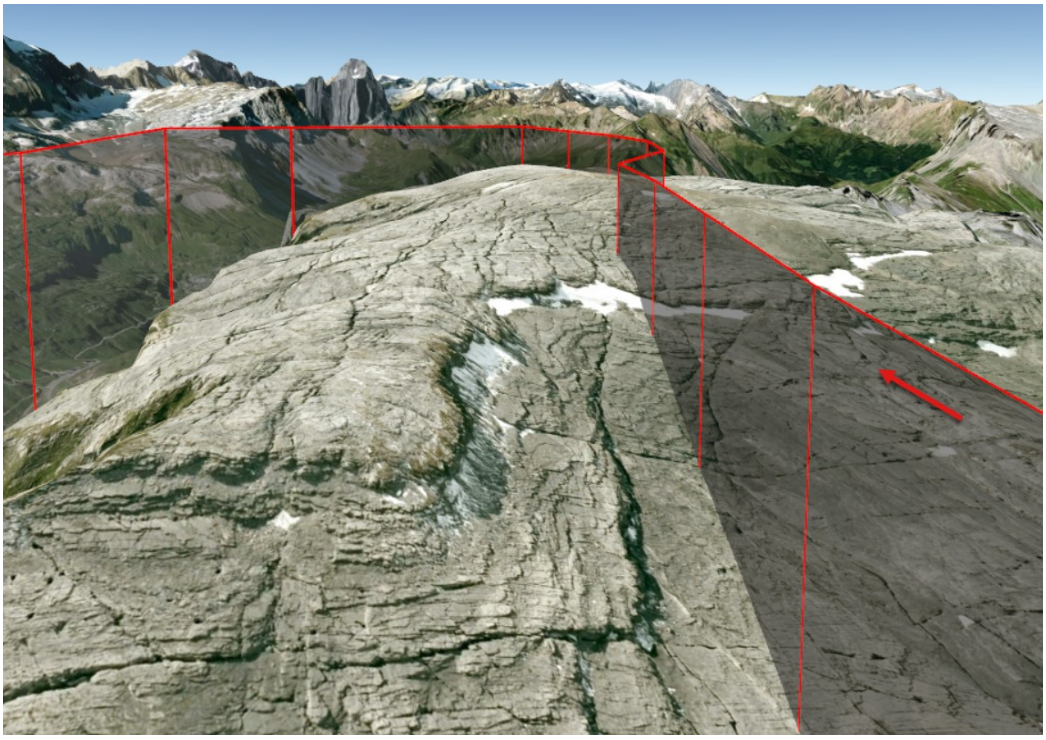

Figure 28: Horizontal flight over the terrain at an altitude of 2,541 m AMSL with a height of 60 m above ground directly below the radar flight path and 76 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 28 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Limited possibility of an alternative flight path;
- Restricted view of the following section of terrain;
- Very low-level flight over the terrain.

A1.18.6.6 Flight_0623_02_HOT

A1.18.6.6.1 Overview of the flight path

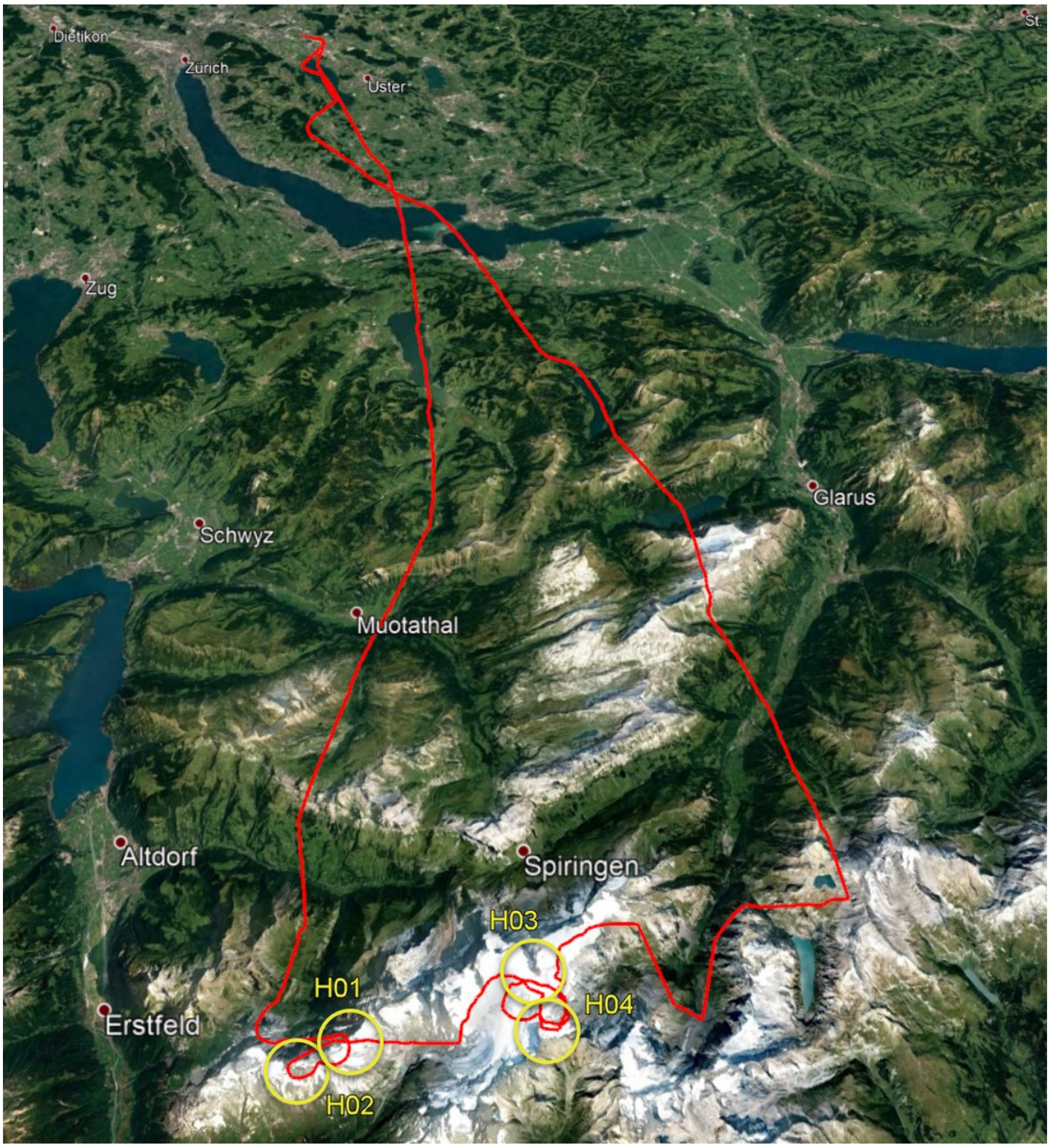

Figure 29: Overview of the flight path including hotspots H01 to H04 (yellow circles). Shown on Google Earth.

A1.18.6.6.2 Hotspot H01

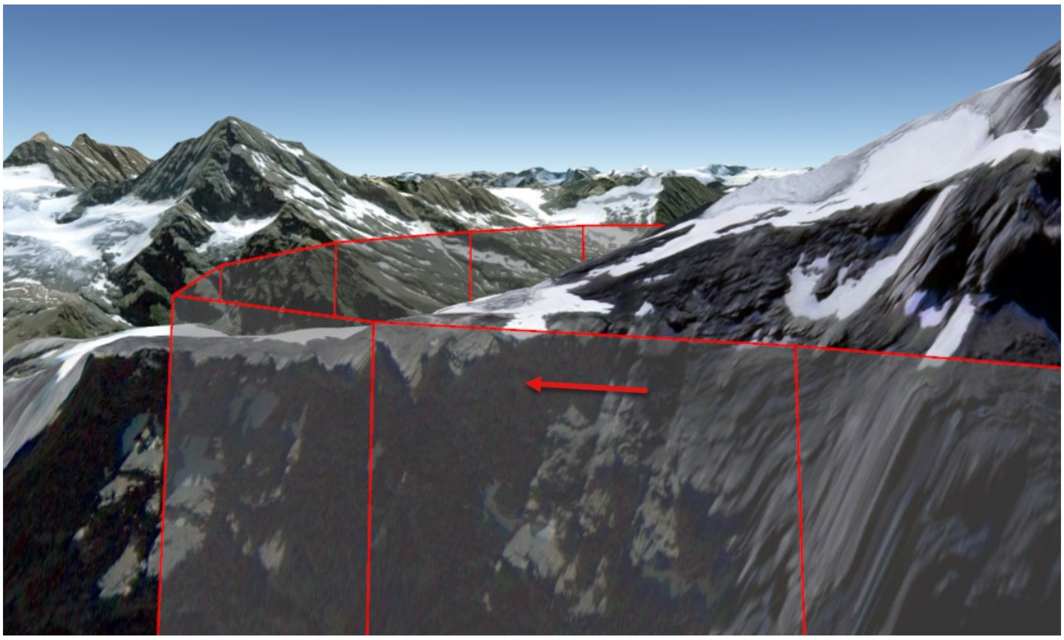

Figure 30: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,887 m AMSL with a height of 65 m above ground directly below the radar flight path and 81 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 30 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.6.3 Hotspot H02

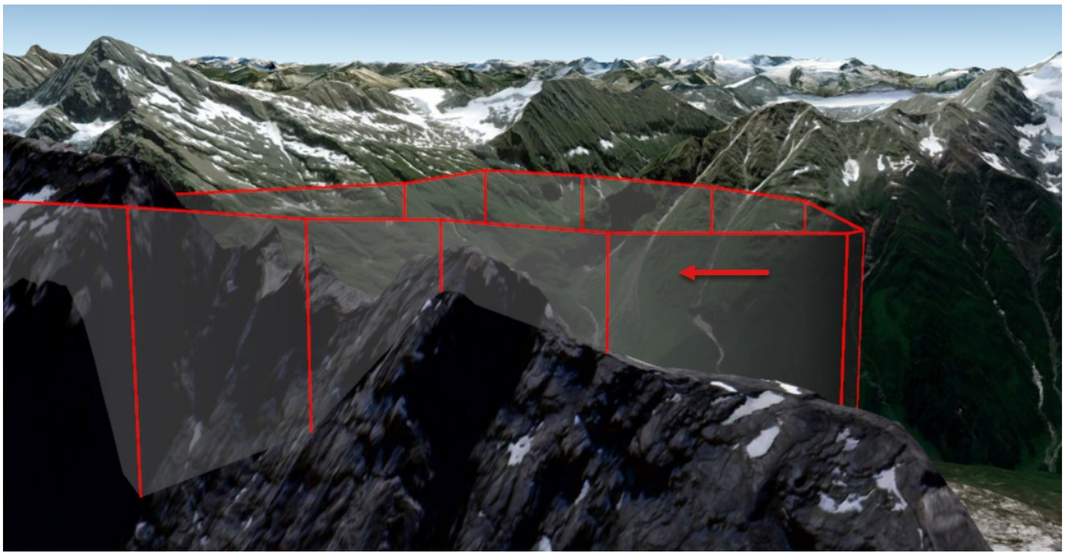

Figure 31: Climbing flight over the crest of the mountain ridge at an altitude of 2,949 m AMSL with a height of 95 m above ground directly below the radar flight path and 121 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 31 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Approaching an obstacle whilst climbing.

A1.18.6.6.4 Hotspot H03

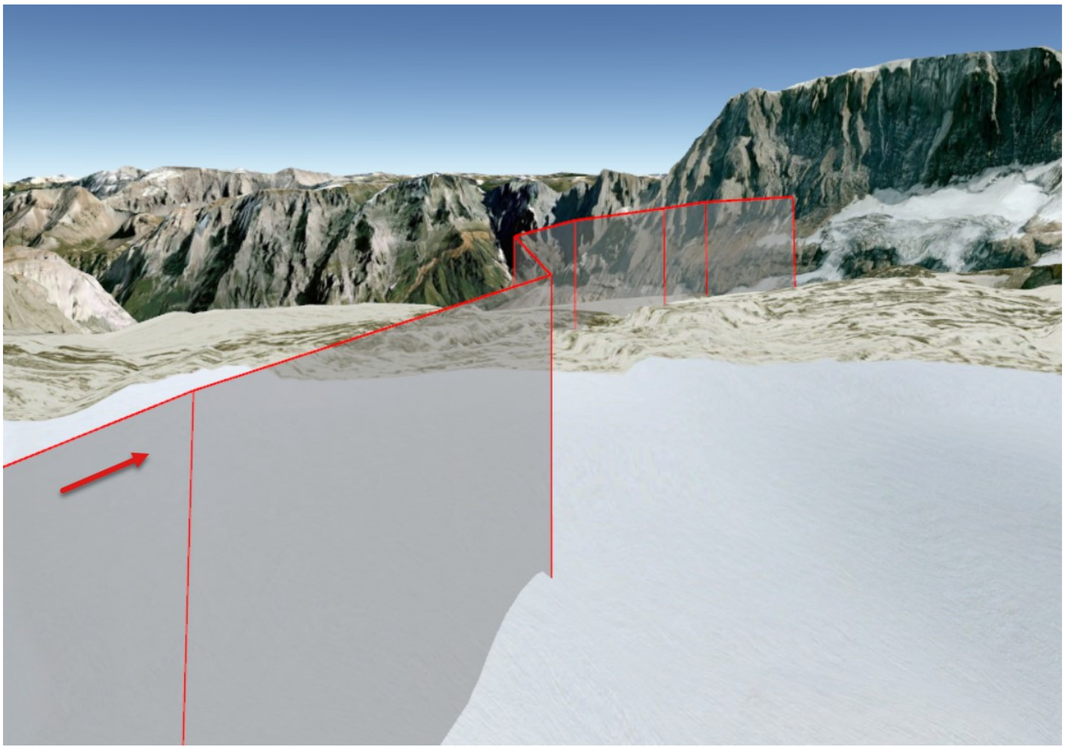

Figure 32: Horizontal flight over the terrain at an altitude of 3,045 m AMSL with a height of 102 m above ground directly below the radar flight path and 102 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 32 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path.

A1.18.6.6.5 Hotspot H04

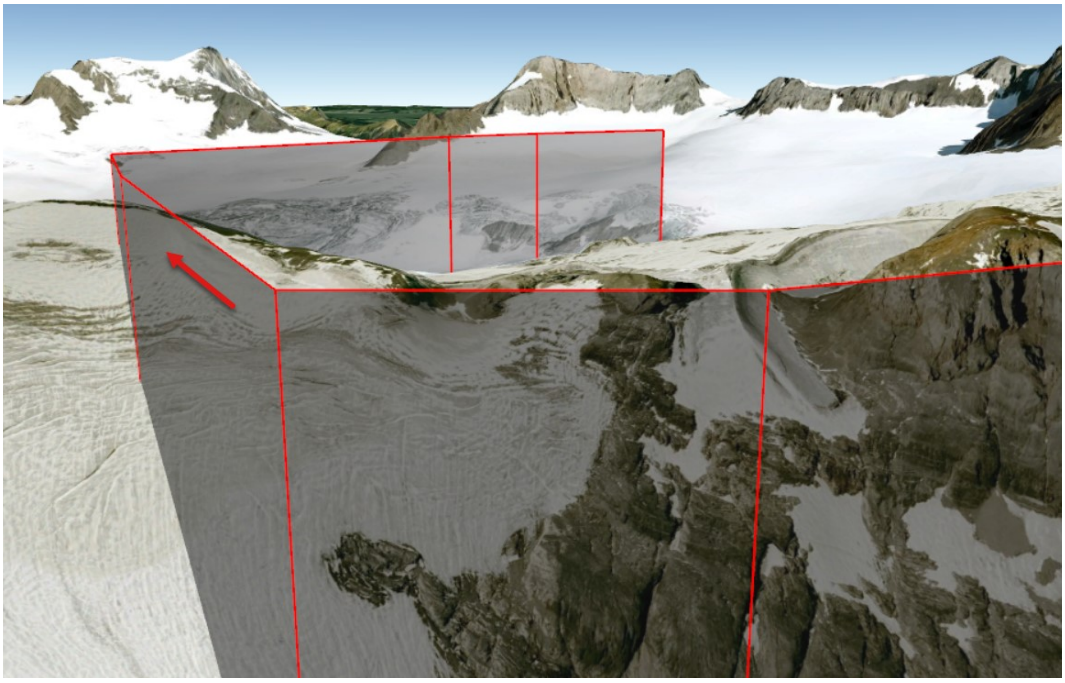

Figure 33: Horizontal flight over the crest of the mountain ridge at an altitude of 3,045 m AMSL with a height of 84 m above ground directly below the radar flight path and 121 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 33 shows a choice of flight path classified as ‘very high-risk’, which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.7 Flight_0712_01_HOS

A1.18.6.7.1 Overview of the flight path

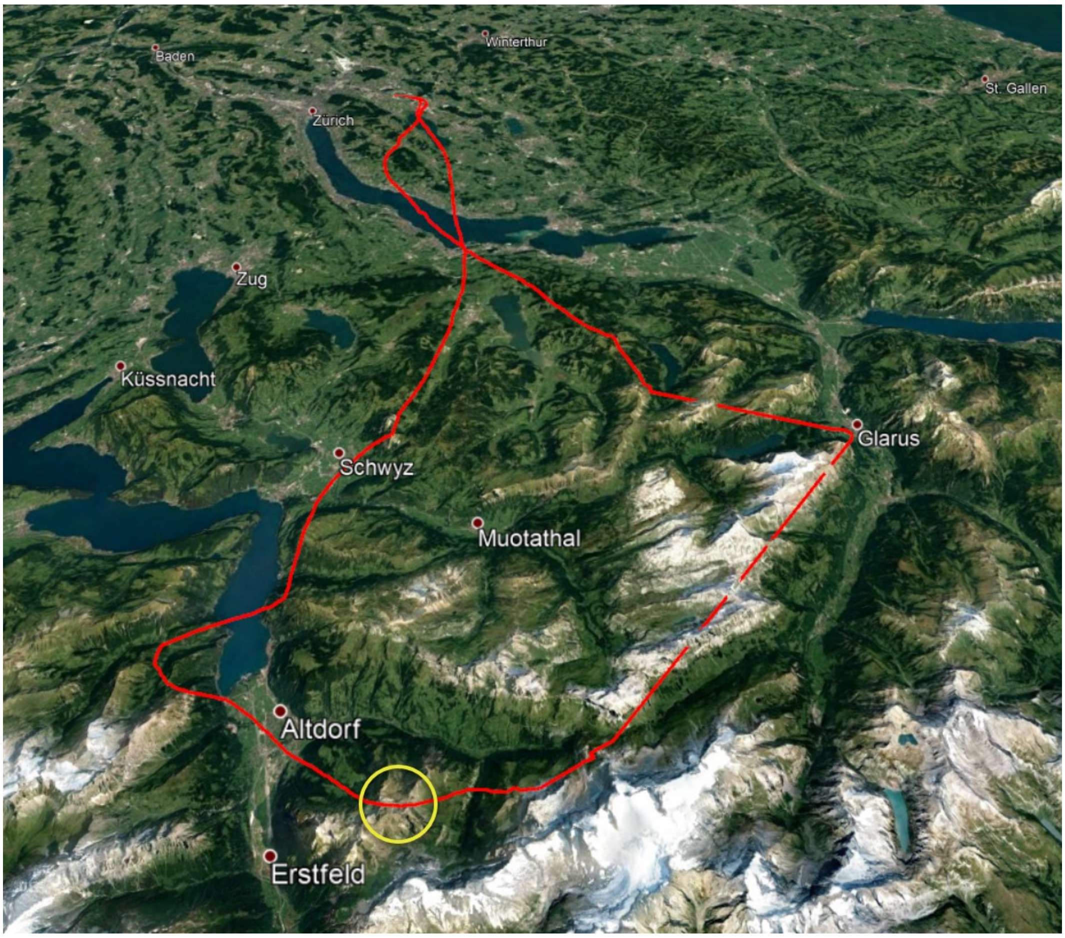

Figure 34: Overview of the flight path including hotspot (yellow circle). Shown on Google Earth.

A1.18.6.7.2 Hotspot

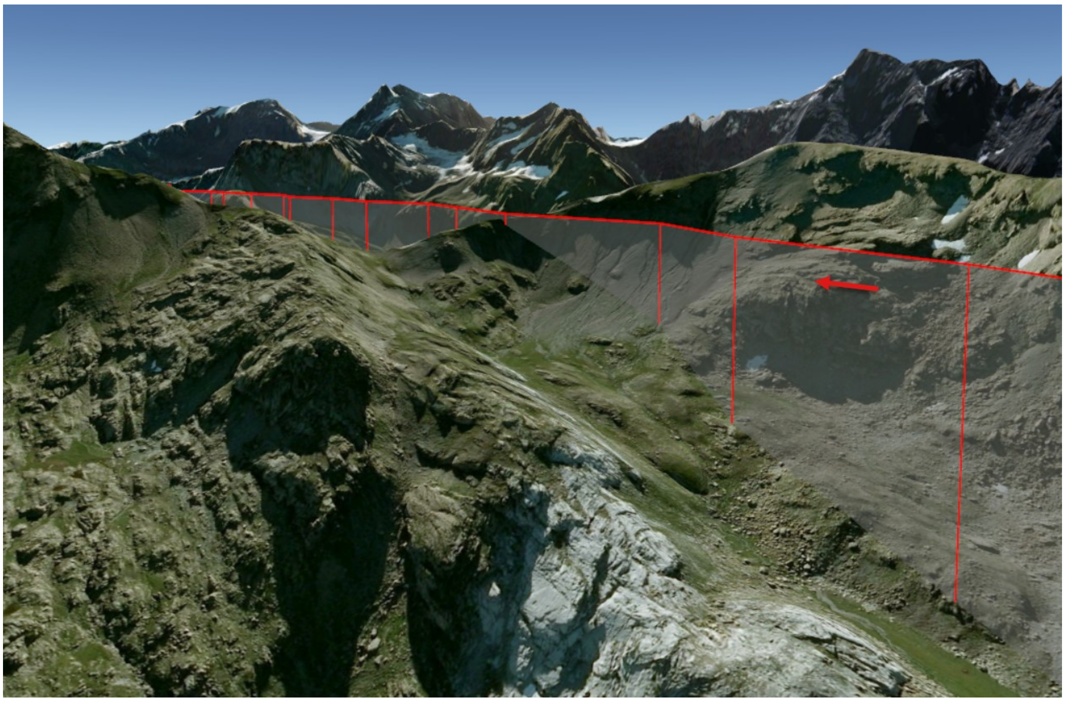

Figure 35: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,375 m AMSL with a height of 9 m above ground directly below the radar flight path and 42 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 35 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Restricted view of the following section of terrain;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.8 Flight_0713_02_HOT

A1.18.6.8.1 Overview of the flight path

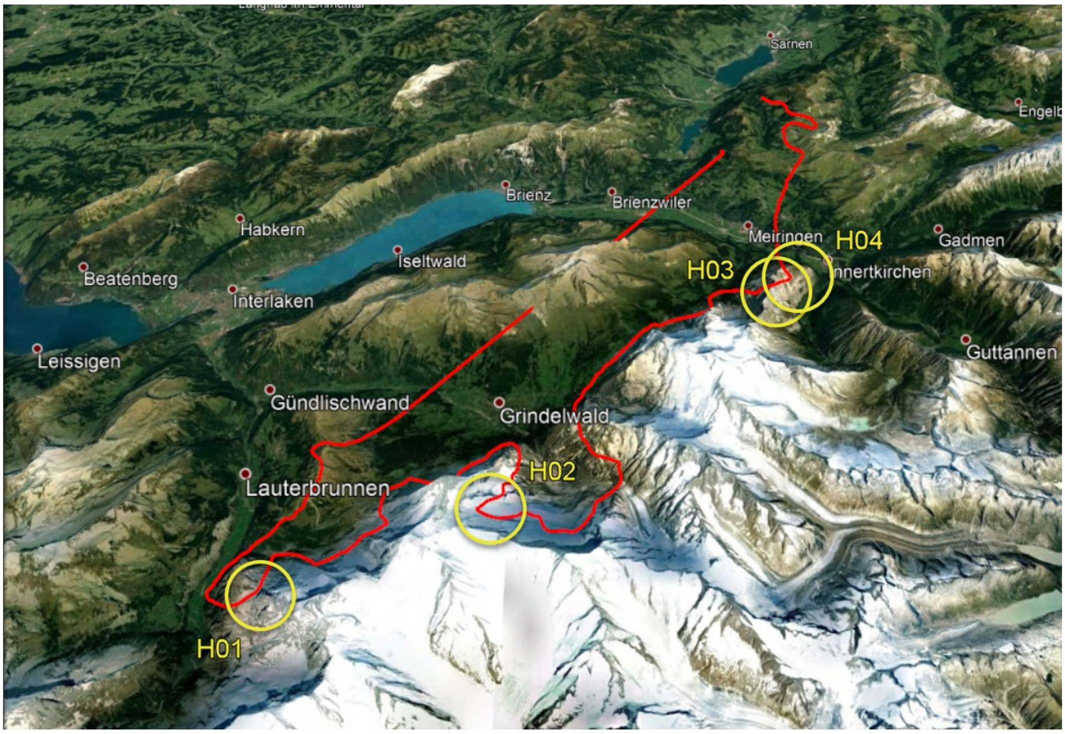

Figure 36: Overview of the flight path including hotspots H01 to H04 (yellow circles). Shown on Google Earth.

A1.18.6.8.2 Overview of the approach path

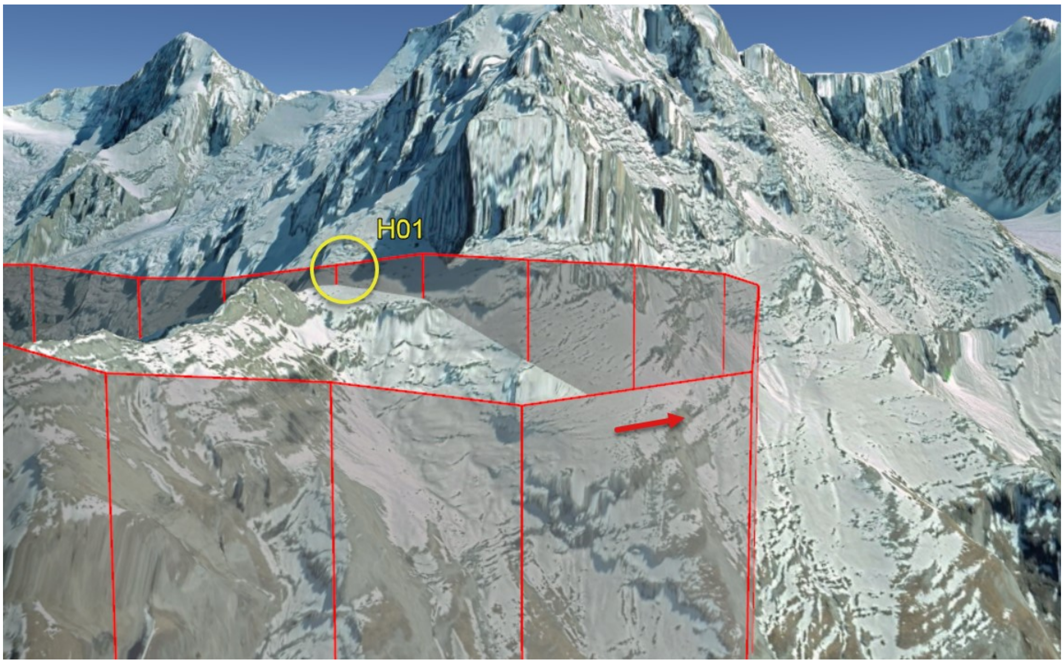

Figure 37: Representation of the approach path to hotspot H01 (yellow circle). Shown on Google Earth.

A1.18.6.8.3 Hotspot H01

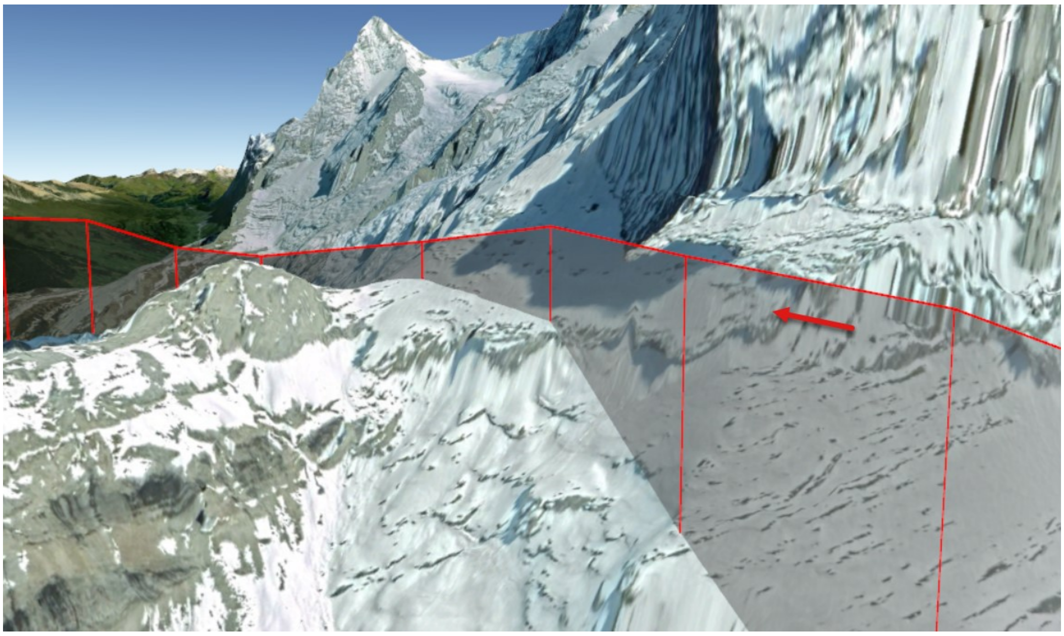

Figure 38: Descending overflight at almost 90 degrees to the crest of the mountain ridge at an altitude of 2,720 m AMSL with a height of 58 m above ground directly below the radar flight path and 71 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 38 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.8.4 Hotspot H02

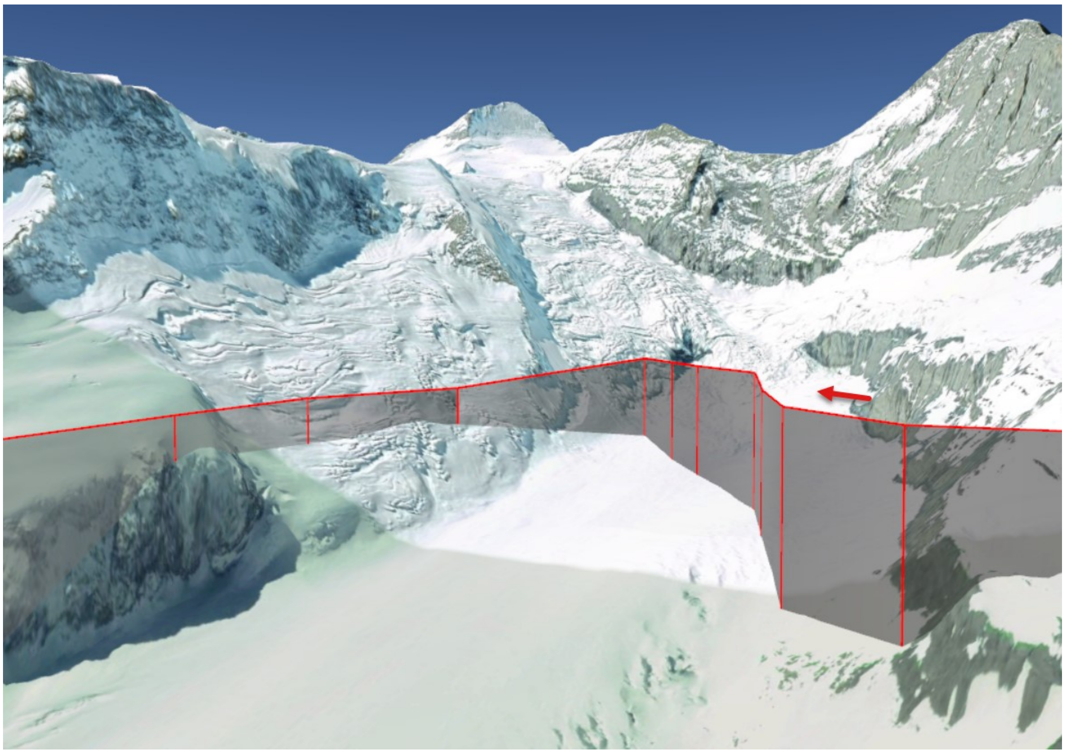

Figure 39: Descending overflight at an altitude of 2,908 m AMSL with a height of 95 m above ground directly below the radar flight path and 178 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 39 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related features:

- Turning towards an obstacle;
- Low-level flight over the terrain.

In addition, when turning into a left turn, the 'belly to the wall' flight attitude bears the risk of the pilots not being able to assess the aircraft's position in space due to missing vertical and horizontal visual references in the terrain.

A1.18.6.8.5 Hotspot H03

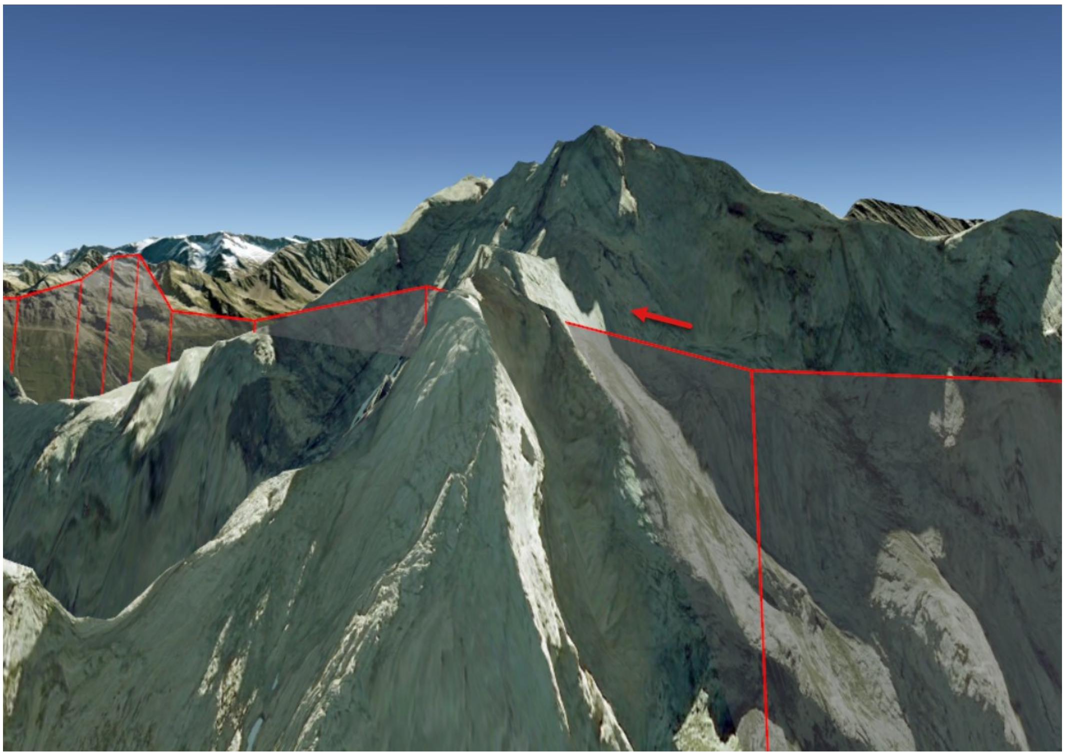

Figure 40: Horizontal flight over the crest of the mountain ridge at an altitude of 2,623 m AMSL with a height of -35 m above ground directly below the radar flight path and 43 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 40 shows a choice of flight path classified as ‘high-risk’, which is characterised by the following safety-related features:

- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

Due to leeway in the lateral position of the radar flight path, the flight path intersects the terrain here. The overflight therefore took place close to the terrain.

A1.18.6.8.6 Hotspot H04

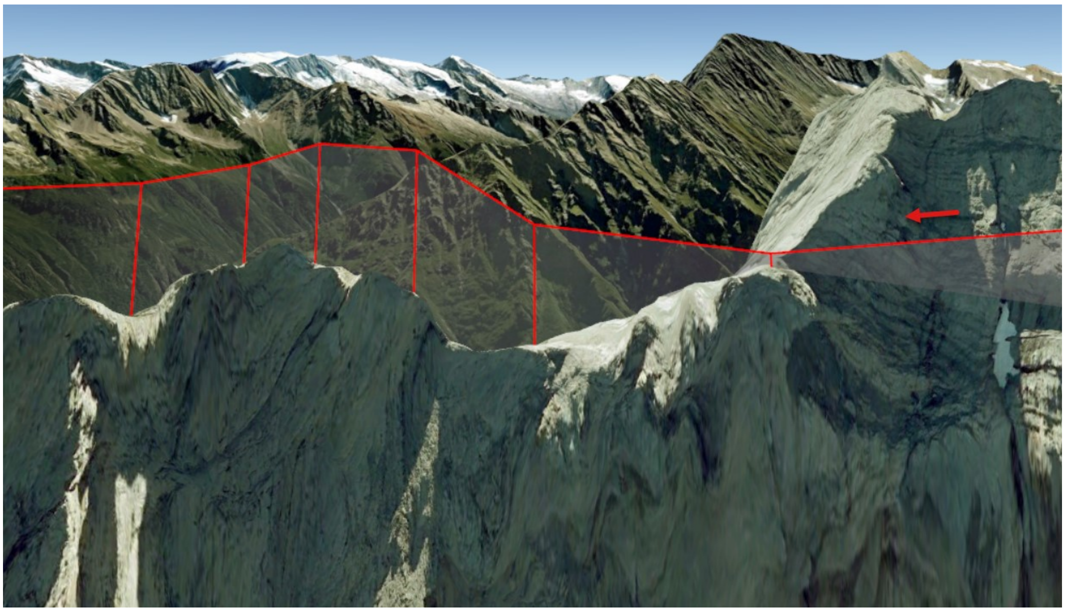

Figure 41: Horizontal flight over the crest of the mountain ridge at an altitude of 2,623 m AMSL with a height of 5 m above ground directly below the radar flight path and 58 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 41 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.9 Flight_0803_01_HOP

A1.18.6.9.1 Overview of the flight path

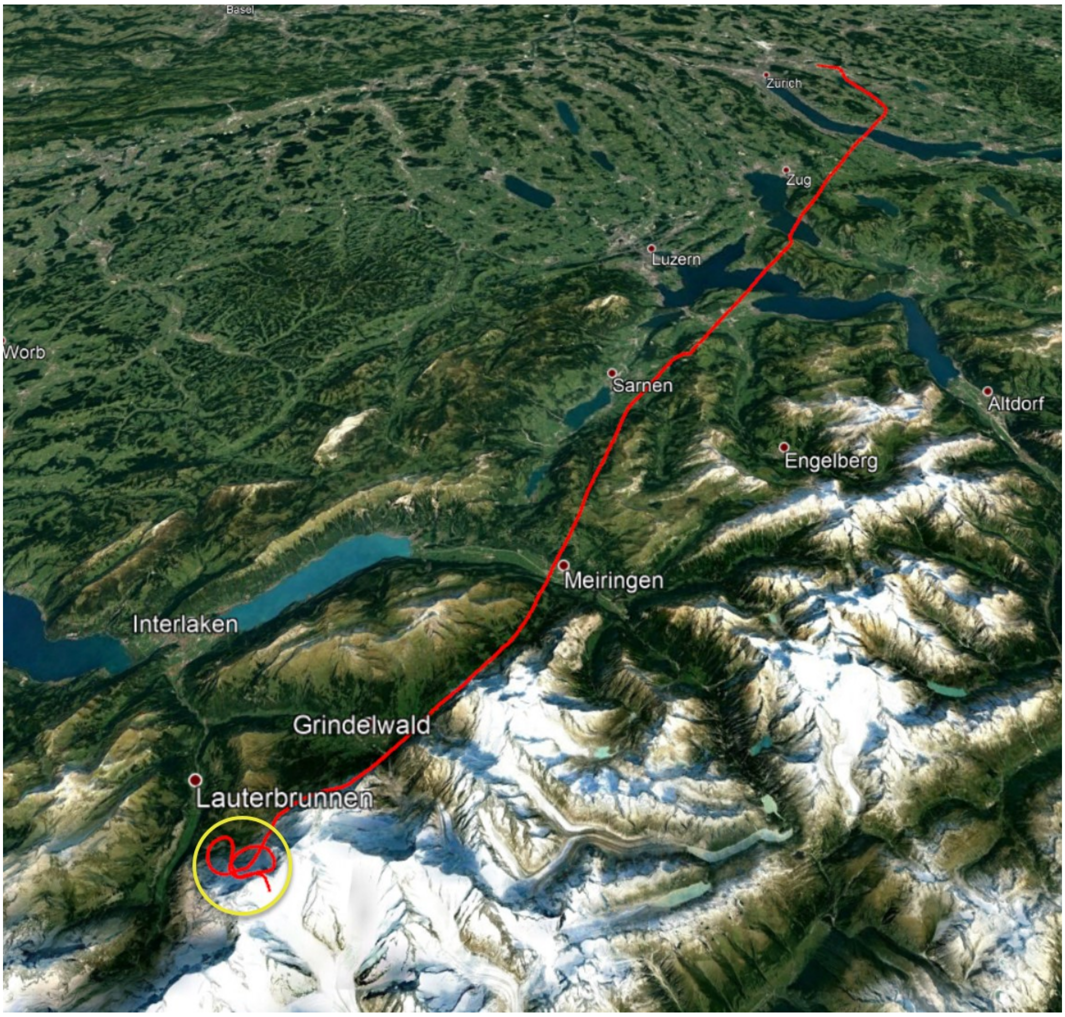

Figure 42: Overview of the flight path including hotspot (yellow circle). Shown on Google Earth.

A1.18.6.9.2 Overview of the approach path

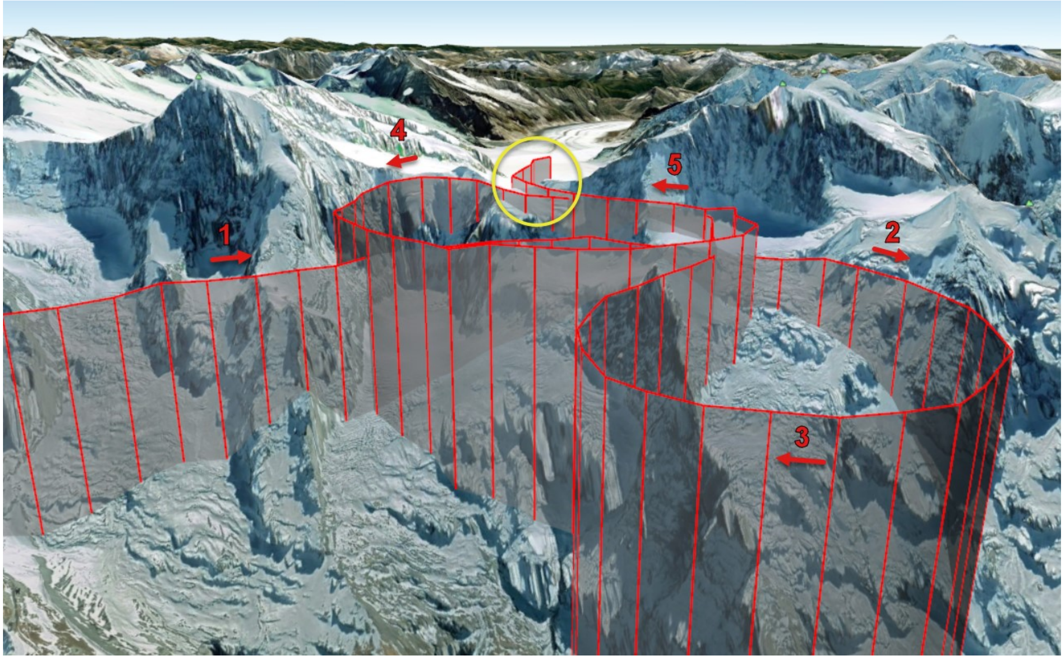

Figure 43: Representation of the approach path (travelling from 1 to 5) and hotspot (yellow circle). Shown on Google Earth.

A1.18.6.9.3 Hotspot

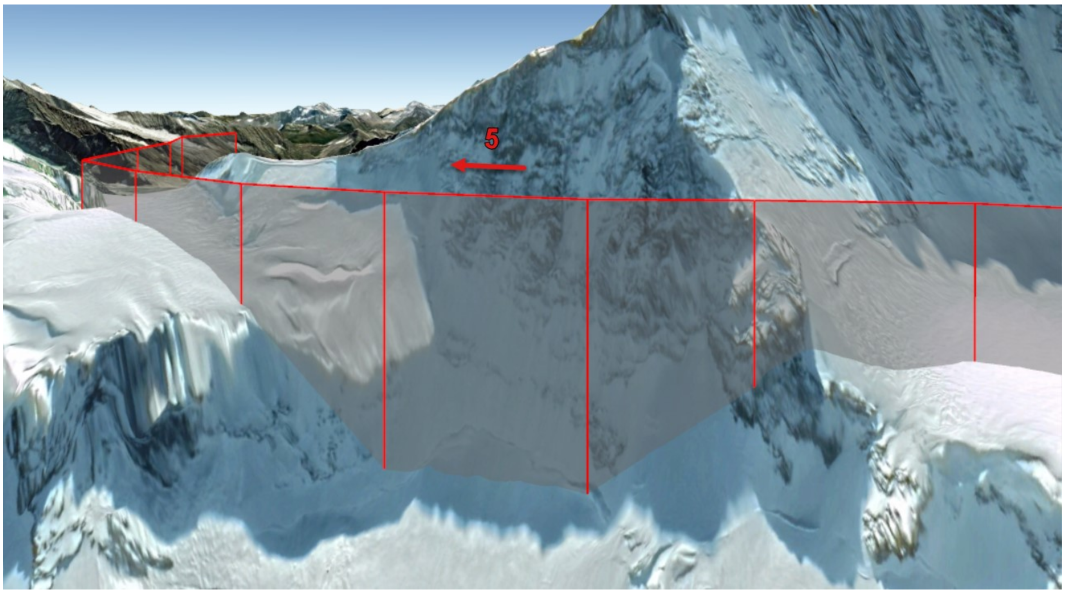

Figure 44: Horizontal flight over the terrain at an altitude of 3,539 m AMSL with a height of 74 m above ground directly below the radar flight path and 74 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 44 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.10 Flight_0804_02_HOP

A1.18.6.10.1 Overview of the flight path

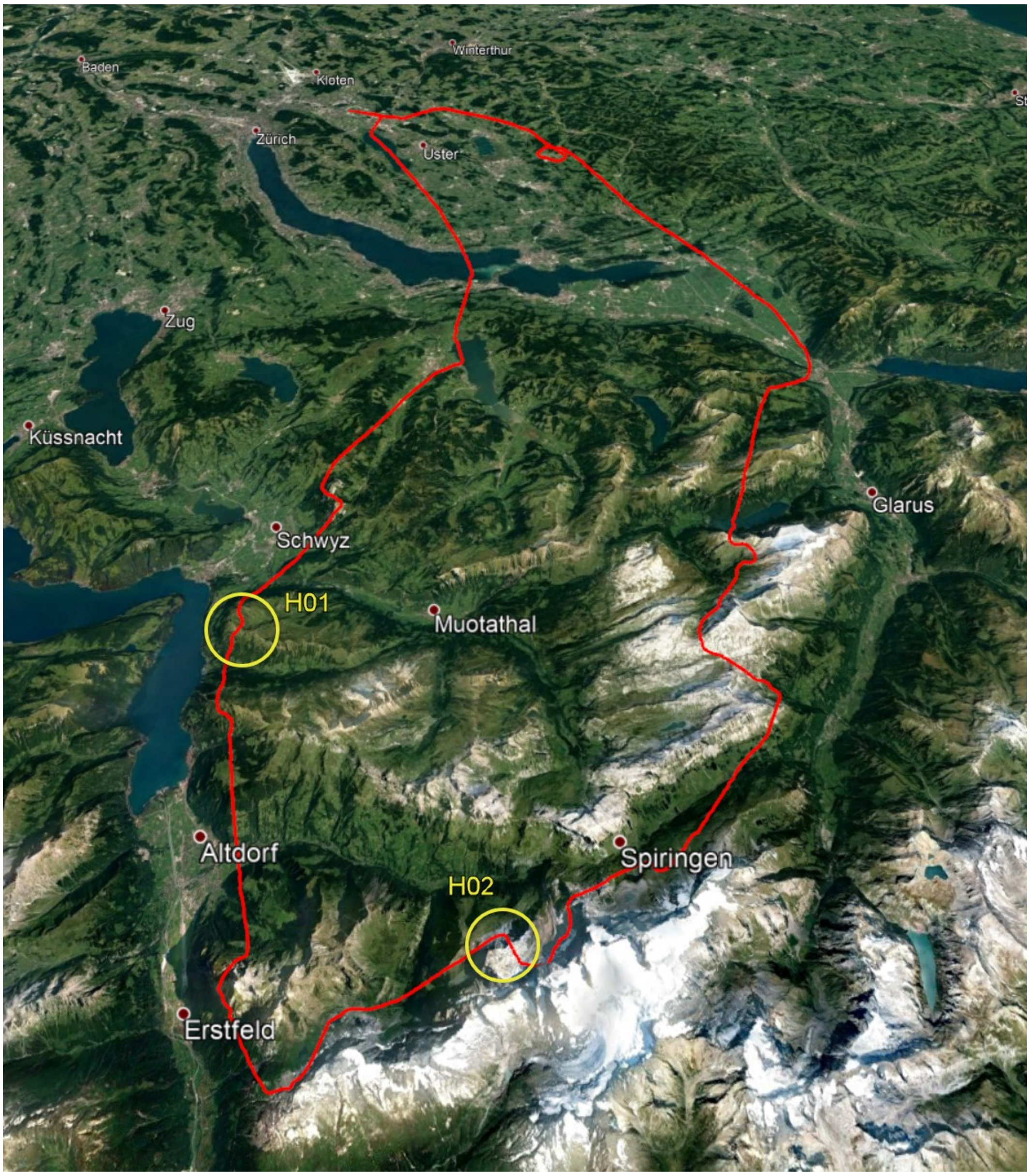

Figure 45: Overview of the flight path including hotspots H1 and H2 (yellow circles). Shown on Google Earth.

A1.18.6.10.2 Hotspot H01

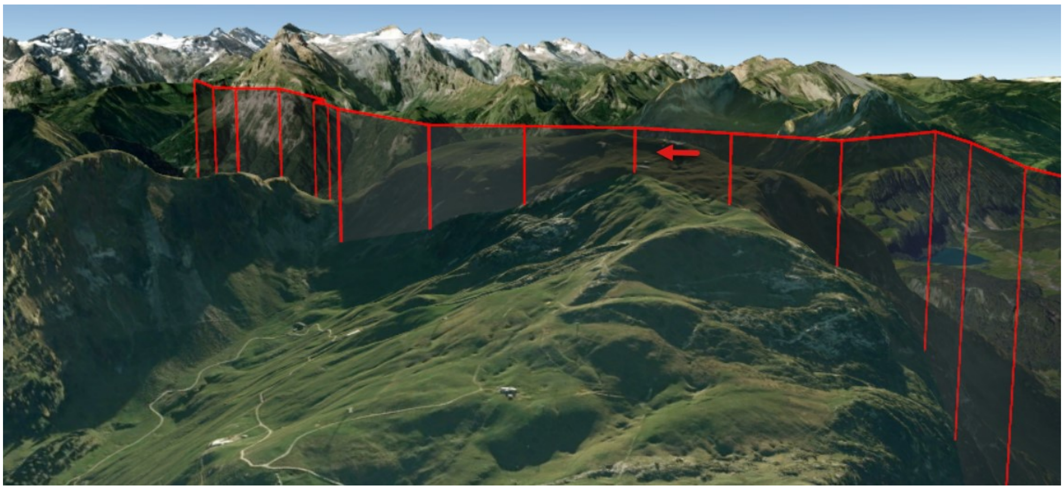

Figure 46: Horizontal flight over the terrain at an altitude of 1,951 m AMSL with a height of 98 m above ground directly below the radar flight path and 177 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 46 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.6.10.3 Hotspot H02

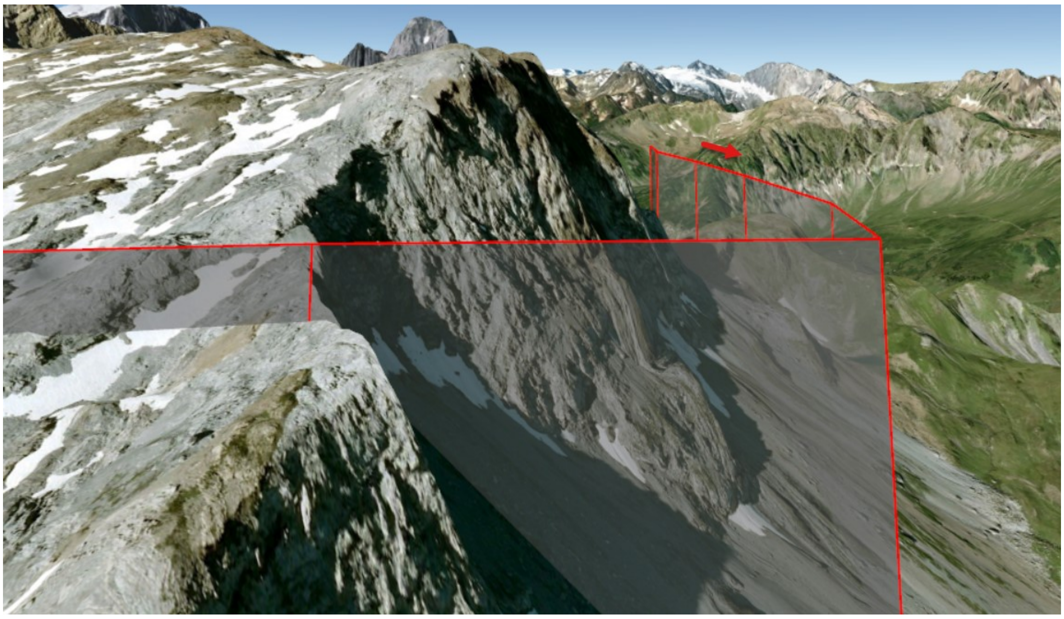

Figure 47: Climbing overflight at almost 90 degrees to the crest of the mountain ridge at an altitude of 2,525 m AMSL with a height of 45 m above ground directly below the radar flight path and 58 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 47 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.6.11 Flight_0804_04_HOP

A1.18.6.11.1 Overview of the flight path

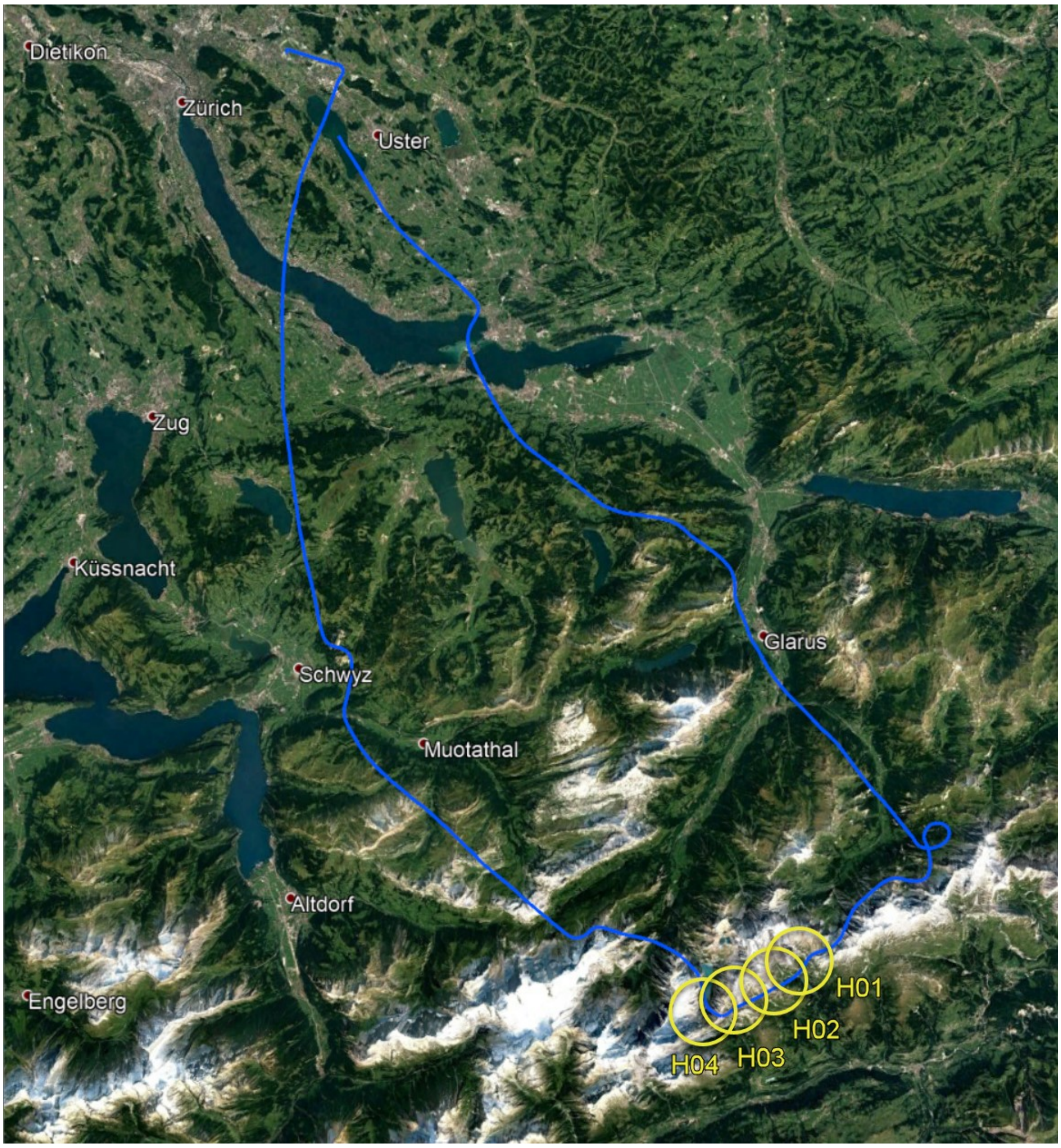

Figure 48: Overview of the GPS flight path (blue) including hotspots H01 to H04 (yellow circles). Shown on Google Earth.

A1.18.6.11.2 Overview of the approach path

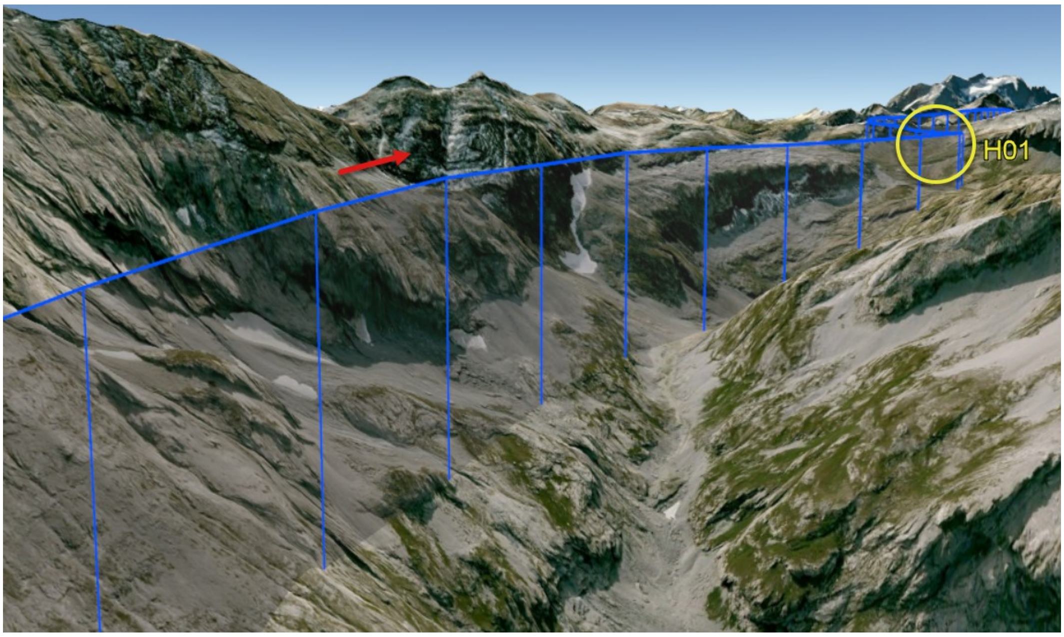

Figure 49: Representation of the GPS approach path (blue) to hotspot H01 (yellow circle). Shown on Google Earth.

A1.18.6.11.3 Hotspot H01

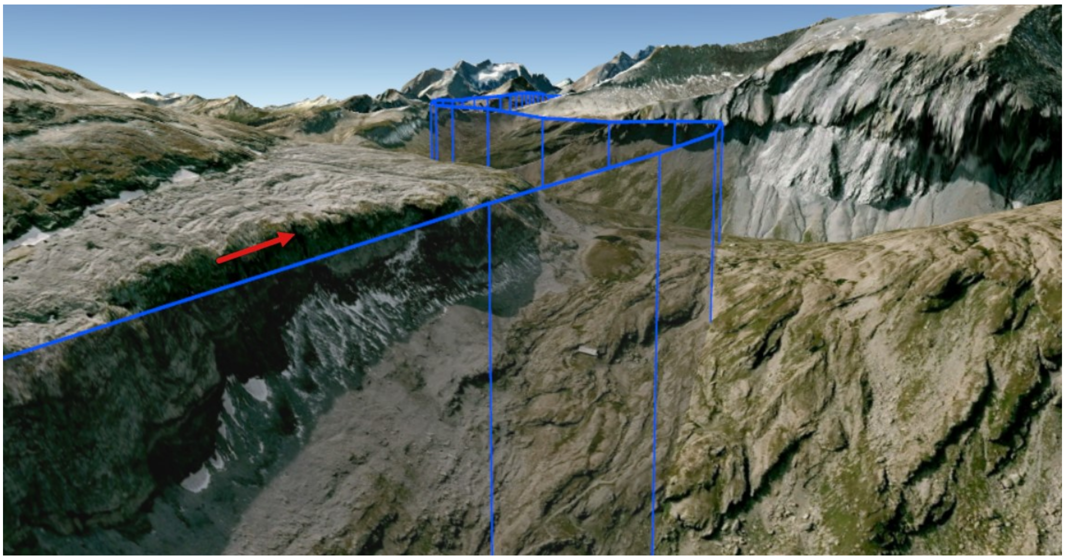

Figure 50: Climbing overflight at almost 90 degrees to the crest of the mountain ridge at a GPS altitude of 2,545 m AMSL with a height of 141 m above ground directly below the GPS flight path and 141 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 50 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Approaching an obstacle whilst climbing;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.11.4 Hotspot H02

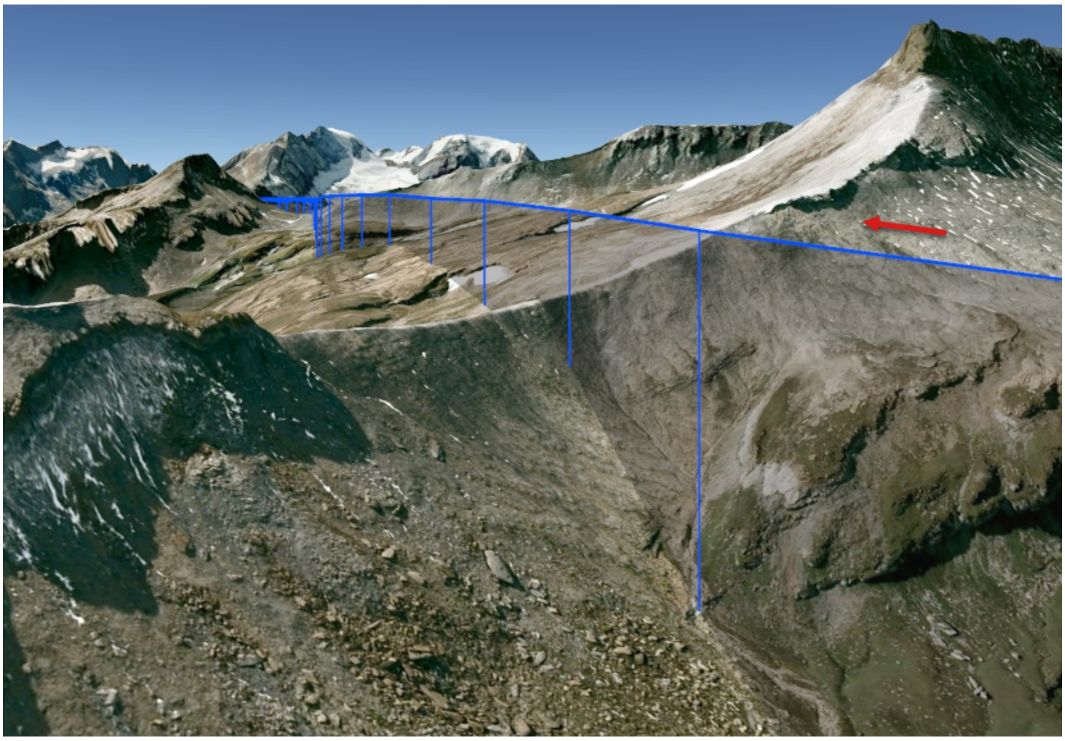

Figure 51: Climbing overflight at 90 degrees to the crest of the mountain ridge at a GPS altitude of 2,610 m AMSL with a height of 75 m above ground directly below the GPS flight path and 84 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 51 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Approaching an obstacle whilst climbing.

A1.18.6.11.5 Hotspot H03

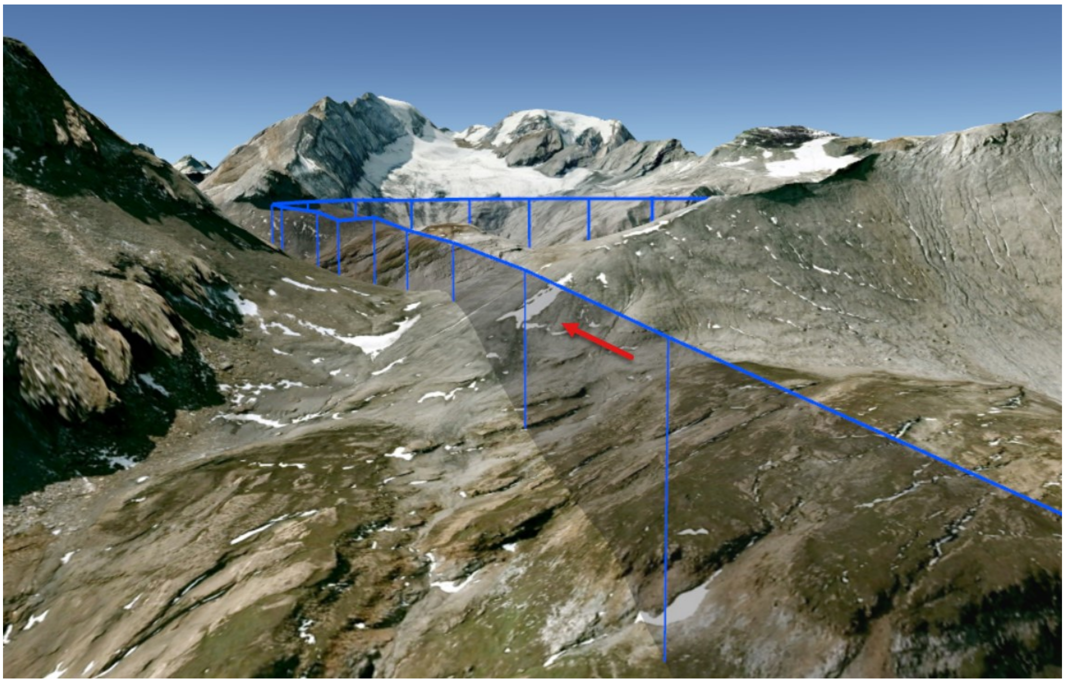

Figure 52: Climbing overflight at 90 degrees to the crest of the mountain ridge at a GPS altitude of 2,624 m AMSL with a height of 48 m above ground directly below the GPS flight path and 58 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 52 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Restricted view of the following section of terrain;
- Approaching an obstacle whilst climbing;
- Very low-level flight over the terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.6.11.6 Hotspot H04

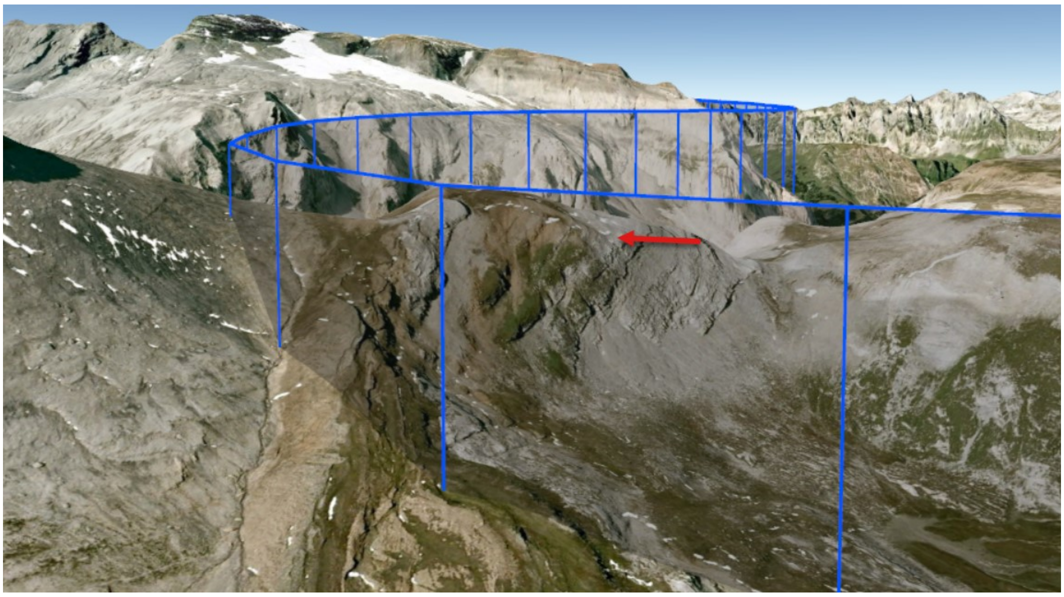

Figure 53: Horizontal overflight at 90 degrees to the crest of the mountain ridge at a GPS altitude of 2,642 m AMSL with a height of 64 m above ground directly below the GPS flight path and 84 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 53 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.7 Further Ju-Air flights examined

A1.18.7.1 General

The following list of other Ju-Air flights, which were classified as 'moderate-risk', 'high-risk' or 'very high-risk', are described in detail on the upcoming pages. They are relevant due to their systemic importance:

Line check, pilot A	:	Flight_0407_04_HOP	:	H01, H02, H03
Line checks, pilot B	:	Flight_0512_01_HOS	:	H01, H02, H03, H04
	:	Flight_0512_02_HOS	:	H01, H02
FOCA inspection flight	:	Flight_0913_00_HOS	:	H01, H02, H03
Flights already undertaken by pilot B on the day of the accident	:	Flight_0804_01_HOP	:	H01, H02, H03
	:	Flight_0804_03_HOP	:	H
In-cloud fly-by	:	Flight_0602_03_HOS	:	H

A1.18.7.2 Flight_0407_04_HOP

A1.18.7.2.1 Overview of the flight path

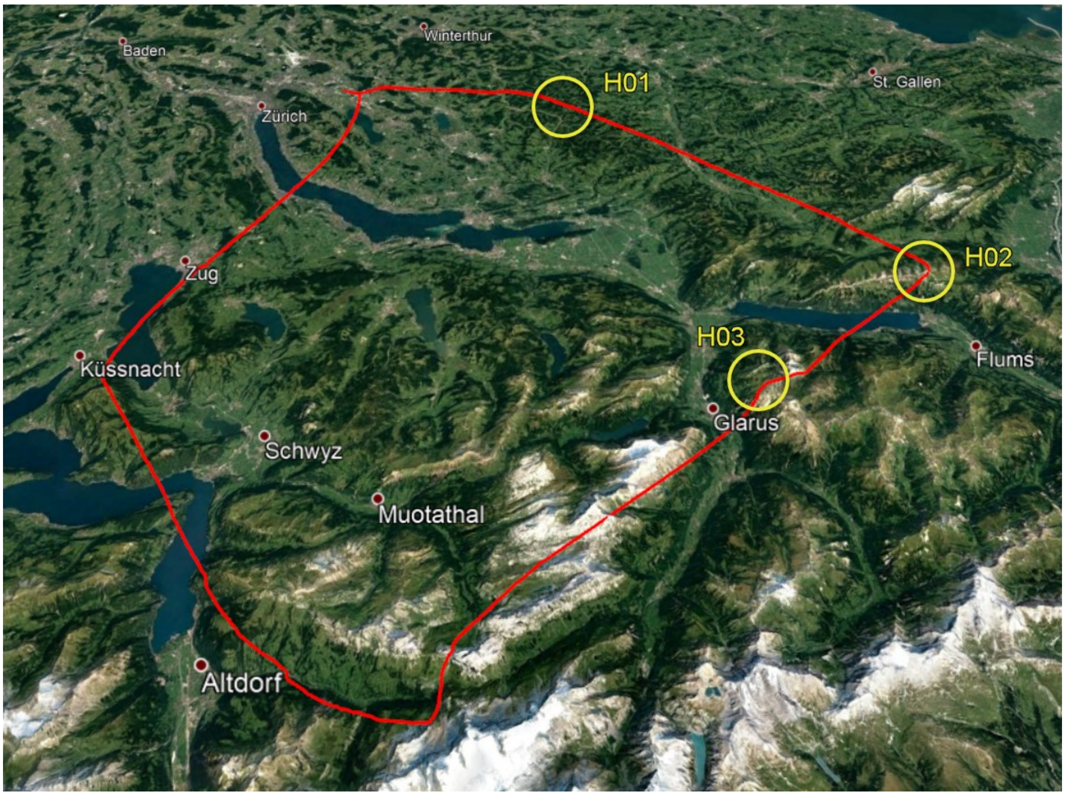

Figure 54: Overview of the flight path including hotspots H01 to H03 (yellow circles). Shown on Google Earth.

A1.18.7.2.2 Hotspot H01

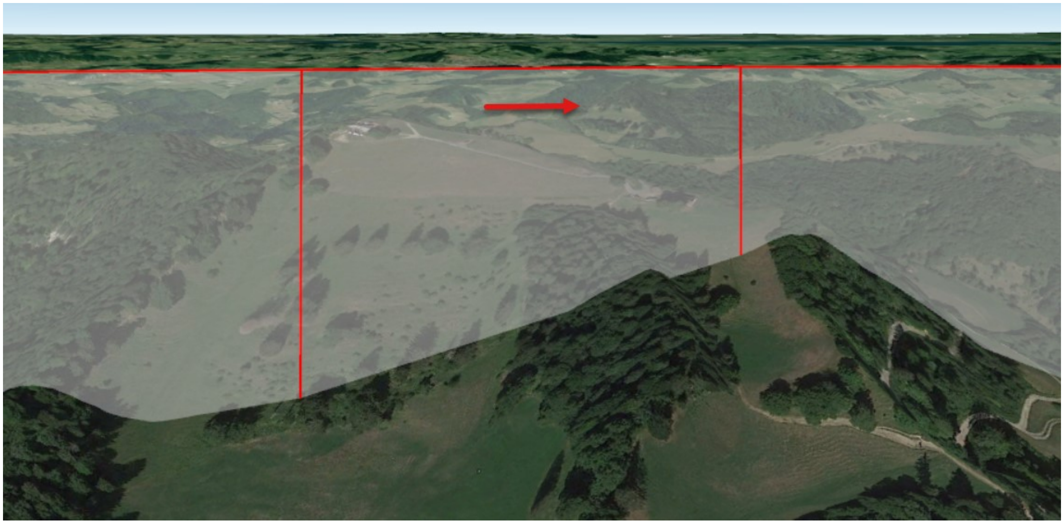

Figure 55: Horizontal flight over the terrain at an altitude of 1,189 m AMSL with a height of 107 m above ground directly below the radar flight path and 165 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 55 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.7.2.3 Hotspot H02

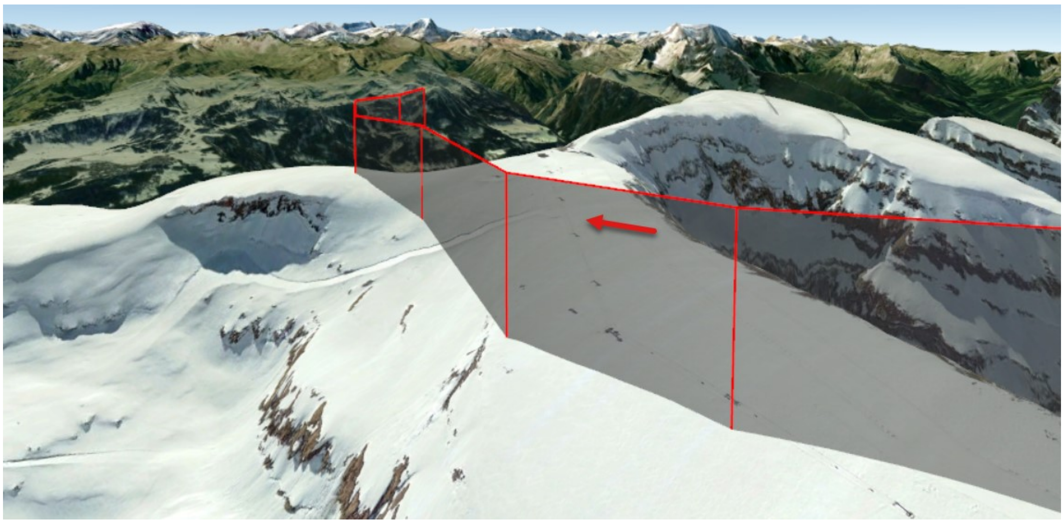

Figure 56: Horizontal overflight at almost 90 degrees to the crest of the mountain ridge at an altitude of 2,310 m AMSL with a height of 74 m above ground directly below the radar flight path and 85 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 56 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path;
- Very low-level flight over the terrain.

A1.18.7.2.4 Hotspot H03

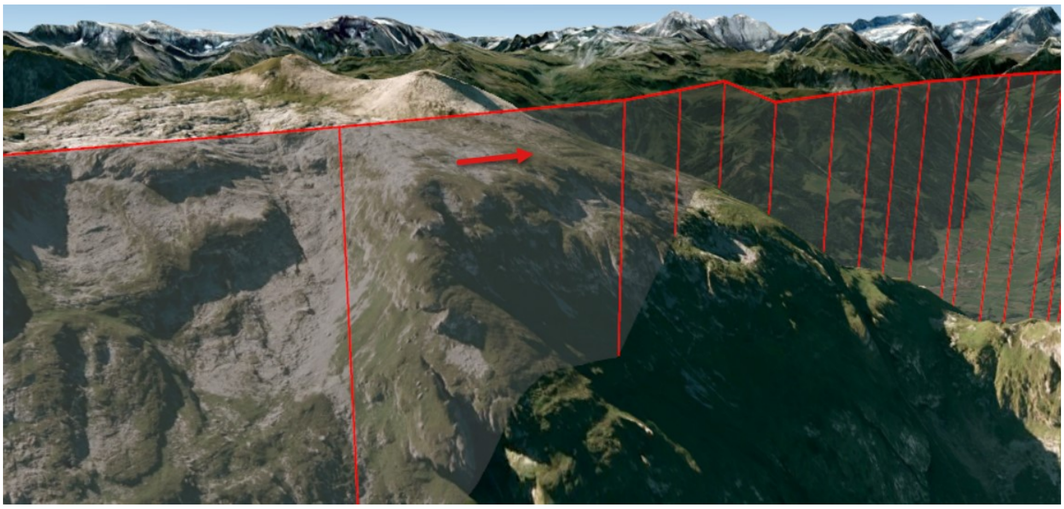

Figure 57: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,269 m AMSL with a height of 111 m above ground directly below the radar flight path and 219 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 57 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.7.3 Flight_0512_01_HOS

A1.18.7.3.1 Overview of the flight path

Figure 58: Overview of the flight path including hotspots H01 to H04 (yellow circles). Shown on Google Earth.

A1.18.7.3.2 Hotspot H01

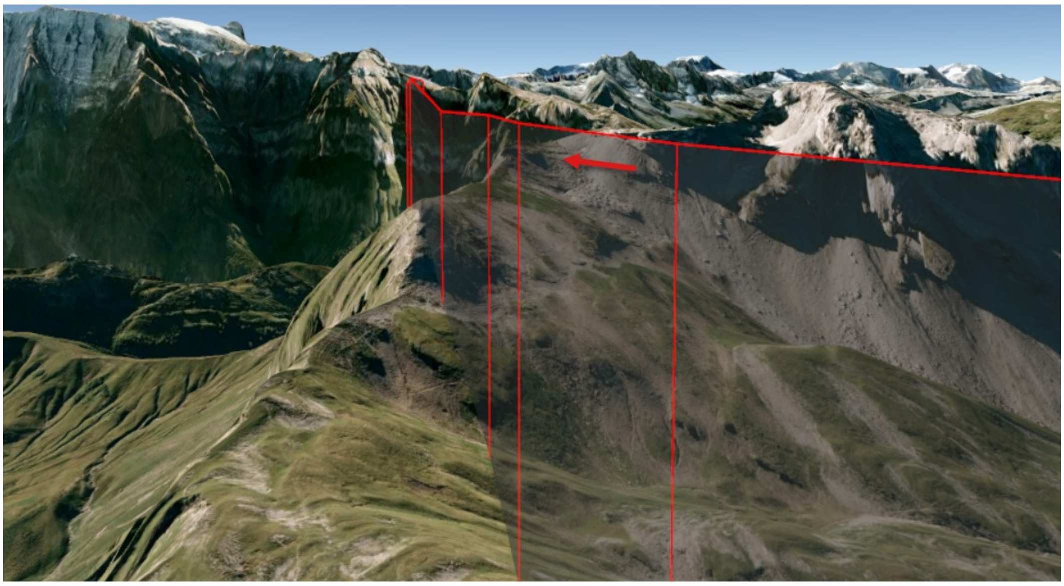

Figure 59: Climbing flight over the terrain at an altitude of 2,285 m AMSL with a height of 129 m above ground directly below the radar flight path and 190 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 59 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Approaching an obstacle whilst climbing.

A1.18.7.3.3 Hotspot H02

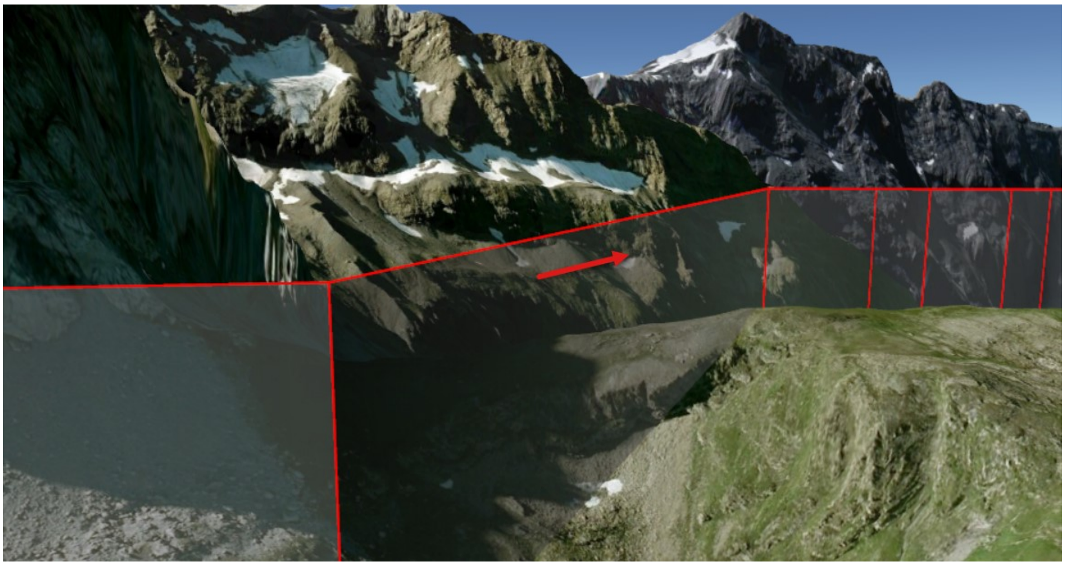

Figure 60: Horizontal flight over the terrain at an altitude of 2,412 m AMSL with a height of 75 m above ground directly below the radar flight path and 115 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 60 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.7.3.4 Hotspot H03

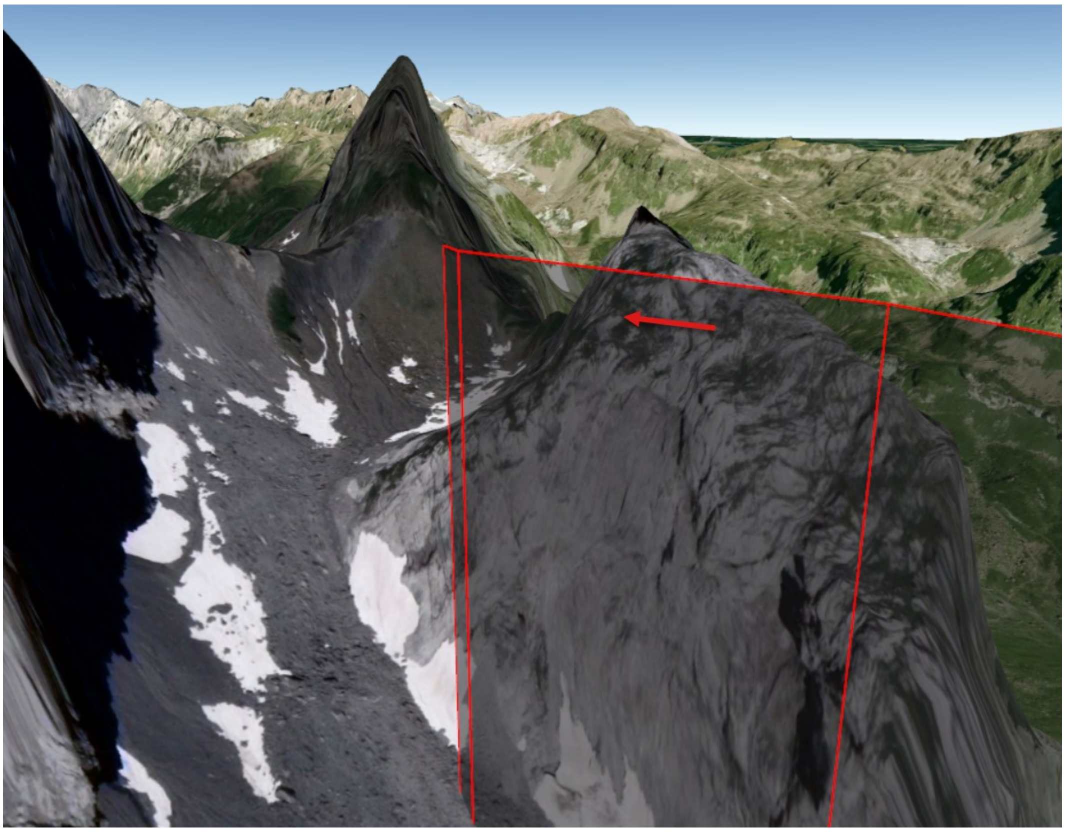

Figure 61: Horizontal flight over the crest of the mountain ridge at an altitude of 2,413 m AMSL with a resulting height at a constant flying altitude of 78 m above ground directly below the radar flight path and 80 m above ground with respect to the lowest point of the terrain profile. Data extrapolated by the radar system were omitted. Shown on Google Earth.

Figure 61 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.7.3.5 Hotspot H04

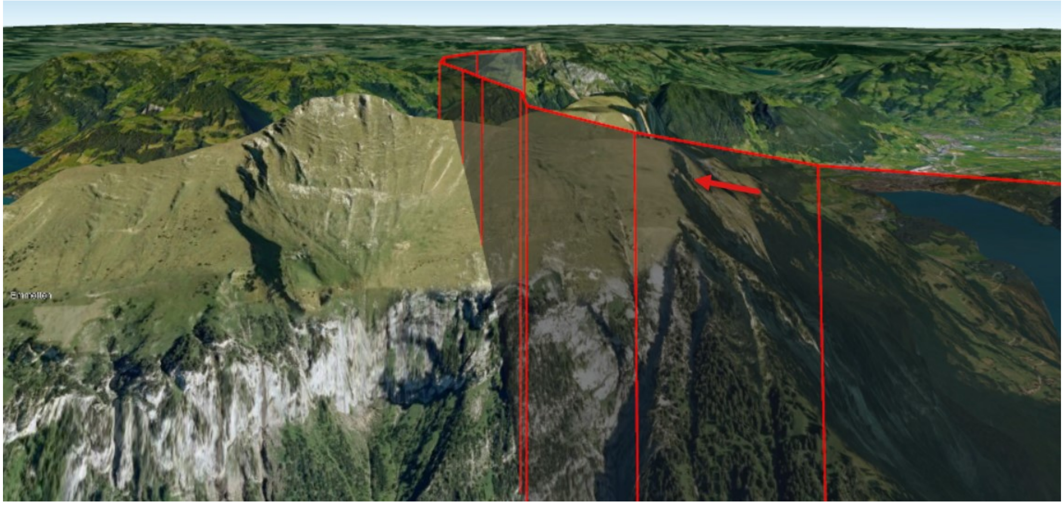

Figure 62: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 2,170 m AMSL with a height of 110 m above ground directly below the radar flight path and 127 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 62 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.7.4 Flight_0512_02_HOS

A1.18.7.4.1 Overview of the flight path

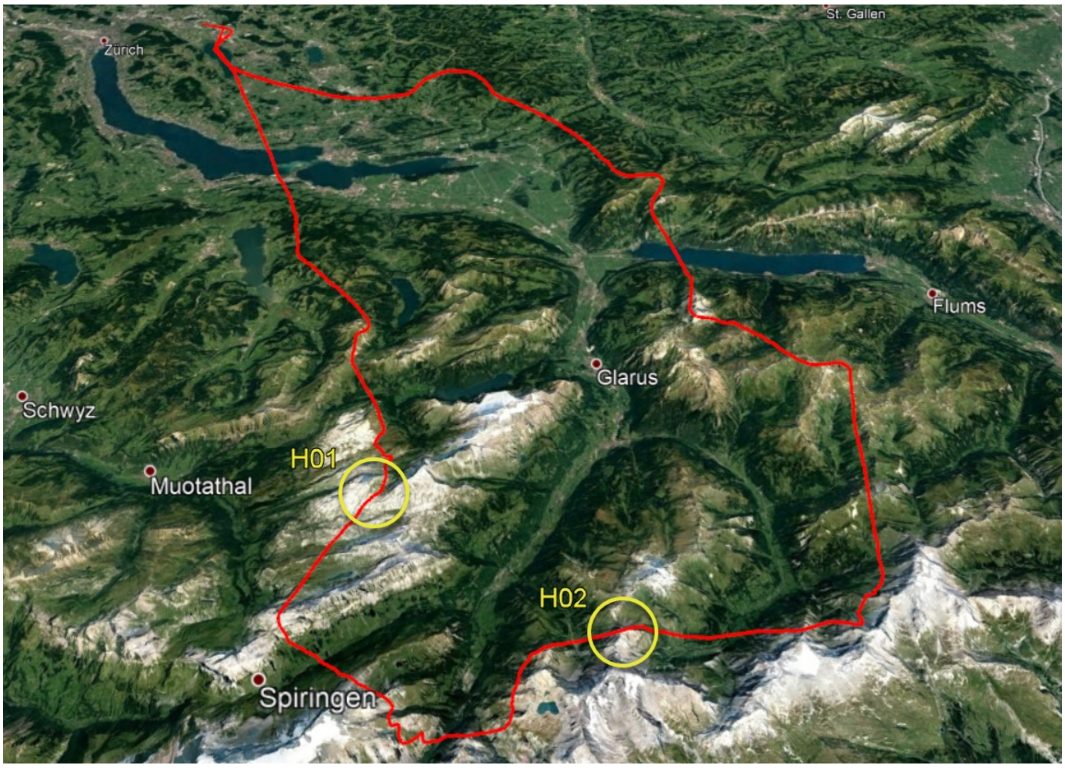

Figure 63: Overview of the flight path including hotspots H01 and H02 (yellow circles). Shown on Google Earth.

A1.18.7.4.2 Hotspot H01

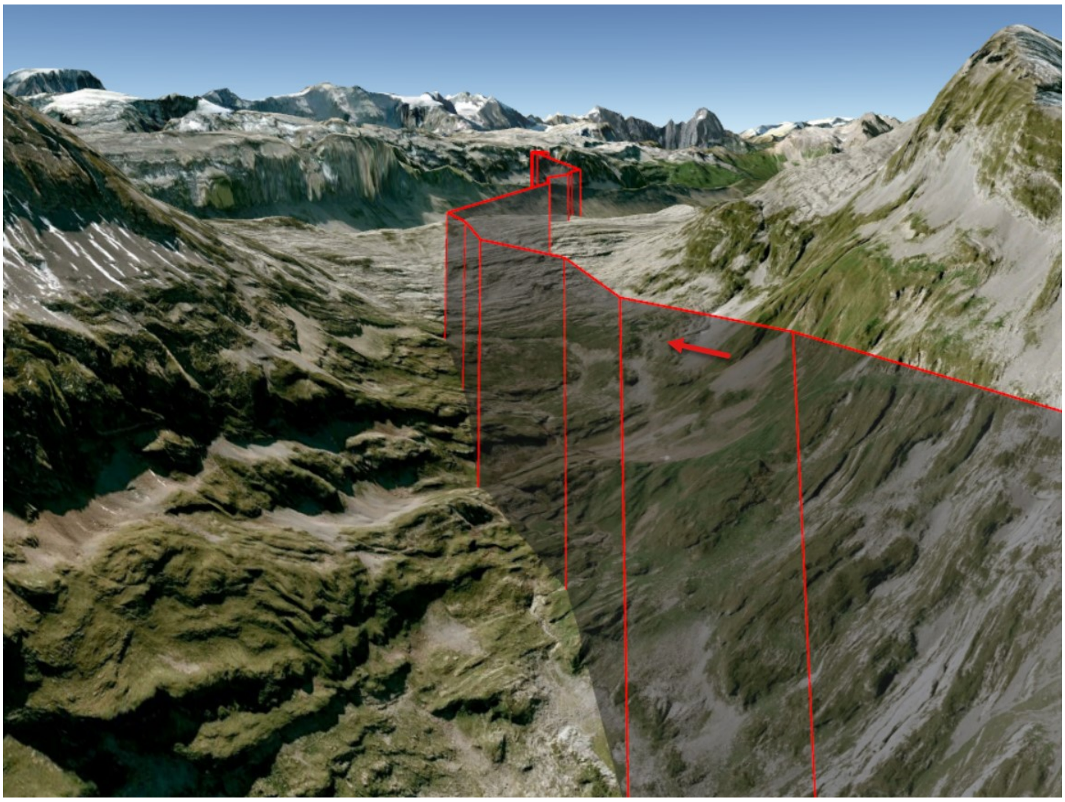

Figure 64: Climbing flight over the terrain at an altitude of 2,313 m AMSL with a height of 107 m above ground directly below the radar flight path and 127 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 64 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Approaching an obstacle whilst climbing;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.7.4.3 Hotspot H02

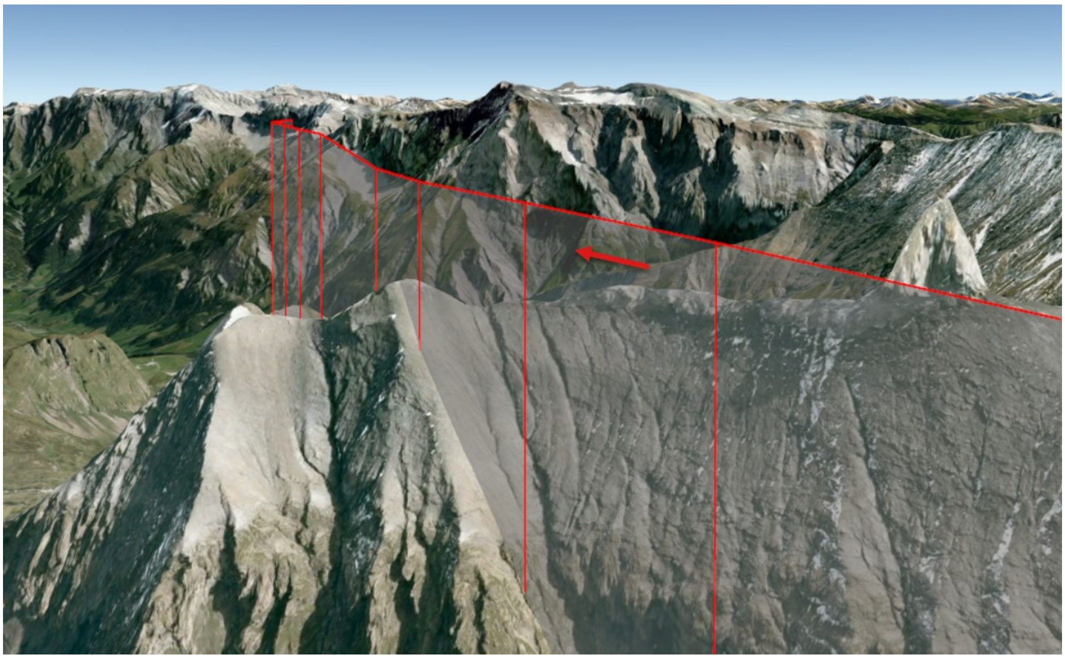

Figure 65: Horizontal flight over the terrain at an altitude of 2,811 m AMSL with a height of 106 m above ground directly below the radar flight path and 153 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 65 shows a choice of flight path classified as 'moderate-risk', which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain.

A1.18.7.5 Flight_0913_00_HOS

A1.18.7.5.1 Overview of the flight path

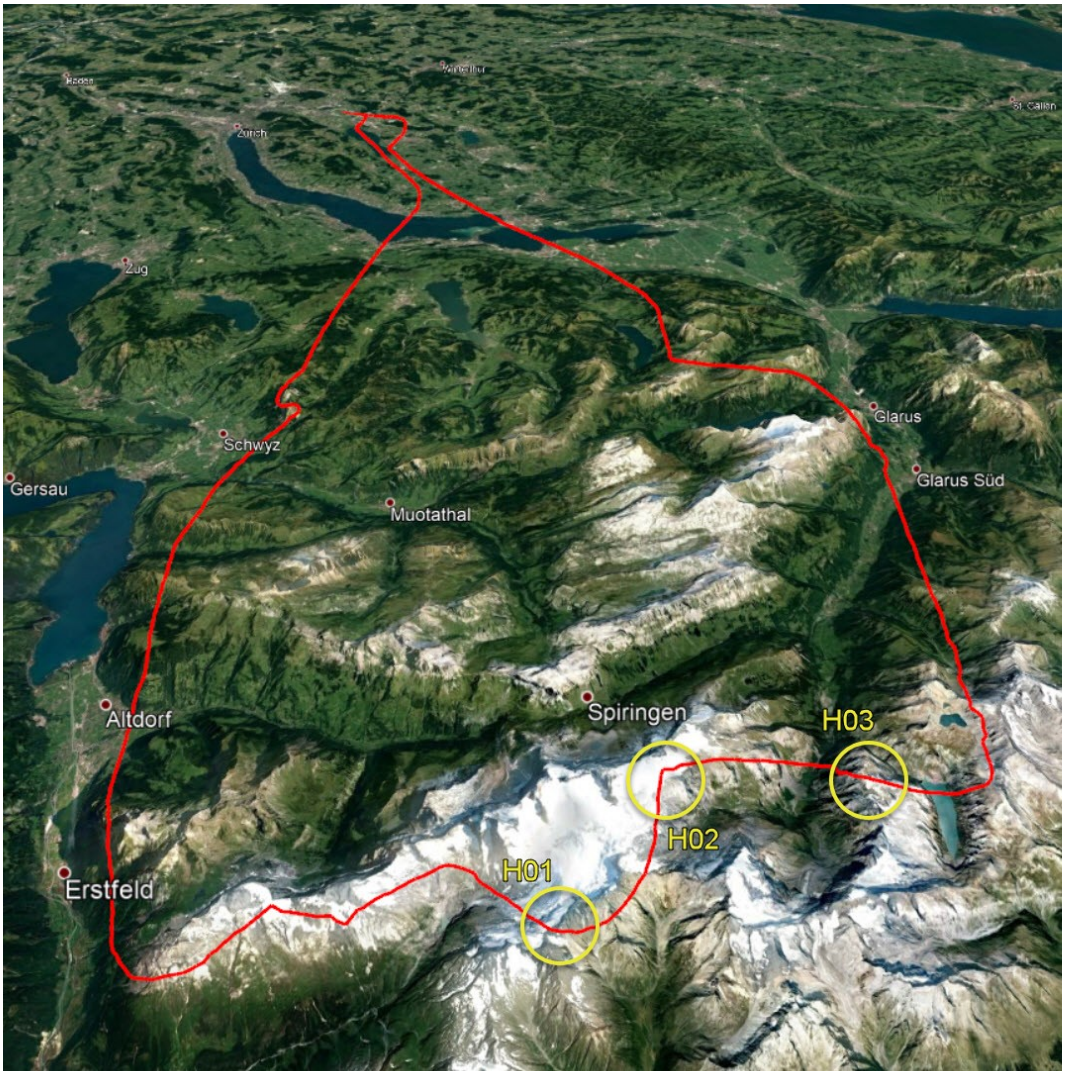

Figure 66: Overview of the flight path including hotspots H01 to H03 (yellow circles). Shown on Google Earth.

A1.18.7.5.2 Hotspot H01

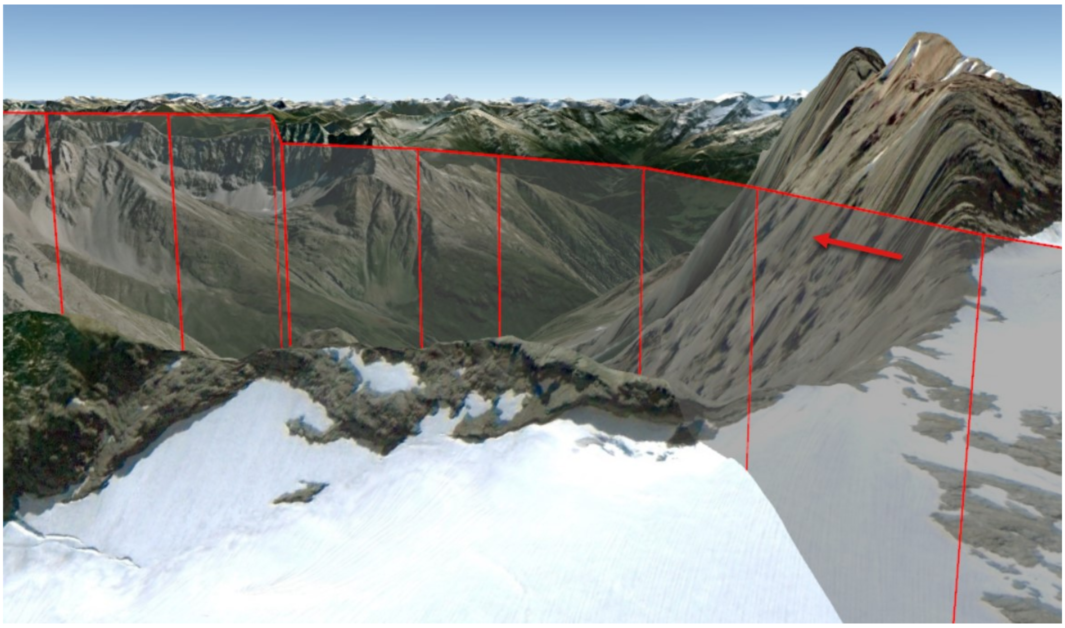

Figure 67: Climbing flight over the crest of the mountain ridge at an altitude of 3,060 m AMSL with a height of 163 m above ground directly below the radar flight path and 194 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

A1.18.7.5.3 Hotspot H02

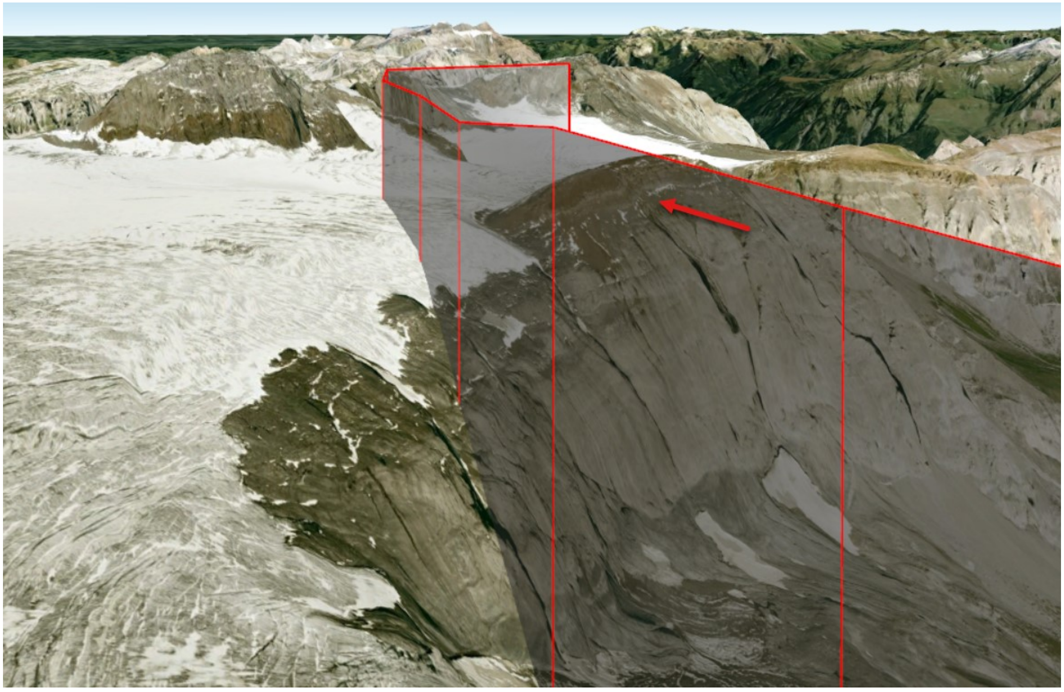

Figure 68: Descending overflight at an altitude of 3,060 m AMSL with a height of 185 m above ground directly below the radar flight path and 218 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

A1.18.7.5.4 Hotspot H03

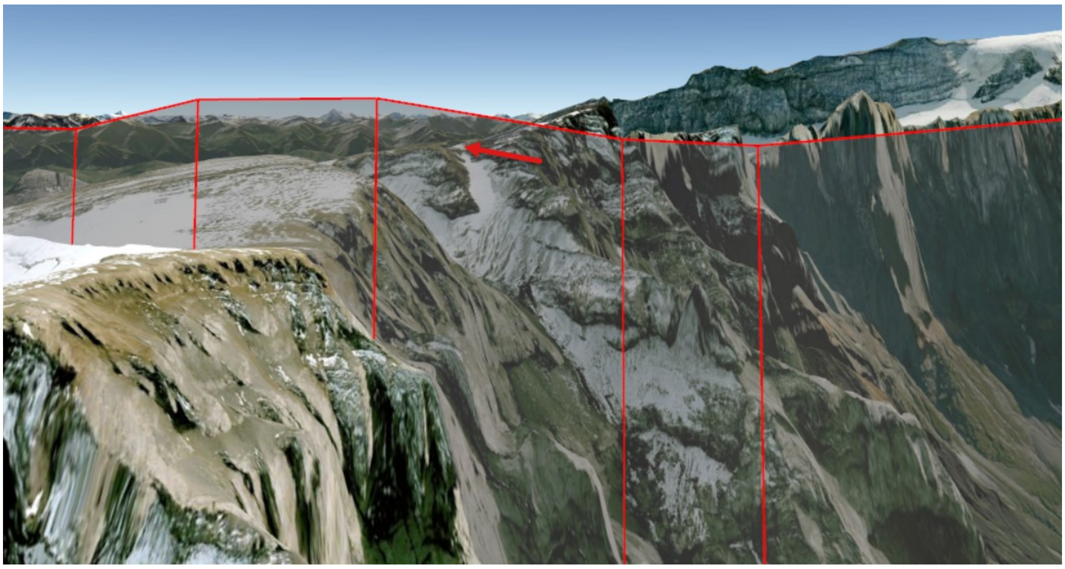

Figure 69: Horizontal overflight at 90 degrees to the crest of the mountain ridge at an altitude of 3,027 m AMSL with a height of 141 m above ground directly below the radar flight path and 142 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 69 shows a choice of flight path classified as ‘moderate-risk’, which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

Figures 67, 68 and 69 show that during the FOCA inspection flight, the Ju-Air aircraft was also flown in mountainous areas well below the safety margin of at least 1,000 ft AGL (300 m above ground). Furthermore, basic principles for safely flying in mountainous areas were disregarded. The choice of flight path clearly contradicted the guidelines for flights in the Alps drawn up by FOCA itself, as published in the Aeronautical Information Publication (AIP) of Switzerland, VFR guide RAC 6-3 (see section A1.17.6.2.2).

A1.18.7.6 Flight_0804_01_HOP

A1.18.7.6.1 Overview of the flight path

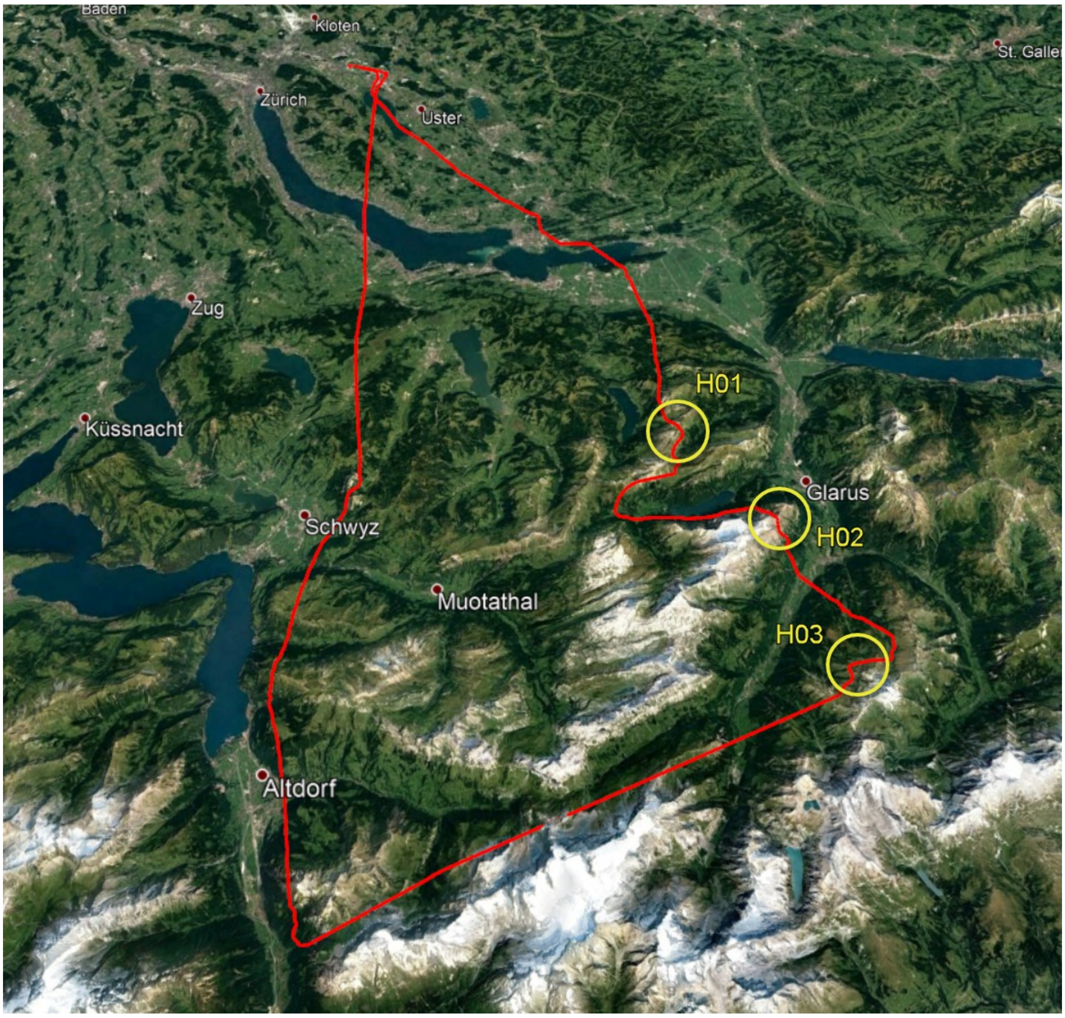

Figure 70: Overview of the flight path including hotspots H01 to H03 (yellow circles). Shown on Google Earth.

A1.18.7.6.2 Hotspot H01

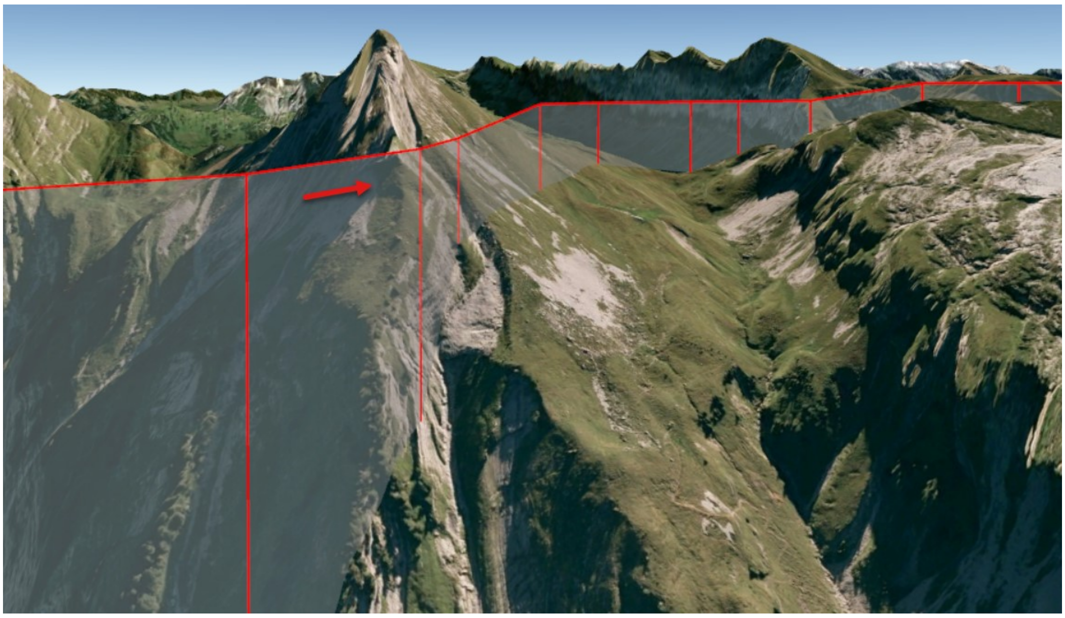

Figure 71: Horizontal overflight at almost 90 degrees to the terrain feature at an altitude of 1,994 m AMSL with a height of 104 m above ground directly below the radar flight path and 111 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 71 shows a choice of flight path classified as 'very high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.7.6.3 Hotspot H02

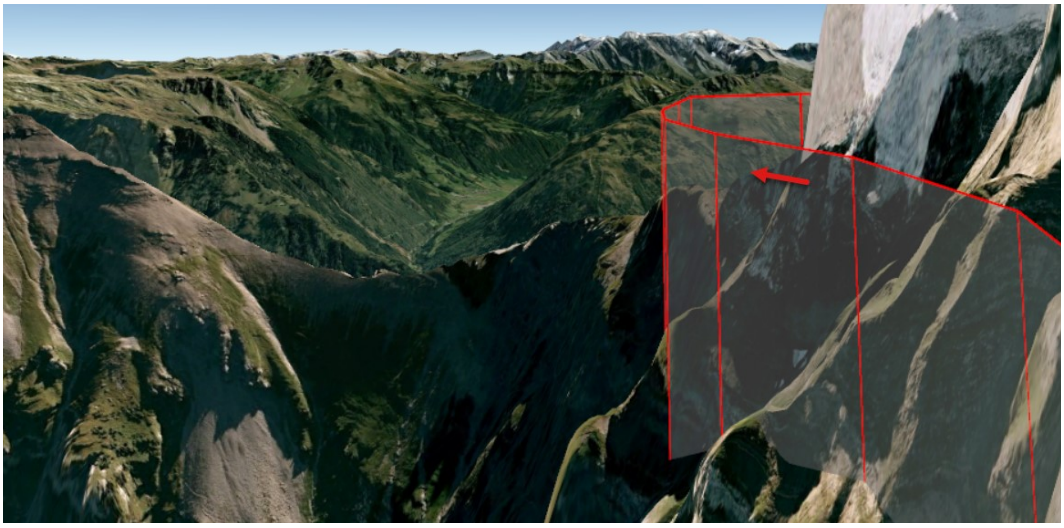

Figure 72: Horizontal overflight at almost 90 degrees to the terrain feature at an altitude of 2,362 m AMSL with a height of 100 m above ground directly below the radar flight path and 184 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 72 shows a choice of flight path classified as ‘very high-risk’, which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- No possibility of an alternative flight path for a prolonged period of time.

A1.18.7.6.4 Hotspot H03

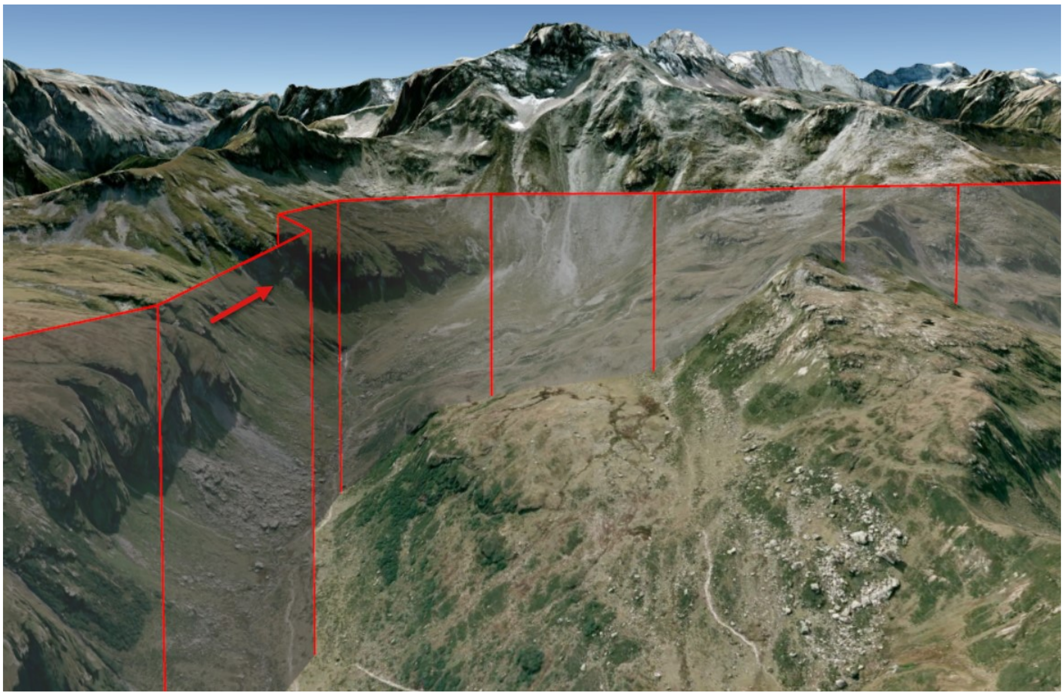

Figure 73: Horizontal flight over the terrain at an altitude of 2,298 m AMSL with a height of 93 m above ground directly below the radar flight path and 149 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 73 shows a choice of flight path classified as ‘moderate-risk’, which is characterised by the following safety-related feature:

- Low-level flight over the terrain.

A1.18.7.7 Flight_0804_03_HOP

A1.18.7.7.1 Overview of the flight path

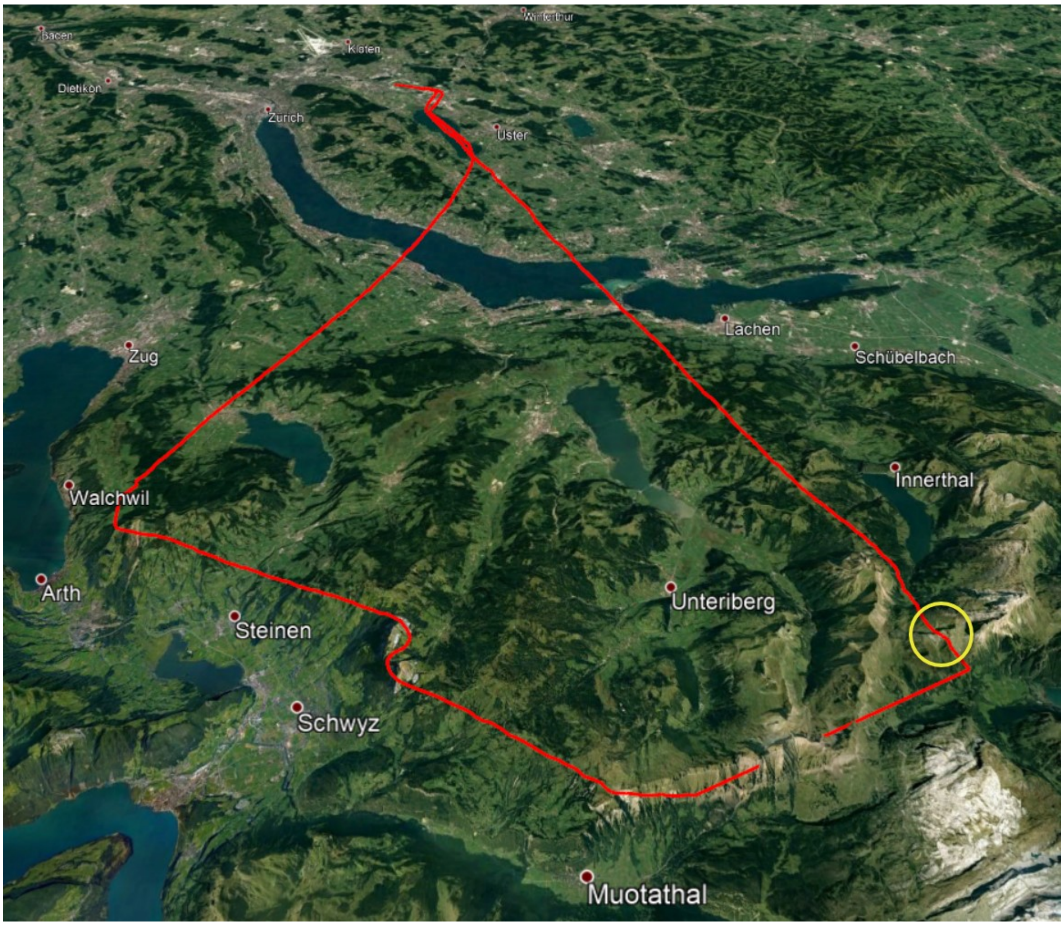

Figure 74: Overview of the flight path including hotspot (yellow circle). Shown on Google Earth.

A1.18.7.7.2 Hotspot

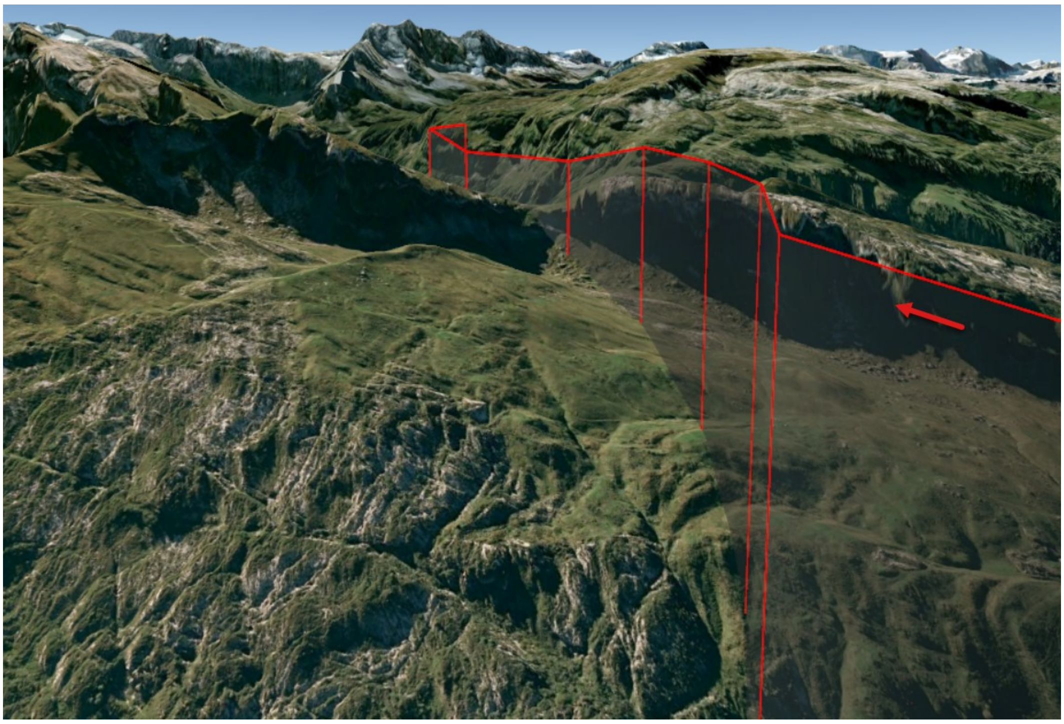

Figure 75: Descending overflight at almost 90 degrees to the terrain feature at an altitude of 1,901 m AMSL with a height of 78 m above ground directly below the radar flight path and 81 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 75 shows a choice of flight path classified as 'high-risk', which is characterised by the following safety-related features:

- Rising terrain in the direction of flight;
- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Limited possibility of an alternative flight path.

A1.18.7.8 Flight_0602_03_HOS

A1.18.7.8.1 Overview of the flight path

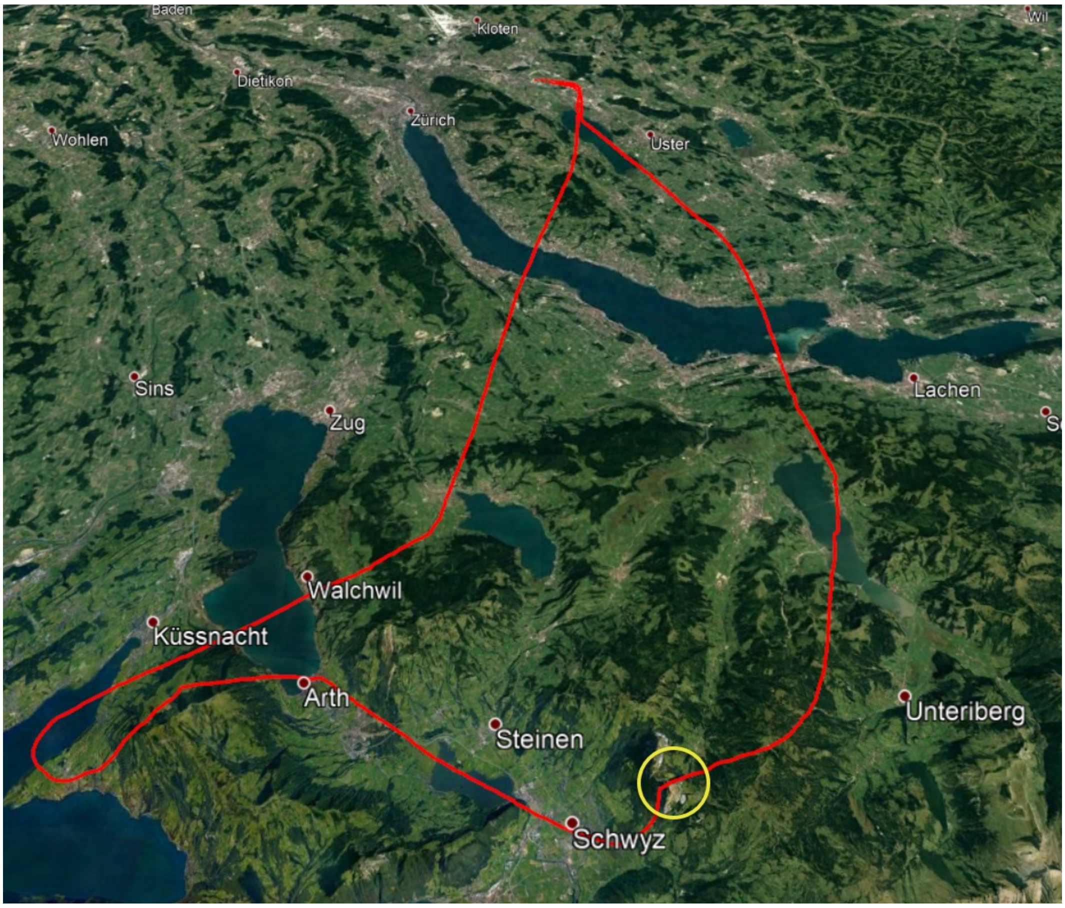

Figure 76: Overview of the flight path including hotspot (yellow circle). Shown on Google Earth.

A1.18.7.8.2 Hotspot

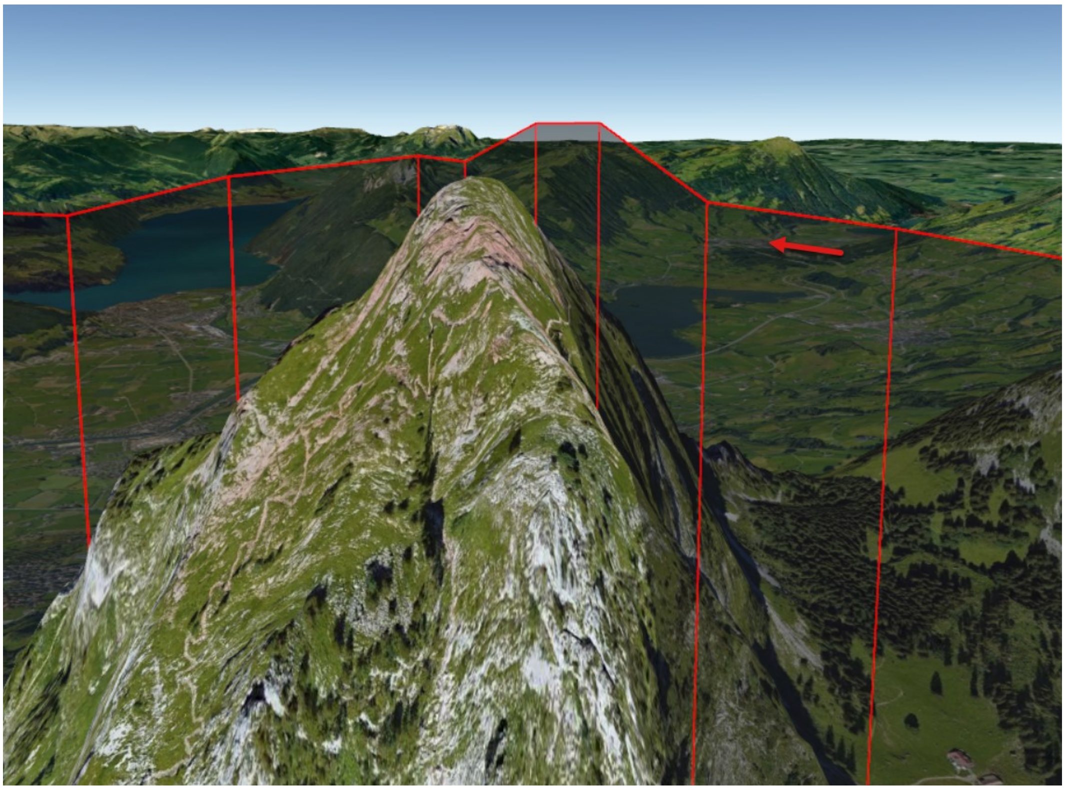

Figure 77: Climbing flight over the terrain at an altitude of 1,944 m AMSL with a height of 87 m above ground directly below the radar flight path and 353 m above ground with respect to the lowest point of the terrain profile. Shown on Google Earth.

Figure 77 shows a choice of flight path classified as 'high-risk'[4], which is characterised by the following safety-related features:

- Low-level flight over the terrain;
- Restricted view of the following section of terrain;
- Approaching an obstacle whilst climbing.

The lateral distance from the rocky outcrop when passing Gross Mythen was approximately 33 m (see figure 78).

[4] Chosen flight path classified as 'very high-risk' due to the instrument meteorological conditions at the time

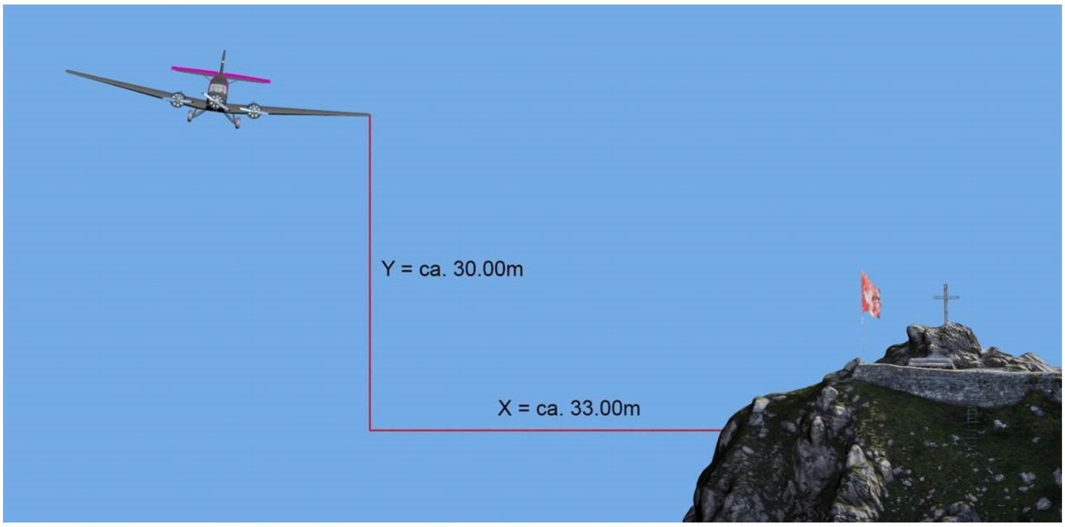

Figure 78: Reconstructed position and attitude using a three-dimensional model of an aircraft flying past Gross Mythen. Lateral distance from the rocky outcrop approximately 33 m, with a vertical distance of approximately 30 m.

The radar flight path (see figure 77) shows the climbing and very high-risk approach to Gross Mythen, with an approach up to the summit cross under temporary instrument meteorological conditions (IMC). A descent is initiated after passing the summit cross. In addition, screenshots from a video file show the level of visibility prevailing on that day and the Ju-52's near-terrain fly-by at Gross Mythen (see figures 79 and 80). During the daytime, visual flight rules (VFR) operations for aircraft in class Golf airspace are to be conducted in such a way that the aircraft is outside of the clouds with a constant view of the ground or water.

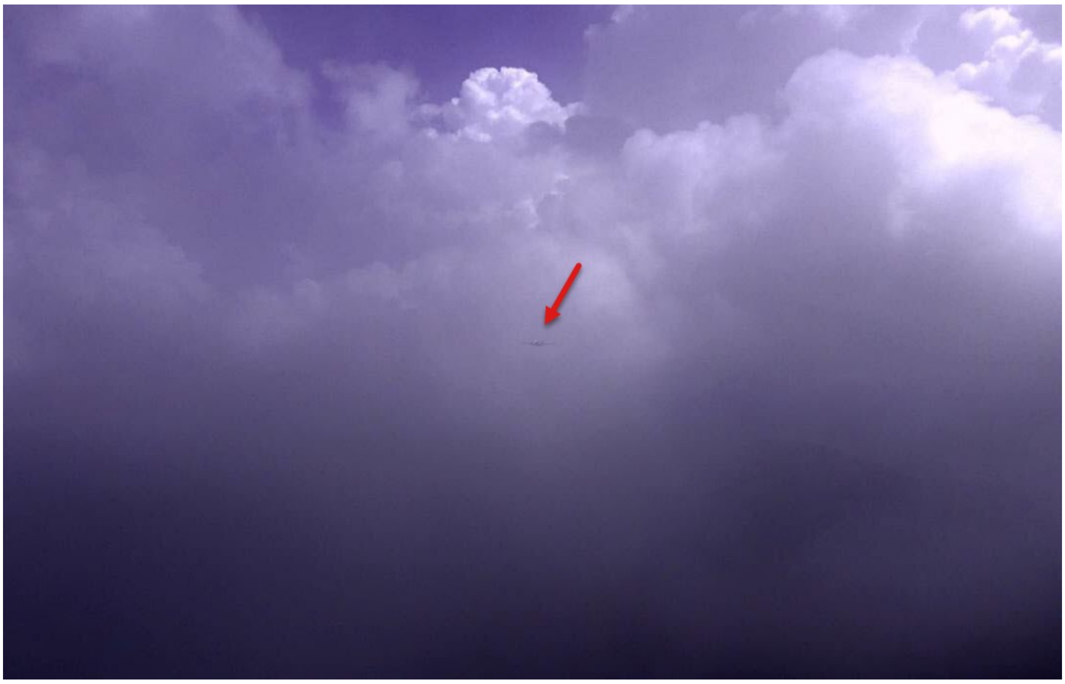

Figure 79: The faintly visible silhouette of an approaching Ju 52/3m g4e (red arrow) travelling towards Gross Mythen (image contrast increased). Footage provided by private individual.

Figure 80: The Ju 52/3m g4e flying past the summit cross is only faintly visible due to the weather conditions at Gross Mythen (image contrast increased). Footage provided by private individual.

Contents

A1. Factual information

A1.19 Useful or effective investigation techniques

A1.19.1 Use of data memories from mobile phones and cameras

The Ju 52/3m g4e was not equipped with any accident-resistant recording devices such as a flight data recorder (FDR) or a cockpit voice recorder (CVR), as is common and mandatory in commercial air transport aircraft today. FDRs specifically log flight parameters such as altitude, speeds, accelerations, heading, attitudes and positions. CVRs register conversations and radio communications as well as other sounds in the cockpit on various channels.

These days, the majority of light aircraft and gliders are also fitted with a basic recording device, such as a Flarm[1] collision warning device or a GPS logger.

As the historic Ju 52 aeroplane attracted attention during its flight, a good number of pictures and video recordings showing HB-HOT from the outside were available for the investigation. Several appeals were made to the public, which generated images and video footage of HB-HOT providing great support for the investigation. The images and videos capturing the outside of the aircraft supplemented the existing material and the descriptions of eyewitnesses in the vicinity of the accident site.

From inside the aircraft, primarily the recording devices belonging to the passengers, such as analogue or digital cameras and mobile phones as well as their electronic memory chips or SD cards[2] were of interest. The majority of this evidence was severely damaged and contaminated.

Using the STSB’s own resources and with the help of Forensic Services from the cantonal police of Grisons, it was possible to recover some of the data from these storage units. The data from severely damaged components were recovered by the French safety investigation authority – the *Bureau d’Enquêtes et d’Analyses pour la Sécurité de l’Aviation Civile* (BEA) – and other specialist laboratories.

Out of the 44 electronic devices secured, the data from ten data storage units could be read.

A1.19.1.1 Preparations for data recovery

The electronic components were taken apart, cleaned and their data storage units removed in an ESD[3]-protected area in the BEA laboratory in Paris (see figure 1). For certain mobile phones, in addition to the data storage unit, the associated encryption unit had to be removed as well, so that the data could also be read at a later stage. After cleaning, the data storage units were dried in a special oven for approximately 72 hours.

[1] A Flarm is a collision warning device with the additional capability of logging altitudes and positions of the flight. GPS loggers can do the same with regards to the flight path.

[2] An SD card, meaning a secure digital memory card, is an electronic data storage device.

[3] ESD: Electrostatic discharge can damage electronic components.

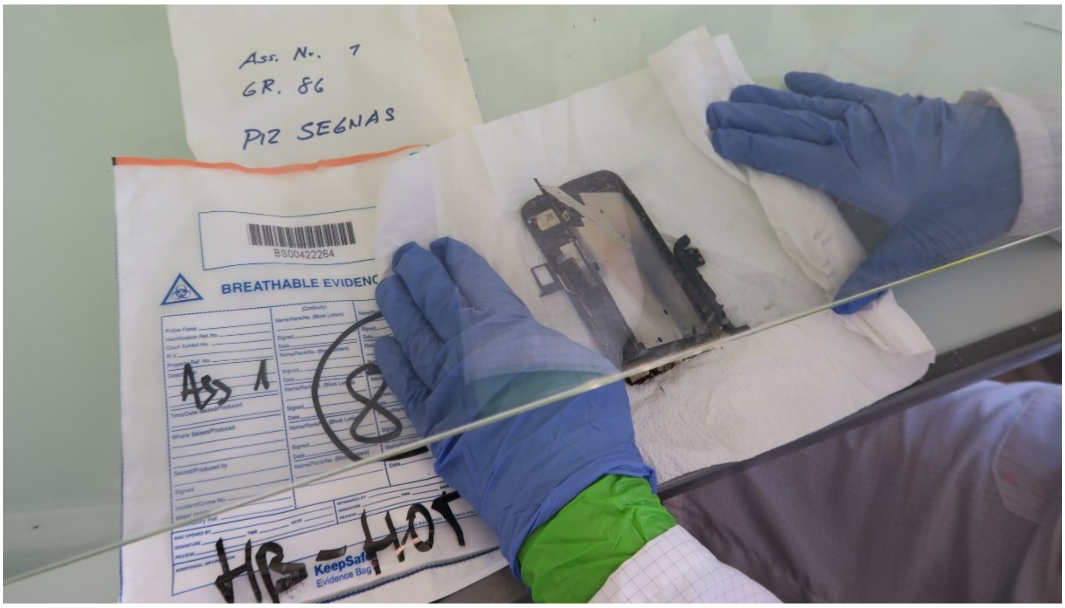

Figure 1: Removal of the data storage unit from a damaged mobile phone in the BEA laboratory.

For the mobile phones, data was recovered using the Golden Chassis method. For this, identical mobile phones to the ones secured from the aircraft were procured and their data storage and encryption cards were removed. Subsequently, the exhibits' processed data storage and encryption units were installed in the new Golden Chassis devices. For some of the devices, this restored access to the data and allowed it to be read.

In the cases where the data could not be retrieved after the data storage units had been rebuilt, internal defects were suspected in their data storage cards. Using a special CT[4] device available at the BEA, which heavily magnified the observed objects, it was possible to examine the inside of the data storage cards and chips without damaging them and to detect any defects.

Some of the mobile phones exhibited cracks in the very small quartz components on their data storage card and could not be read. However, the data storage blocks in the main data storage unit and in the encryption unit were intact.

Using nano soldering technology, the data storage chips and the encryption unit were removed and reinserted on an identical and intact Golden Chassis data storage card. The Golden Chassis data storage card was then inserted into the Golden Chassis phone.

Some of the mobile phones were damaged to such an extent that the silicon blocks in the data storage units were broken or destroyed. In these cases, it was not possible to repair the data storage units.

SD cards that could not be repaired using IT forensics were also analysed using a CT device. Their internal circuitry and the silicon blocks in the data storage units were assessed for damage (see figure 2).

[4] CT: Computed tomography is an imaging procedure used in radiology. Objects are X-rayed so that they can then be viewed three-dimensionally on a computer.

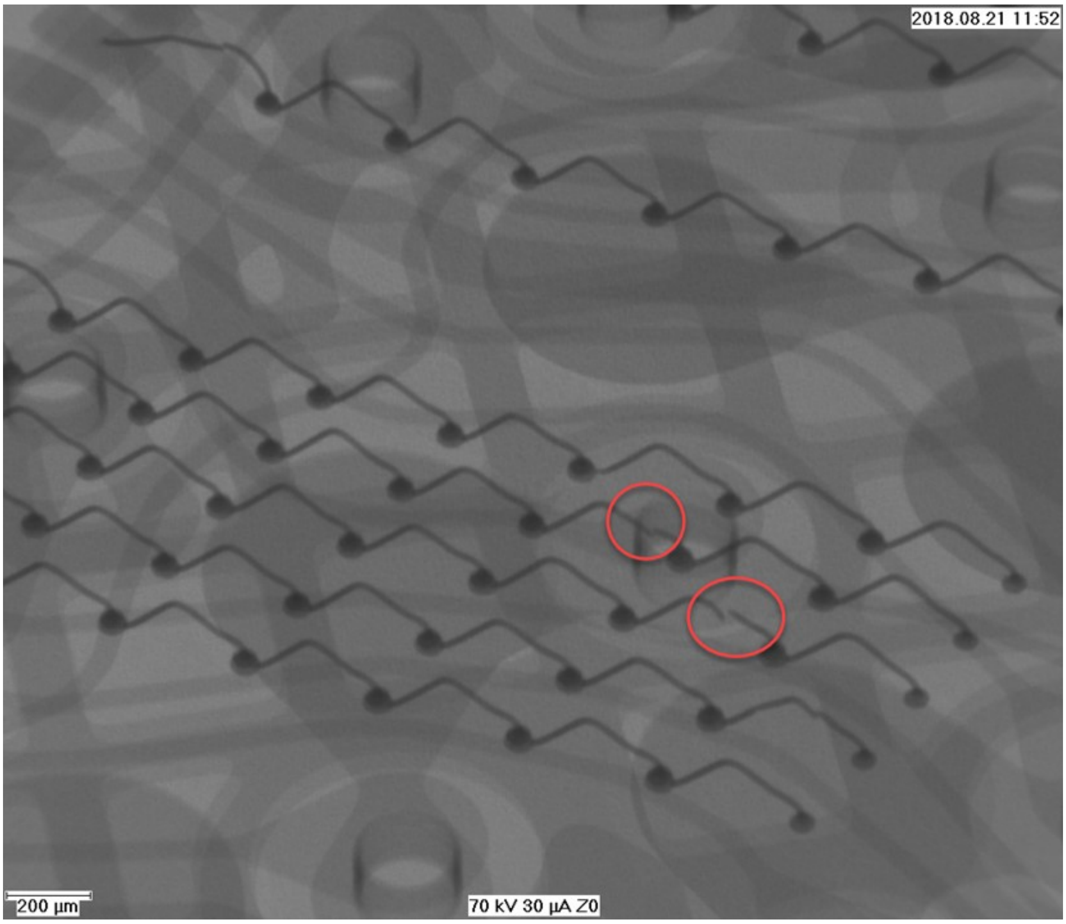

Figure 2: Heavily magnified CT scan of an SD card. Damage to the circuitry within is circled in red. Source: BEA.

A1.19.1.2 Data recovery and reading of the data

The data storage units of each device were read and assessed with regards to the data's relevance concerning the HB-HOT flights on 3 and 4 August 2018. Individual images and video footage could be restored in this process.

A passenger's GoPro camera contained a defective and incomplete video file. This was recorded during the accident and could not be completely written to the SD card due to the damage caused to the device as a result of the impact. Using BEA methods, it was possible to restore this video file in high resolution (4K). In addition, it was possible to read the buffering cache[5] of the camera in order to obtain additional lower-resolution video material. This allowed for an additional 5.06 seconds of video and audio material to be restored.

The lower-resolution footage is congruent, frame by frame, with the 4K footage and is 5.06 seconds longer, as mentioned above. Following recovery, this longer, lower-quality footage exhibited image interference and loss of images at two locations, totalling 2.17 seconds. It was, however, possible to replace the missing individual frames of the video footage with frames from the high-quality footage as, at that time in the video, the two streams were running in parallel and featuring identical images. Only the lower-quality video exhibited desynchronisation between the video and the corresponding sound, starting from the location of the image interference. The audio tracks of the two videos were binarily identical over their entire

[5] A camera's cache buffers the frames taken before compressing and writing them to the SD card as an MP4 video file.

common runtime and were therefore not subject to a failure in recording. Thus, the chronological sequence of the images and sound could be reconstructed despite some missing images.

A1.19.1.3 Data evaluation of image and video data

Further data evaluation was based on the recovery of the data on the damaged data storage units from the recording devices belonging to the aircraft passengers. Individual images and videos were analysed. The audio track was removed from some of the video footage and sonographically evaluated using spectral analysis. Details on this method and the procedure can be found under section A1.19.2.

The reconstructed photographs of the entire trip on 3 and 4 August 2018 were assigned to the respective flight paths. In many instances, the time stamps in the image files did not match the actual time as they were dependent on the date and time set in the recording devices. Nevertheless, it was not a problem to reconcile the relative time between two images with the flight path. For each reconstructed unit, a separate relative timeline was set up. By using the subjects captured in the images, it was possible to confirm the respective aircraft position. The method applied is explained in greater detail under section A1.19.3.

The recovered videos were also assigned to the flight path and thus to a common timeline. Individual videos could be recovered which were recorded in the cockpit of HB-HOT during the flights on 3 and 4 August 2018. Using the audio tracks of the footage made it possible to determine the rotational speeds of the propellers and the engines, and to compare them with the displays in the cockpit from the video images. The video footage taken closer to the time of the accident was analysed in greater detail. The video files were additionally split into their individual frames. A selection of these individual frames was photogrammetrically analysed. Details on this procedure can be found under section A1.19.4.

A1.19.2 Evaluation of the sound characteristics of the engines

As no flight recorder data was available, there was no information on the number of engine revolutions. In order to obtain this data, the audio tracks of video footage were used. Larger moving parts such as propellers, pistons, gears and crankshafts generate typical acoustic signals that can be evaluated using spectral analysis to create sonograms. A sonogram represents the different frequencies of sound over time. Stronger signals are depicted more intensively or are more intense in colour. Subsequently, the frequencies and the individual components' rotational speeds derived from those frequencies can be determined for the respective video footage. Furthermore, attention was paid to changes in the sound signature, looking out for unfamiliar or unexpected noises in the sonogram that could be suggestive of a technical defect in the aircraft.

It was possible to evaluate the videos' audio files containing characteristic sound signatures of Ju-Air's Ju 52 aeroplanes. These analyses were carried out by specialists in the BEA laboratory. The audio tracks of 23 video files of HB-HOT, from inside the aircraft and on the ground, as well as of a sister aircraft were examined. Detailed sonograms were produced for ten audio tracks. The Doppler effect[6] was taken into account for recordings that were taken from outside the aircraft. In addition, video footage available online was used to determine the standard sound spectrum for other Ju 52 aeroplanes.

[6] When the source of a sound and an observer move relative to one another, the received frequency will differ from the sent frequency depending on the relative speed between the source and the observer. The Doppler effect has to be taken into account in the sonographic evaluation.

Generally, it was possible to identify each engine's crankshaft rate (CSR), blade rate (BR) of the propellers, and cylinder rate (CR) for all of their nine cylinders. As can be seen in figure 3, the most distinct noises were emitted by the propellers. As the aircraft featured directly driven fixed-pitch propellers, it was possible to determine the identical speed of the propeller and its corresponding engine at known times of the video recordings.

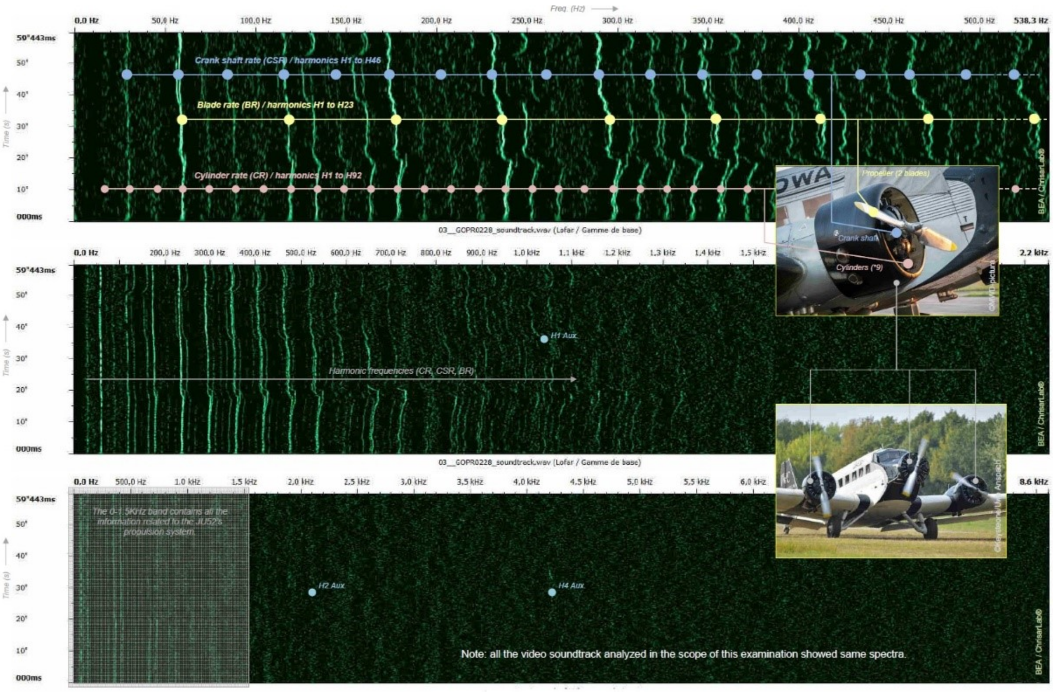

Figure 3: Example of a sonogram for a video recording from the cockpit of HB-HOT. The identified components CSR (blue), CR (pale red) and BR (yellow) are labelled. The images of the aircraft show the components. Here, the y-axis describes the time and the three x-axes describe the frequencies in three different amplifications. The harmonic frequencies of the main signal caused by interferences are also visible. Source: BEA.

When sonographically analysing video recordings that have been filmed from the cabin of an aircraft, a high level of accuracy with regard to engine speeds can be assumed, varying by just a few hertz (Hz).

For the engine speeds calculated from all of the sonograms analysed, the engines were assigned as engine A, B and C for each video sequence. It was, however, not possible to assign the determined speeds to the actual engines.

A1.19.2.1 Engine synchronisation

During the video recording relating to figure 3 as well as some other video footage, passengers were videoing the outside from the cockpit. When doing so, the engine instruments could be seen in the footage.

In the cockpit, the engine speed (rpm) is displayed on three tachometers featuring analogue and digital gauges. The digital gauge in the middle shows the speed of the centre engine. The digital gauges for the left and right engines each show the difference in speed for the respective engine in relation to the centre engine. In figure 4, the digital gauge for the centre engine shows a speed of 1,727 rpm. The left engine tachometer displays a value of + 3 (1,730 rpm); the right engine tachometer displays a value of + 2 (1,729 rpm).

When all three engines run at slightly different speeds, it is not uncommon for acoustic standing waves to be formed. These unpleasant interferences are perceived as low-frequency, rising and falling ambient noise. By synchronising the left and right engines as best as possible, the centre engine can be operated at a higher or lower speed. This allows fine adjustments to be made without interferences occurring.

The digital gauges are used to synchronise the engines as closely as possible; adjustments can be made by slightly moving the throttle levers. Due to lack of accuracy, fine adjustment for synchronisation of two engines is not possible using an analogue gauge. It must be made by observing the digital gauges. This means that at least one of the pilots' pairs of eyes will linger on these gauges for a longer period of time.

Figure 4: Tachometers with digital displays, marked by yellow rectangles. The yellow arrows point to the three throttle levers that must be operated to set the respective rpm.

A1.19.2.2 Advanced technical sonogram analysis

A1.19.2.2.1 General

The BEA was able to determine the engine speeds in individual phases of the two flights from Dübendorf to Locarno on 3 August 2018 and the accident flight from Locarno on 4 August 2018 using the ten sonogram analyses carried out overall.

In the following section, the fly-by past Mount Rigi is shown as an example.

The video sequence shows in-cockpit footage on which the main aircraft instruments are visible. Thus, using still images, it is possible to identify the analogue read-outs for the engine speeds as well as the indicated altitude and airspeed. In some still images documenting the flight past Mount Rigi, the digital engine-speed gauges could also be seen. The BEA recorded the speeds determined from the pictures and compared these with the speeds determined through analyses.

For most of the sonographically evaluated flights flown by the accident crew, it stood out that the propellers were synchronised very delicately, slowly and precisely. The engines were regularly resynchronised. In this sense, a flight crew leaves a 'fingerprint' on the sonogram when handling the engines.

A1.19.2.2.2 Mount Rigi fly-by

Figure 5 shows a graph of the three engine speeds from HB-HOT during its flight past Mount Rigi on 3 August 2018. The yellow, red and green dots indicate the rpm speeds of the three engines read from the analogue gauges in the still images over the course of the fly-by. In some still images, it was also possible to see the digital displays of the tachometers. These are shown as numbers on the graph. The numbers in the square brackets relate to the speed of the centre engine, the numbers to the left and right of these brackets correspond to the speed differences of the left and right engine in relation to the centre engine.

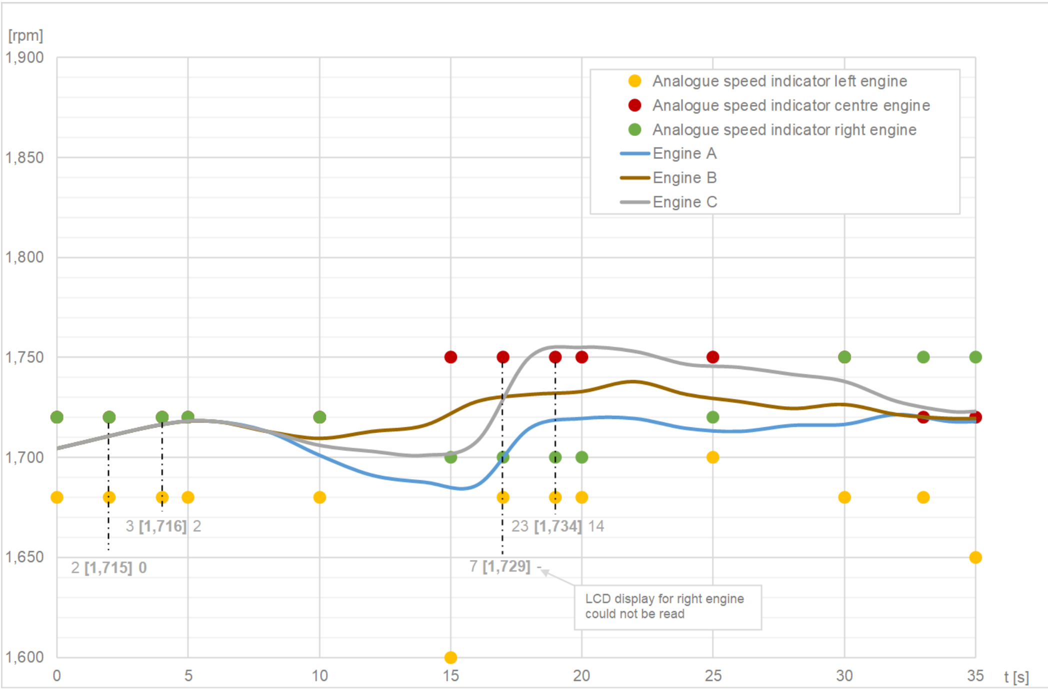

Figure 5: Graph of the engine speeds from HB-HOT over the course of the video footage recorded whilst flying past Mount Rigi on 3 August 2018.

In the first phase of the fly-by, the engine speeds were between 1,700 and 1,720 rpm. After 15 seconds, the speeds of engines A and C were increased by 20 to 30 rpm, now ranging between 1,720 and 1,750 rpm. The speed of engine A never exceeded 1,720 rpm.

The graph reveals that there are considerable discrepancies between the speeds determined from sonogram analysis and those read from the still images displayed in analogue form on the gauges. At 20 seconds, for example, the speed from the sonogram ranges between 1,720 and 1,750 rpm, whilst the values read from the analogue gauges range from 1,680 to 1,750 rpm.

At the 2-, 4-, 17- and 19-second marks in the video footage, it was also possible to read the three digital tachometers from the respective still images. This established that the four readings corresponded rather accurately to the respective sonogram analysis speeds.

The fly-by was performed at an indicated altitude ranging between 1,805 and 1,810 m AMSL. The indicated airspeed was in the range of 150 to 165 km/h.

A1.19.2.3 Conclusion of the BEA report on its sonographic evaluation

The BEA report and further investigation came to the conclusion that the same sound signatures that are characteristic and typical for Ju 52 aeroplanes can be ascertained in all the sonograms evaluated, be it from the accident aircraft or from audio tracks of another Ju 52/3m g4e. Furthermore, with regards to all recordings including accident video footage from inside the aircraft as well as impact videos from outside the aircraft, the following can be stated:

- No unusual or unfamiliar noises were apparent on any of the recordings.
- The analysis did not reveal any spectral anomaly concerning HB-HOT's propulsion system, neither for the engines nor the propellers. Near the Segnespass, there were no anomalies or faults in the propulsion system either.
- The analysis allowed for the engine speeds set for HB-HOT during each flight phase (take-off, climb, cruise, accident sequence) to be determined. On the approach to the Segnespass and in most other cases, it was possible to examine the three engine speeds individually.
- Further analysis combined with the results from the examination of the engine instruments revealed great inaccuracies in HB-HOT's analogue tachometers. The digital displays were much more accurate.

A1.19.3 Methodology for the reconstruction of HB-HOT flights

The reconstruction of the flight paths was primarily based on radar recordings from multi-radar tracking (MRT), i.e. data compiled from several radar systems at different locations. Due to terrain topography, the flight path positions ascertained from radar data vary in accuracy, particularly for flights in mountainous areas, and can deviate considerably from the actual positions. Several positions in a row may be missing, resulting in gaps in a radar flight path. The flight altitudes relating to the radar positions are transmitted as pressure altitudes based on the ICAO standard atmosphere; they have been corrected with an accuracy of ± 30 m for the following examinations based on the actual pressure conditions.

In addition, a wide range of images and video footage, as well as statements of numerous eyewitnesses who were watching HB-HOT from the ground, were available for the investigation, as well as image and video material from devices belonging to the passengers found at the scene of the accident.

The images and video footage were visually evaluated in the geometry of the terrain. Based on the evaluation of these data and the information obtained, the gaps in the radar flight paths could be filled in most instances, the inaccuracies eliminated to a large extent, and the flight paths reconstructed (see figure 6).

In order to determine the positions of the aircraft in space, its attitude relative to the terrain and its speed relative to the ground, complex photogrammetric evaluations were carried out, especially for the decisive flight phase before the accident. For this purpose, the basin south-west of Piz Segnas was surveyed using a 3D laser scanner and the measurements were incorporated into the three-dimensional terrain model of the Swiss Federal Office of Topography (Swisstopo). To determine the relevant details of a three-dimensional model for a Ju 52/3m g4e aircraft, a laser scan was taken of one of HB-HOT's sister aircraft. By using a series of specific software programs for the creation and processing of three-dimensional models as well as for image processing, it was possible to determine the positions and attitudes of HB-HOT based on images captured on cameras both inside the aircraft and on the ground.

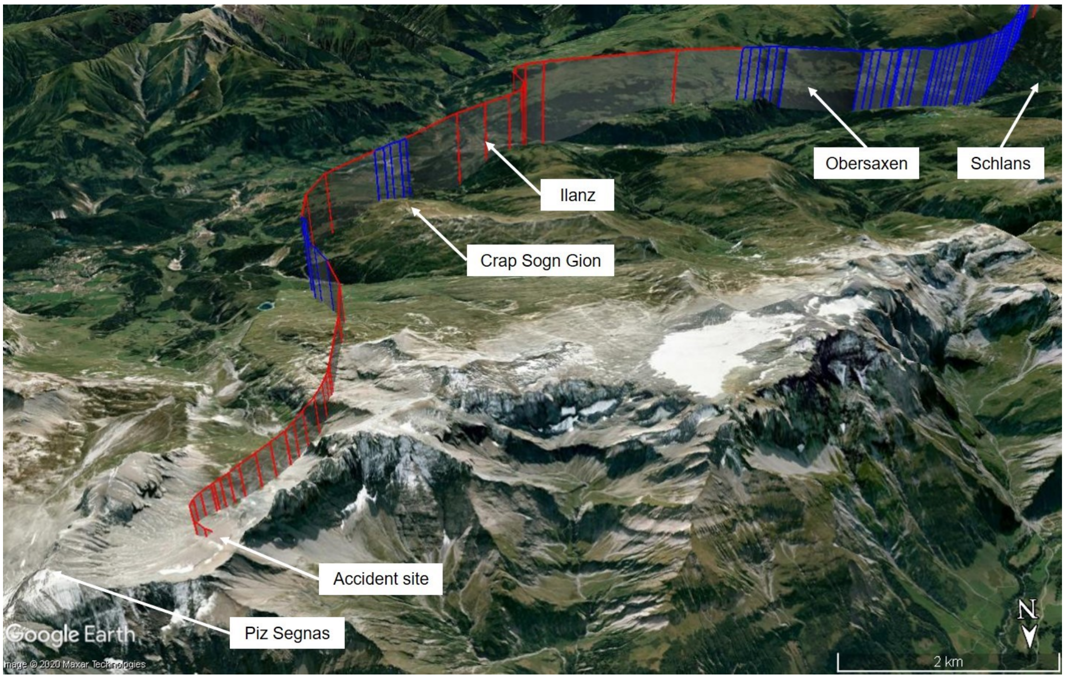

Figure 6: Section of the accident flight on 4 August 2018 with stretches derived from radar data (blue) and that have been reconstructed (red). Shown on Google Earth.

The radar data points corrected in height are marked in the sections shown in blue, connecting them to the ground with vertical lines. In addition to position and altitude, MRT also calculates and records the time and ground speed (GS) for each data point. In the absence of radar data points, a missing stretch can be filled in with a straight line between adjacent known positions based on the information available – provided that no alternative flight paths are possible, as was the case near Obersaxen (see figure 6).

Some of the missing or obviously inaccurate radar flight path sections, which could not be connected by a straight line taking into account the above considerations, could be reconstructed based on the observations of eyewitnesses on the ground. Emanating from the positions established by these eyewitnesses, the lines to the sighted aircraft were constructed in three-dimensional space using their descriptions. The aircraft's spatial positions were then determined through iteration, as was the case near Ilanz (see red stretch of flight path in figure 6). To check the plausibility of such a flight path section, the average speed relative to the ground was calculated based on the length of the flight segment and the time difference between the adjacent known data points; this was then compared with the GS of the adjacent data points.

Where pictures of the passing aircraft, taken from the ground, were available, the reconstruction of the flight segments was carried out in the same way as described above, i.e. the images were visually incorporated into three-dimensional terrain models, thereby devising the lines of sight.

In order to determine the positions of the aircraft in space, its attitudes in relation to the terrain and its speed relative to the ground, the much more precise, photogrammetric evaluations mentioned earlier in this section were carried out for the decisive flight phase before the accident in the basin south-west of Piz Segnas (see section A1.19.4).

A1.19.4 Methodology for photogrammetric evaluations

The Zurich Forensic Science Institute (FOR) was commissioned with the photogrammetric analysis of images and video footage obtained from eyewitnesses who had watched the Ju-Air aircraft from the ground as well as from passenger devices. In addition to the reconstruction of HB-HOT's accident flight path, especially in the last flight phase before the accident site, individual positions and attitudes of the Ju-Air aircraft were determined in order to objectively assess the risks during flight operations.

The methods used and the results of these photogrammetric evaluations were described in detail by the forensic institute. The following sections briefly summarise key elements of the methodology used.

Individual sections of terrain and objects were surveyed using a 3D laser scanner, both from the ground and from the air using a helicopter. The point clouds produced from this were then combined into a single point cloud using the appropriate software. Subsequently, this point cloud was photogrammetrically evaluated, together with the corresponding image series, and high-resolution 3D models of the photographed objects or sections of terrain were computed.

Two-dimensional photographs and video images from cameras with a distorted perspective were algorithmically restored and then incorporated into the three-dimensional models using reference points and specialised software. These methods, described here in a very simplified manner, allowed for the photogrammetric evaluation of both images captured from known locations (eyewitnesses on the ground) as well as from unknown locations (passengers' images).

The level of accuracy of an aircraft's positions and attitudes in space determined in this way very much depend on the image quality as well as the camera's location and direction of view, among other things. For example, the positions and attitudes can be determined more accurately if they are based on images taken from the aircraft abeam the direction of flight, overlooking a wing against a backdrop featuring distinctive terrain, than those lacking the aforementioned elements. Several iterations – in which the parameters were varied up to pixel blur – were required before it was possible to specify the most appropriate position and attitude of the aircraft.

For these reasons, the level of accuracy with regards to the individual positions and attitudes varies from case to case and cannot be quantified universally. It was possible to determine some positions and attitudes to within a few decimetres and less than 0.1 degree respectively, whilst, with a particularly unfavourable scene captured in the image, the position in the direction of the flight was determined with an accuracy of up to 90 m. This margin of error was taken into account when using the values determined, for example in the reconstruction of the flight paths and the calculation of the ground speeds.

The following model representation exemplifies the result of the photogrammetrically reconstructed positions and flight attitudes of HB-HOT in the last flight phase before the accident.

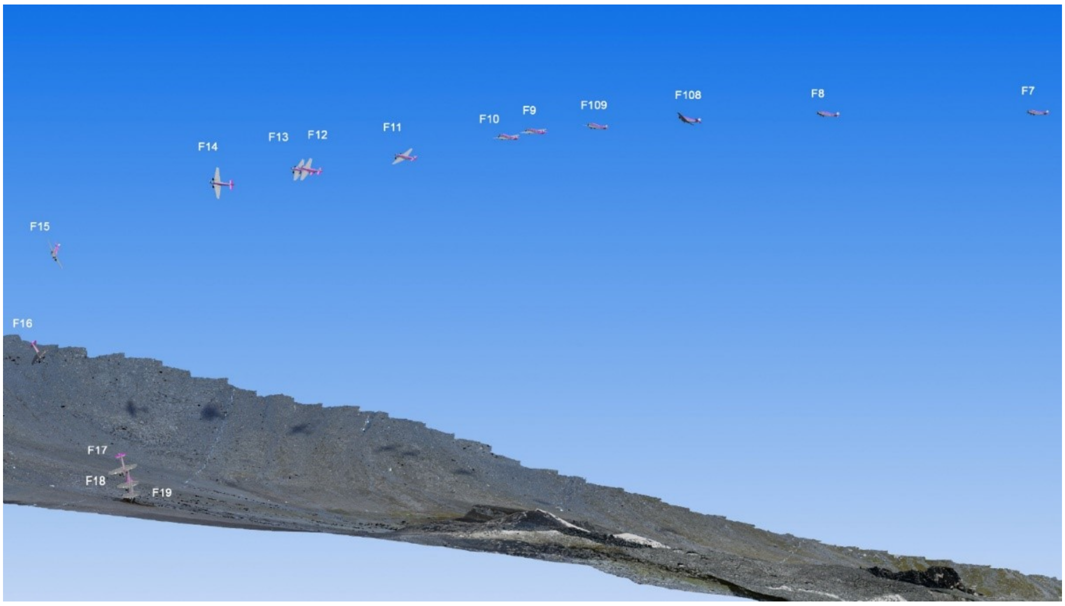

Figure 7: Photogrammetrically reconstructed positions and flight attitudes (F7 to F19) of HB-HOT in the last flight phase before the accident, depicted using the scan data of the terrain.

A1.19.5 Methodology for numerical analysis

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 when the aircraft entered the section of terrain surrounding the Segnespass:

- Results of the meteorological evaluation, in particular the wind speeds and wind directions, based on COSMO analysis (see annex A1.7);
- Results (sonograms) of the evaluation carried out by the BEA of acoustic data from a video recorded from inside the aircraft;
- Results of a visual, qualitative assessment of the aileron deflection carried out by the STSB based on video footage recorded from inside the aircraft.

A1.19.5.1 Methodology and precision in the use of radar data

As part of a multi-radar tracking (MRT) system, a data point is recorded every four seconds. The radar data of a 60-minute flight consists of about 1,000 radar data points. The lateral positions are average values from the bearings of all radar stations. Due to terrain topography, these flight path positions ascertained from radar data vary in accuracy, particularly for flights in mountainous areas, and can deviate considerably from the actual positions. After loss of the radar signal in particular, the continued flight path is extrapolated for a few seconds. These and other inaccuracies as well as the system inaccuracies described below were known and taken into account during further investigation.

The accuracy of the lateral radar positions was discussed in collaboration with Skyguide, the operator of the radar system. Under ideal conditions, a lateral error in the range of 30 m can be assumed. When several radar stations cover an area, placed at an ideal angle to each other, an accuracy of 30 to 60 m or better can normally also be achieved in the mountains. With poor radar coverage, the lateral error can be significantly higher. However, the terrain, as well as the altitude flown and the time elapsed between missing radar data points, allow conclusions to be drawn about the possible flight paths.

When the STSB experts assessed the flights based on radar data, they assumed a lateral radar data inaccuracy of a maximum of ± 150 m.

The altitudes in the radar recordings are pressure altitudes based on the ICAO standard atmosphere transmitted by the aircraft's transponder. This means that a properly calibrated transponder signal can be assigned to the pressure prevailing at flight altitude (QFE). This in turn is known with an accuracy of 0.5 to 1.0 hPa (about 5 to 10 m vertically) due to the pressure field known from station measurements and model calculations (see annex A1.7). This allowed for the altitudes recorded in increments of 100 ft (about 30 m) to be converted to true altitudes and for them to be compared with the ground level elevation. Inaccuracies relating to both the method and the analysis of flight phases using GPS coverage show an accuracy of ± 15 m in altitude. Together with a digitalisation inaccuracy relating to the transponder' height increments, an overall inaccuracy of 30 m can be assumed.

A1.19.6 Background information for the flight path analysis

Determined, aerodynamically possible turn radii can only be achieved if the necessary kinetic energy is available, be it through the power available from the engines or through the conversion of potential energy into kinetic energy when the aircraft descends in a controlled manner.

In the evaluation of the flights from summer 2018, a total aircraft mass of 9,500 kg was used as a basis for gauging the turn radii. As an aircraft cannot be operated accurately at its stall speed (v_s), a safety margin of 30% has been included on v_s to calculate the turn radii possible at a bank attitude of 30 degrees. This margin is very low for when flying in high-altitude mountains and is equivalent to the margin referred to in the aircraft flight manual (AFM) for the final approach when landing. Turns were assumed for normal passenger flight operation with a bank attitude of a maximum of 30 degrees. Possible turn radii were considered at minimum speed (with the 30% stall margin) and additionally with the actual speed without any wind influence.

The reaction time when approaching a ridge, crest or similar at 90 degrees to the direction of flight was assessed at seven seconds. Five seconds were adopted for the time taken to recognise an unfavourable situation (downdraught, engine failure, other aircraft, etc.) and map out alternatives, and two seconds for initiating any necessary measures such as bank attitude and engine adjustments.

For the section of the flight near the Segnespass, the determined aircraft mass of 9,206 kg was used for the calculation. According to the table in the AFM, the indicated stall speed in this configuration is 107 km/h indicated airspeed (IAS), which corresponds to a true airspeed (TAS) relative to the surrounding air at the density altitude near the Segnespass prevailing at the time of the accident of 125 km/h. The aerodynamically possible radii and figures near the Segnespass were calculated without a safety margin or other allowance.

Turn radii in relation to the terrain were estimated using the ground speed (TAS with the assumption of GS = TAS). Aerodynamically possible maximum bank attitudes were calculated using the assumed IAS. Temperature and air pressure were taken into account as density altitude. Additional factors can slightly change the stall speed (v_s) at higher altitudes. This was neither taken into account in the AFM, nor in this investigation.

In contrast to TAS, IAS decreases at higher altitudes due to lower air density. A constant IAS at a higher altitude results in significantly greater turn radii due to the increased TAS. This fact was taken into account in the calculations.