Contents

A1. Factual information

A1.1 Background and course of the accident flight

A1.1.1 Preliminary remarks and conventions regarding altitude information

The following conventions apply to the presentations of the background and course of the accident flight in this section:

- GPS altitude – True altitude above mean sea level (AMSL), determined by a GPS receiver.
- Uncorrected transponder altitude – Flight altitude (pressure altitude) in hectofeet above the atmospheric pressure of 1,013.25 hPa, determined barometrically and sent to radar receivers on the ground by the aircraft's transponder. The uncorrected transponder altitude is based on the ICAO standard atmosphere.
- Corrected transponder altitude – Uncorrected transponder altitude converted to the true altitude above mean sea level based on the actual pressure gradient depending on the altitude.
- Density altitude – Altitude above mean sea level in the standard atmosphere, at which the air density is the same as at the true altitude. The density altitude is important for an aircraft's flight performance.
- Photogrammetric altitude – True altitude above mean sea level, determined photogrammetrically over the course of the investigation from photographs or video footage.
- Displayed altitude – Altitude above mean sea level indicated on a barometric altimeter in the cockpit. This can deviate considerably from the true altitude above sea level. This displayed flight altitude is normally used for navigation and communication with ground-based radio stations.

In this report, altitude information is primarily given in metres and only secondarily in feet. This makes it easier to compare with altitude information from the topographic maps of the Swiss Federal Office of Topography used as base maps. One altimeter in the cockpit of the Ju 52/3m g4e aircraft HB-HOT displayed a metric reading, whilst the two other altimeters gave their readings in feet.

Predominantly true altitudes determined as corrected transponder altitudes or photogrammetric altitudes were used for the reconstruction of the mentioned flight paths.

A1.1.2 Background

A1.1.2.1 Days, weeks and months prior to the accident

Since 2002, Ju-Air had been offering a flight and cultural trip from its home base in Dübendorf, Zurich, to the canton of Ticino in southern Switzerland every August. According to public advertising for this 'Locarno adventure tour', as it was referred to, the following flight-related items were on the agenda for the 2018 trip:

- Check-in at the Dübendorf Air Force Center[1] at 08:30 on Friday, 3 August 2018;
- Flight (outward) in a Ju 52 from Dübendorf to Locarno "*via the Saint-Gotthard Massif mountain range*";

[1] The Air Force Center is a civilian business park at Dübendorf Air Base including an experience centre and with close ties to the military. The Air Force Center is home, most notably, to an air force museum and Ju-Air, which is based there as part of the Association of the Friends of the Swiss Air Force (*Verein der Freunde der Schweizerischen Luftwaffe* or VFL).

- Flight (return) in a Ju 52 from Locarno to Dübendorf (without specifying the route) on Saturday, 4 August 2018;
- Landing in Dübendorf at “*approximately 17:00*”.

A programme of cultural events in Ticino and Italy as well as an overnight stay in a hotel in Lugano were arranged for the time between the outward flight on the Friday morning and the return flight on the Saturday afternoon.

Ju-Air advertised the trip towards the end of 2017. From spring 2018, it was fully booked.

Ju-Air had already arranged the in-flight service personnel (ISP) for the 2018 Locarno adventure tour as part of its annual planning in January 2018. This was in response to this person’s request to be appointed ISP and tour guide for the trip.

During the same annual planning, two pilots had also been arranged for this tour to Ticino. In July 2018, however, these two pilots renounced their commitment to the trip. As a result, Ju-Air was left with no flight crew for the 2018 Locarno adventure tour one week before it was scheduled to take place and had to find a replacement in the Ju-Air cohort of pilots at short notice. Pilot A then proposed to Ju-Air that he and his good friend, pilot B, could take on the role of flight crew for the adventure trip. This was provided that Ju-Air would pay for the crew transfer flights, which a trainee pilot of pilot A would carry out in a four-seater motor-powered aeroplane. According to pilot A, these crew transfer flights were necessary because he and pilot B wished to stay in northern Switzerland on the evening of 3 August 2018 and therefore could not spend the time between the outward and return flights in Ticino. Ju-Air accepted this offer and subsequently assigned pilots A and B to carry out the 2018 Locarno adventure tour flights.

The brief of 30 July 2018 for the 2018 Locarno adventure tour for the attention of the crew included the following:

- Execution as a commercial flight;
- Use of the Ju 52/3m g4e aircraft, registered as HB-HOT, filled with 1,600 litres of fuel;
- Pilot B as the duty officer;
- Pilot A as the person responsible for flight preparations;
- Take-off from Dübendorf at 09:00 on 3 August 2018, landing in Locarno at “*approximately 10:15*”;
- Take-off from Locarno at 16:00 on 4 August, landing in Dübendorf at “*approximately 17:15*”.

The brief was signed by the accountable manager (ACM) of the air operator, Ju-Air, including his name and role ‘flight operations manager’.

A1.1.2.2 Wednesday, 1 August 2018

On the afternoon of 1 August 2018, pilot A, as the flight instructor, and a trainee pilot of his, carried out a flight from Lommis Airfield (LSZT) in north-eastern Switzerland. This was the first flight of the difference training (see annex A1.17) that this trainee pilot intended to undergo with pilot A as the flight instructor in the four-seater Robin DR 400/140 B motor-powered aeroplane. Three landings were made during this flight. Pilot A and the trainee pilot did not carry out any other flights on this Robin DR 400/140 B that day. On the checklist for this difference training, dated and signed by the flight instructor, pilot A, it was recorded that this trainee pilot had completed his difference training on 1 August 2018.

On the evening of 1 August 2018, the tour guide attended a Swiss National Day celebration in Ruschein in the canton of Grisons (municipality of Ilanz), where she was staying in her holiday home for a few days. The tour guide told others present at the celebration that, as a Ju-Air tour guide, she would probably be flying over the Ruschein region in a Junkers Ju 52/3m 'Iron Annie' on 4 August 2018 and that she would notify them shortly before flying over.

A1.1.2.3 Thursday, 2 August 2018

No significant events.

A1.1.2.4 Friday, 3 August 2018 (the day before the accident)

At 7 a.m., Ju-Air maintenance staff began preparing the Ju 52/3m g4e aircraft, registered as HB-HOT, for the upcoming flight to Locarno.

In the Air Force Center briefing room at 07:52, pilot A, the person responsible for flight preparations, printed out the operational flight plan (OFP) for the outward flight, and, at 07:54, did the same for the return flight. The OFP for the outward flight included a route via Rapperswil, the Oberalp pass, the Gotthard pass and Bellinzona (see figure 9). On the outward flight's OFP, which also acted as load sheet for the flight, a mass of 9,965 kg and a centre of gravity at 1.99 m were noted for take-off in Dübendorf (see figure 9 and annex A1.6). The reconstructed value for the mass at take-off from Dübendorf was 9,714 kg and the centre of gravity at 2.098 m (see annex A1.6).

Pilots A and B did not submit an ATC[2] flight plan for the upcoming flight to Locarno. The Dübendorf aerodrome control tower (Dübendorf Tower), on the other hand, created a 'mini departure flight plan' in the Air Force command and information system (FIS-LW). The radio call sign, flight rules, the runway identifier, departure route and take-off time were noted on this, but not the destination airport nor information regarding the route over the Alps.

At around 08:30 on 3 August 2018, the 17 people who were part of the tour group arrived at the Air Force Center at Dübendorf Air Base. The individuals and small groups had signed up for the two-day 2018 Locarno adventure tour during winter 2017/2018 (see section A1.1.2.1). The outward and return journeys were to be made in one of the three historic Ju 52 aeroplanes in service with Ju-Air.

Once the passengers had arrived, their hold luggage ('checked luggage') was stowed in the fuselage of the Ju 52/3m g4e aircraft, registered as HB-HOT, by Ju-Air's maintenance staff. Shortly afterwards, the passengers boarded the prepared aircraft in the presence of the pilots and the ISP.

At 08:59, HB-HOT took off from runway 11 at Dübendorf Air Base (LSMD) for its commercial flight to Locarno under visual flight rules (VFR). Seventeen passengers, the ISP, and pilots A and B were on board the aircraft. For this flight, pilot A acted as the co-pilot and assisting pilot in the right-hand seat, whilst pilot B was the commander and pilot flying seated on the left.[3] A map outlining the outward flight is given as an overview in figure 1 in the final report.

With the aim of keeping aircraft noise in densely populated areas to a minimum, HB-HOT turned south just seconds after take-off and then continued its climb in a south-easterly direction after another turn approximately above the centre of the

[2] ATC: air traffic control

[3] When two pilots, who like pilots A and B had the internal rank of captain at Ju-Air, piloted a Ju-Air Ju 52/3m together, the procedure and practice at Ju-Air was that the pilot seated on the left, i.e. the commander, had the role of pilot flying, and the pilot on the right, i.e. the co-pilot, acted as the assisting pilot. The pilot flying piloted the aircraft, whilst the assisting pilot was responsible particularly for handling radio communication.

Greifensee lake. Shortly afterwards, Dübendorf Tower granted HB-HOT permission via radio to leave the aerodrome frequency. HB-HOT confirmed this and bid farewell to Dübendorf Tower. Between 09:06 and 09:08, HB-HOT crossed Lake Zurich on the Männedorf–Wädenswil route, before continuing on a generally south-westerly heading towards Mount Rigi and Lake Lucerne.

Meanwhile, the trainee pilot of pilot A had taken off from Lommis Airfield in a Robin DR 400/140 B at 9 a.m., also heading to Locarno, to pick up his flight instructor (pilot A) and his flight instructor's friend (pilot B) (see section A1.1.2.1). The trainee pilot was alone on board the motor-powered aeroplane and was piloting it. Shortly after take-off, he made radio contact with the flight information service Zurich Information and declared his VFR flight to Locarno and route via Schänis and Ambrì. At 09:48, the aeroplane landed on runway 26C and was instructed to taxi to parking zone Bravo. After parking the Robin DR 400/140 B on grass parking Bravo and completing the administrative work in the AIS office, the trainee pilot waited in the airport restaurant for HB-HOT to arrive.

Meanwhile, HB-HOT was approaching Mount Rigi – still in a climb. At 09:12, HB-HOT, or rather pilot A as the assisting pilot, had already contacted the Buochs aerodrome control tower (Buochs Tower). At the time, HB-HOT was climbing above Unterägeri at a corrected transponder altitude of approximately 1,700 m (5,600 ft). Pilot A informed the Buochs Tower aerodrome controller that HB-HOT would fly over Buochs Airport (LSZC) on the Rigi–Melchtal route.[4] The Buochs Tower aerodrome controller then gave HB-HOT clearance to cross the control zone (CTR) of Buochs Airport. The aerodrome controller also instructed HB-HOT to make contact again directly above the airport.

At 09:16, HB-HOT passed Rigi Kulm (main summit: 1,797 m AMSL) and entered the Buochs control zone. When flying past the main summit of Mount Rigi at a lateral distance of approximately 500 m, the corrected transponder altitude was approximately 1,870 m AMSL. At 09:19, the position "*overhead*" was reported relating to Buochs Airport. At 09:21, HB-HOT left the control zone of Buochs Airport approximately 2 km east of Mount Stanserhorn (1,897 m AMSL) and at an altitude of approximately 2,250 m AMSL. Buochs Tower subsequently bid HB-HOT farewell upon leaving its frequency.

At around 09:26, HB-HOT contacted the Meiringen aerodrome control tower (Meiringen Tower). At this time, HB-HOT was climbing above Melchtal at approximately 2,500 m AMSL, equivalent to 8,200 ft AMSL. Pilot A informed the Meiringen Tower aerodrome controller that HB-HOT would be flying through the control zone of Meiringen Air Base (LSMM) on the Planplatten–Wetterhorn route. Shortly before entering the control zone, HB-HOT was given clearance by the Meiringen Tower air traffic controller to cross the control zone of Meiringen Air Base. The aerodrome controller also instructed HB-HOT to make contact again after crossing the CTR near the Wetterhorn peak. Between 09:30 and 09:32, HB-HOT crossed the control zone of Meiringen Air Base and thus the Hasli valley, before flying on towards Rosenlaui. After HB-HOT had crossed the control zone, Meiringen Tower bid farewell to the aircraft upon it leaving the frequency.

At around 09:36, HB-HOT finished its climb at approximately 2,990 m AMSL.[5] In the subsequent phase of the cruising flight, the ground speed varied between 100 and 115 knots, approximately equivalent to between 185 km/h and 215 km/h.[6]

[4] At this flight altitude, this automatically also means crossing the control zone (CTR) of Buochs Airport.

[5] The density altitude at this altitude and time was approximately 3,310 m AMSL.

[6] This speed was calculated by various radar stations on the ground.

At 09:37, the Ritzlihorn mountain (3,277 m AMSL) was passed during a slight right turn and at a short distance from the rock face – estimated at 30 to 50 m between wing tip and rock face. The flight past the Ritzlihorn was filmed by several passengers (see figure 1).[7]

Figure 1: Still image from one of the videos recorded from inside the aircraft when passing the Ritzlihorn mountain (3,277 m AMSL). The still image shows the right wing of HB-HOT and part of the engine cowling (bottom left corner of the image) in front of the northern flank of the Ritzlihorn. Footage from a private individual.

At 09:40, HB-HOT flew over the Grimsel pass from north-northwest to south-southeast at approximately 2,950 m AMSL. At 09:44:51, HB-HOT left Swiss airspace and entered Italian airspace between the Rotentalhorn summit (Punta di Valrossa, 2,967 m AMSL) and the Helgenhorn peak (Punta di Elgio, 2,836 m AMSL). When crossing the 2,770-m-high ridge between the Rotentalhorn and the Helgenhorn, the flight altitude was approximately 2,920 m AMSL. After crossing the Val Toggia valley at a constant altitude, HB-HOT once again crossed the border between Italy and Switzerland approximately one and a half minutes later and was now back above Swiss territory.

At 09:48, HB-HOT crossed the Val Bavona valley north of San Carlo in a left turn and took a generally north-easterly heading. During an S-turn in the region of the Cristallina mountain (2,912 m AMSL), HB-HOT flew over the Bocchetta del Lago Nero pass (2,563 m AMSL) at a flight altitude of between 2,650 and 2,700 m AMSL. According to video footage recorded from inside the aircraft, HB-HOT at times was flown in close proximity to the terrain during this phase of the flight (see figure 2). Shortly afterwards, the aeroplane passed the Pizzo del Lago Scuro peak (2,647 m AMSL), where a group of hikers saw and captured this on video (see figure 3).

The descent led HB-HOT into the valley of the Lago del Sambuco reservoir. HB-HOT then followed the Maggia river and valley southwards. Above Bignasco, HB-HOT reported to the Locarno aerodrome control tower (Locarno Tower) for landing.

[7] The estimated distance is based on this video footage.

Figure 2: Still image from one of the videos recorded from inside the aircraft when flying past the Cristallina mountain. This frame was captured just before the aeroplane crossed the Bocchetta del Lago Nero pass. The ridge (in the shade), which leads from the Bocchetta del Lago Nero pass towards the southeast can be seen behind the engine (left) and behind the wing's trailing edge (right). Behind the ridge, the basin southeast of the Cristallina mountain is visible. Footage from a private individual.

Figure 3: Still images (details) from two videos recorded by hikers from a position of approximately 330 m west of and 150 m below the summit when HB-HOT passed the Pizzo del Lago Scuro peak (2,647 m AMSL). In the image on the left, HB-HOT and its shadow on the surface of the terrain are marked in red. Footage from private individuals.

A left turn around the Brissago islands followed directly after leaving the Valle Maggia valley. The aircraft made a downwind approach south of Locarno Aerodrome to runway 26C. At 10:13, HB-HOT touched down on grass runway 26C at Locarno Aerodrome. Ground control (Locarno Ground) instructed the pilots to taxi HB-HOT to parking zone Bravo, where the Robin DR 400/140 B was already parked.

After the passengers had disembarked, their luggage had been unloaded and a few souvenir photos had been taken in front of and with the aircraft, the ground-based programme of the adventure tour began for the group, led by the tour guide. The schedule included the group being taken by coach to various locations in the region and finally to a hotel in Lugano. Over the course of the day, some passengers made particularly positive remarks about the morning flight from Dübendorf to Locarno. Two people were especially appreciative of the slow flying close to the terrain. Various passengers electronically shared photos and videos from the day with their friends at home or saved such data on cloud services online. Furthermore, the tour guide wrote in a text message that the day and flight had been "*wonderful*" and "*super*", and that "*it had all gone well*". She notified a friend in Ruschein in the canton of Grisons (municipality of Ilanz) that she would be flying over in the late afternoon of 4 August 2018 (see section A1.1.2.2).

Once the passengers had left the aerodrome by coach, pilots A and B set about preparing the aeroplane for its overnight stay in Locarno, covering the cockpit with a tarpaulin. One of the pilots took care of administrative matters at the aerodrome management's AIS office, during which time he appeared happy and relaxed. In the aircraft technical log (tech log), the pilots declared that the HB-HOT flight from Dübendorf to Locarno on 3 August 2018 was a commercial flight.

Half an hour after HB-HOT had arrived in Locarno, pilots A and B, along with pilot A's trainee pilot, boarded the motor-powered aeroplane Robin DR 400/140 B that was standing by. At 10:52, it took off from runway 26R for a VFR flight to Lommis with the trainee pilot, pilot A as the flight instructor and pilot B as a passenger on board. At 11:45, the Robin DR 400/140 B landed at Lommis Airfield. The flight report, which pilot A subsequently filled out for both the flight from Lommis to Locarno and the return flight to Lommis, implied that both flights had been carried out with him on board as the flight instructor. However, the outward flight had in fact been carried out by the trainee pilot alone and pilot A had only been on board the Robin DR 400/140 B for the return flight. Pilot A and the trainee pilot then travelled home by car and dropped off pilot B at his home on their way.

A1.1.2.5 Saturday, 4 August 2018 (the day of the accident)

At around 7 a.m. on 4 August 2018, pilot A and pilot B got up at their respective homes, had breakfast and prepared for the day.

Pilot B then went to Dübendorf Air Base. He carried out three sightseeing flights for Ju-Air, starting at 09:15, 10:35 and 11:58, and lasting 60, 60 and 40 minutes respectively. These led from Dübendorf to the Alps and back to Dübendorf. On all three flights, the aircraft was piloted by the flight crew in such a way that it flew significantly below the safety margin of at least 1,000 ft AGL (300 m above ground level) in mountainous areas on several occasions (see section A1.17.6.2.2). In addition, the crew disregarded essential principles for safe mountain flying. Pilot B was the commander on all three flights. The flights were carried out on a sister aircraft of HB-HOT, the Junkers Ju 52/3m g4e, registered as HB-HOP. To his co-pilot,[8] pilot B appeared normal, motivated and in good spirits that morning. One of the main topics of conversation between pilot B and his co-pilot that morning

[8] The co-pilot on these flights was not pilot A, but another pilot from the Ju-Air cohort of pilots.

was the high summer temperatures and the associated high density altitudes. Pilot B showed concern with regard to the lack of consideration some pilots of light aircraft gave to high density altitudes. The two pilots also talked about the principles of flying in the mountains. Pilot B stated that it was important for him to always approach ridges at 45 degrees and to always have the option of performing a 180-degree turn to reverse course.

Pilot A and the trainee pilot went to Lommis Airfield shortly after noon. At 13:30, the two of them took off in a Robin DR 400/140 B motor-powered aeroplane for a short flight to Dübendorf, where they landed at 13:42. There they picked up pilot B, who had just finished his third sightseeing flight in HB-HOP, and, at 13:55, they took off towards Locarno. After taking off from Dübendorf, they flew southwards over the Alps via Männedorf, Richterswil, Muotathal and the Lukmanier pass. The stretch between Muotathal and the Lukmanier pass was flown in a reasonably straight line at a GPS altitude of approximately 9,500 ft AMSL, equivalent to 2,900 m AMSL. According to the trainee pilot's memory, it had been slightly cloudy over the mountains; some cumulus clouds had already formed, but much fewer than expected. During the flight, pilots A and B discussed the route for the return flight in HB-HOT. The "*direct*" route was mentioned at the beginning of the discussion. This would have resulted in a flight time of approximately one hour. In the end, however, they agreed that the flight time of one hour and fifteen minutes stated in the brief should be used and that a route of appropriate length should be chosen to accomplish this. However, according to the trainee pilot, pilots A and B had not been more specific.

At 14:34, the Robin DR 400/140 B reported to Locarno Tower for landing at Locarno Aerodrome. The aeroplane touched down at 14:38. Immediately after landing, pilot A radioed the Locarno Tower aerodrome controller and informed them that they would taxi to where HB-HOT was parked and park there.

After the Robin DR 400/140 B had landed, pilots A and B went to the aerodrome management's AIS office, where they took care of administrative matters and expressed their desire to take off from tarmac runway 26R in HB-HOT. The reasons given were the obstacles at the end of the runway and the high temperatures, which reduce the aircraft's flight performance. The aerodrome manager present complied with the pilots' request for runway 26R. The aerodrome manager did not notice any unusual behaviour from the pilots when speaking with them. The pilots then went to HB-HOT and prepared the aircraft for the return flight. More specifically, they removed the tarpaulin that had been covering the cockpit, latched the access door open, and rotated the propellers by hand. HB-HOT was, however, not refuelled during its stay in Locarno.[9] According to reconstructions, the fuel tanks still contained 1,136 litres of fuel, corresponding to a remaining endurance of roughly three hours.

Pilots A and B and the trainee pilot then went to the airport restaurant on site, where they happened to meet two pilot friends from the circle of pilots from Eastern Switzerland. Regarding the route, pilot B reportedly said that they would fly directly to Dübendorf. Pilot A reportedly intervened and said that they would still have to take a detour due to the flight time booked by the passengers. The two pilot friends from Eastern Switzerland and other visitors to the restaurant described pilots A and B as appearing normal, visibly relaxed and in good spirits at this time.

At around 15:45, the tour group and guide arrived at Locarno Aerodrome by coach. They went to HB-HOT, where pilots A and B were loading the luggage and helping passengers to board.

[9] Not refuelling the aeroplane at the destination aerodrome was usual Ju-Air practice for trips of this kind.

Figure 4: The Junkers Ju 52/3m g4e, registered as HB-HOT, in parking zone Bravo at Locarno Aerodrome at 15:41 on 4 August 2018. The cockpit tarpaulin has been removed. The Robin DR 400/140 B (left edge of the picture) is positioned next to HB-HOT. Photograph from private individual.

The trainee pilot of pilot A then went to the Robin DR 400/140 B, started up the aircraft and, at 15:58, took off from runway 26R for his return flight to Lommis. The trainee pilot was alone on board. After another reasonably direct flight across the Alps, he landed in Lommis at 16:48.

A1.1.3 Course of the accident flight on 4 August 2018

A1.1.3.1 Taxiing, take-off and departure

Shortly after 16:00 on 4 August 2018, 17 passengers, one in-flight service personnel (ISP) and the two pilots A and B were on board the Junkers Ju 52/3m g4e, registered as HB-HOT, for their imminent return flight to Dübendorf (LSMD). The aircraft was in grass parking Bravo at Locarno Aerodrome (LSZL) at the time. Like the outward flight the day before, the flight was scheduled to take place under visual flight rules (VFR). The pilots had swapped roles and responsibilities from those of the outward flight: For the return flight, pilot A was in the left-hand seat as commander and had the role of pilot flying. Pilot B was now the co-pilot seated on the right and acted as the assisting pilot (pilot monitoring).

The OFP, which pilot A had already prepared for the return flight the day before, included a route via Bellinzona, the Gotthard pass, the Oberalp pass and Rapperswil. A mass of 9,737 kg and centre of gravity at 1.98 m were noted for take-off (see figure 10). The reconstructed value for the mass at take-off from Locarno was 9,387 kg and the centre of gravity at 2.077 m (see annex A1.6).

At 16:05, the three piston engines were started in the following order: right, left, centre. At 16:07, Locarno Tower gave HB-HOT clearance to taxi to the holding bay of runway 26R. HB-HOT confirmed and began taxiing. At 16:12, the run-up was performed in the allocated holding bay. After the run-up, HB-HOT reported to Locarno Tower that they were ready for departure. Locarno Tower then gave clearance for take-off from tarmac runway 26R and granted HB-HOT permission to continue climbing on the downwind leg. HB-HOT read back this clearance and taxied onto the runway. Aligned on the runway, the pilots immediately applied the take-off power and, at 16:14:05, began take-off roll (rolling take-off). At 16:14:23, HB-HOT took off for its commercial VFR flight to Dübendorf. A map outlining the accident flight can be found in the main section of the final report, and in greater detail on page 14 (figure 8) of this annex.

After a first phase of initial climb in the direction of the runway, HB-HOT made a 180-degree turn to the left above the basin of Lake Maggiore between the town of Locarno and the Magadino plain. When doing so, the aircraft first broke away slightly to the right. The climb continued on the downwind leg, south of the aerodrome. At 16:22:20, HB-HOT left terminal manoeuvring area 1 of Locarno Aerodrome (TMA LSZL 1) at its eastern border near Bellinzona at an altitude of 1,060 m AMSL. At the same time, pilot B routinely bid farewell to Locarno Tower upon leaving its frequency: this was the last recorded radio message from HB-HOT to a ground-based radio station.

A1.1.3.2 Cruise

From Bellinzona, HB-HOT followed a generally north-northwesterly heading – first to Biasca along the Ticino river on the eastern side of the valley, later in the Blenio valley along the Brenno river also on the eastern side of the valley. HB-HOT steadily gained altitude in the process. At 16:38, north of Olivone, HB-HOT made a right turn around the Sosto mountain (2,221 m AMSL) into the valley of the Lago di Luzzone reservoir and thus into the Adula/Greina/Medels/Vals sanctuary for silence and nature[10] (see figure 5).

Figure 5: Still image from a video recorded from inside the aircraft when passing the Sosto mountain (2,221 m AMSL). The image shows the right wing of HB-HOT in front of the western and north-western side of the Sosto as well as the view into the Val Carassina valley including reservoir and dam. Footage from private individual.

When flying past the Sosto mountain, the corrected transponder altitude was 2,270 m AMSL. The south-western spur of the Torno mountain (2,556 m AMSL) was flown over at approximately 120 m above ground, and the western flank of this

[10] According to the official Swiss VFR-Guide, sanctuaries for silence and nature are "*larger areas of countryside which are low in anthropogenic sources of noise*" and where "*the desired aim is to preserve the diversity of natural sounds and silence for human recreation*". It goes on to state that, "[Motor-powered] *aircraft shall avoid these areas, or are to fly over them significantly higher than at the stipulated minimum altitudes (see art. 28 of the Swiss Ordinance on Traffic Rules for Aircraft, VRV-L) and taking the shortest-possible flight path.*" The minimum altitude referred to is 150 m (500 ft) above the ground or water, or 150 m (500 ft) above the highest obstacle within a 150-m (500-ft) radius around the aircraft (see annex A1.17). Sanctuaries for silence and nature are shown on the official ICAO aeronautical chart of Switzerland (see annex A1.6) and are marked as "*zones to be avoided*" in the key. The Adula/Greina/Medels/Vals sanctuary for silence and nature is also shown in figure 8.

mountain was passed at approximately 150 m above ground. At the north-eastern end of the Lago di Luzzone reservoir, HB-HOT initiated a left turn before following a generally northern heading. The Lungadera ridge (2,419 m AMSL) was followed at a flight altitude of approximately 2,400 m AMSL. At 16:42, the Greina plateau was crossed at a height of 200 to 300 m above ground. The north-eastern section of the Greina plateau was covered by cumulus clouds at this time with a cloud base between 3,300 and 3,400 m AMSL (see figure 6).

Figure 6: HB-HOT (red circle) flying over the Greina plateau towards the Terrihütte hut. The cumulus cloud with its base between 3,300 and 3,400 m AMSL is clearly visible. Photograph from private individual.

At 16:42:30, the Terrihütte hut was passed. At this time, the following altitudes were displayed in the cockpit (see figure 7):

- Metric altimeter reading: 2,400 m
- Altimeter reading, displayed in feet: 7,750 ft (2,360 m)

At this time, the altitude determined photogrammetrically was 2,517 m AMSL.

A calibrated altimeter set to the QNH of Locarno would display a reading of 2,358 m AMSL or 7,745 ft AMSL under the local conditions prevailing at that time.

The flight past the Terrihütte hut also marked the entry into the Val Sumvitg valley in the canton of Grisons. At 16:45, HB-HOT left the Adula/Greina/Medels/Vals sanctuary for silence and nature and, via Alp Nadels, turned into the Surselva region (Vorderrheintal valley). This valley was then followed in a generally east-north-easterly direction for the time being. At this time, at 16:45, the ISP wrote a text message to her holiday home neighbour in Ruschein (municipality of Ilanz) to say that the Ju 52 was approaching this location.

Between 16:45 and 16:49, HB-HOT flew reasonably constantly at a corrected transponder altitude of just less than 2,500 m AMSL, equivalent to 8,200 ft AMSL, which at this time corresponded to a density altitude of approximately 2,900 m.

Figure 7: Still image from a video recorded by a passenger in the cockpit when crossing the Adula/Greina/Medels/Vals sanctuary for silence and nature. The image shows the instrument panel and the view from the cockpit when passing the Terrihütte hut. Footage from private individual.

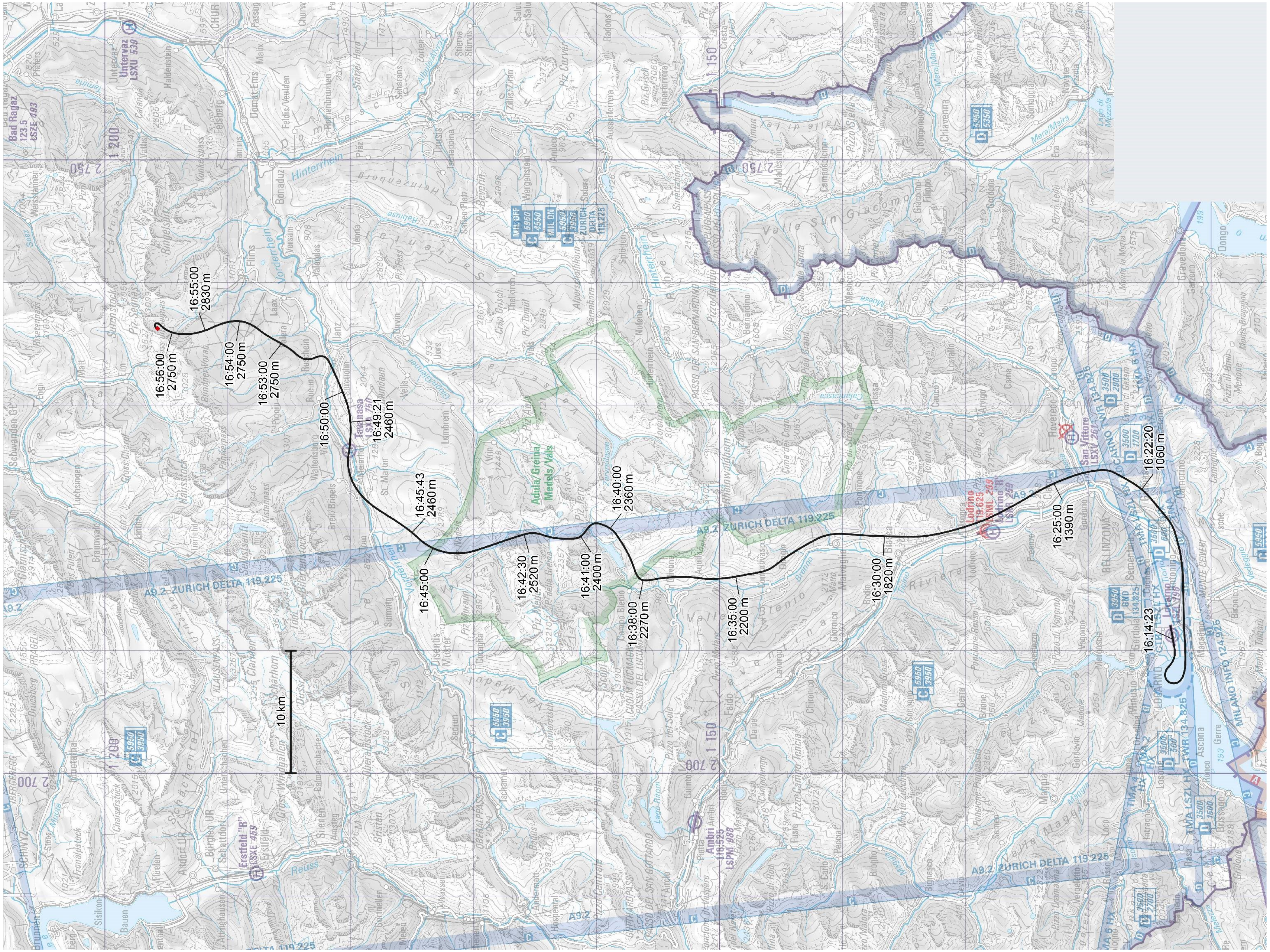

Figure 8: Flight path of HB-HOT on 4 August 2018 (solid line), including times. All altitudes are given in altitude above mean sea level.
Source of the base map: glider chart from the Swiss Federal Office of Topography; reworked.

A1.1.4 Operational flight plans

The following two pages contain the operational flight plans (OFPs) for the 2018 Locarno adventure tour. Comments including references to further explanations have been added to the most significant abnormalities and errors.

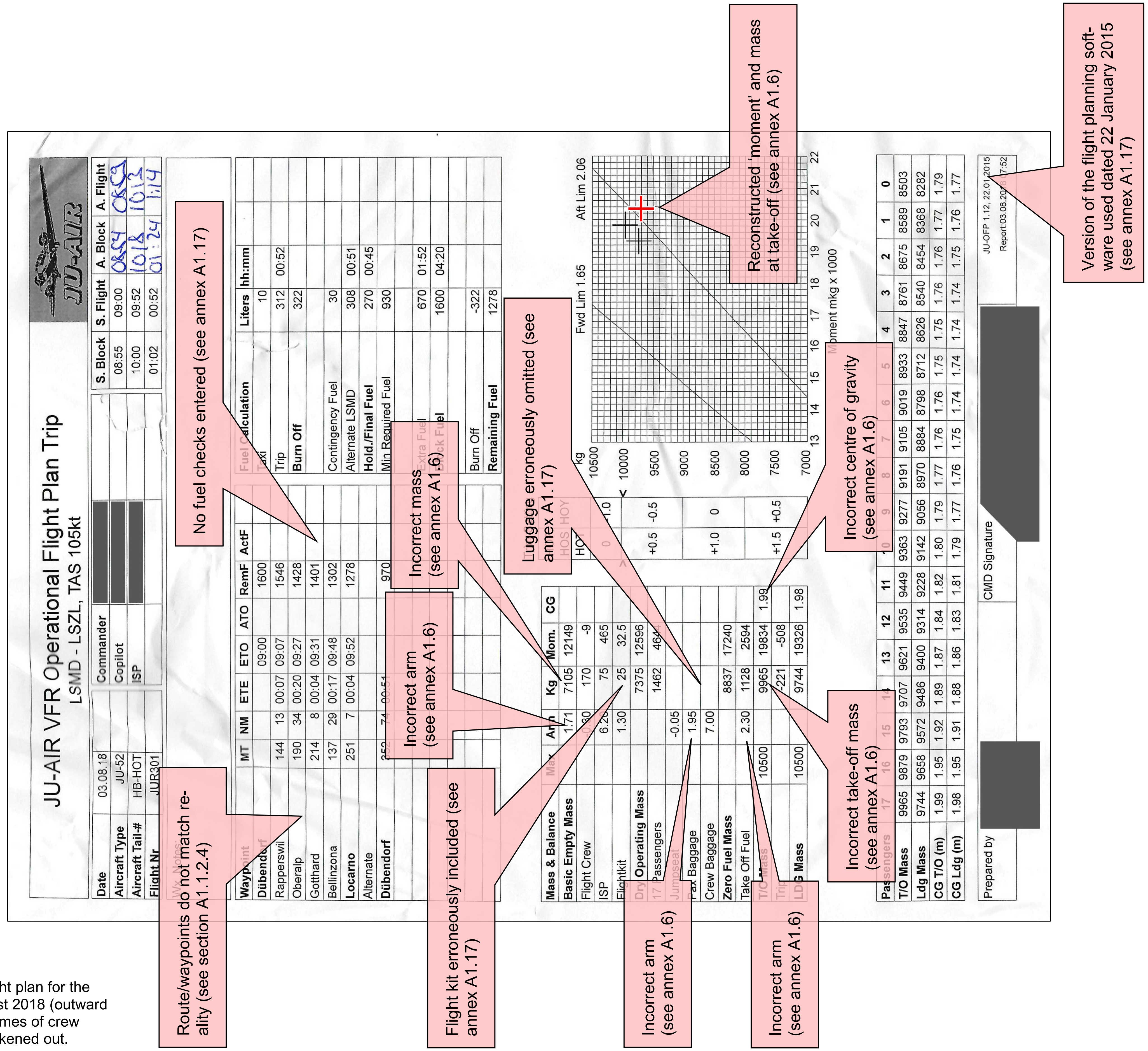

Figure 9: Operational flight plan for the HB-HOT flight on 3 August 2018 (outward flight) with comments. Names of crew members have been blackened out.

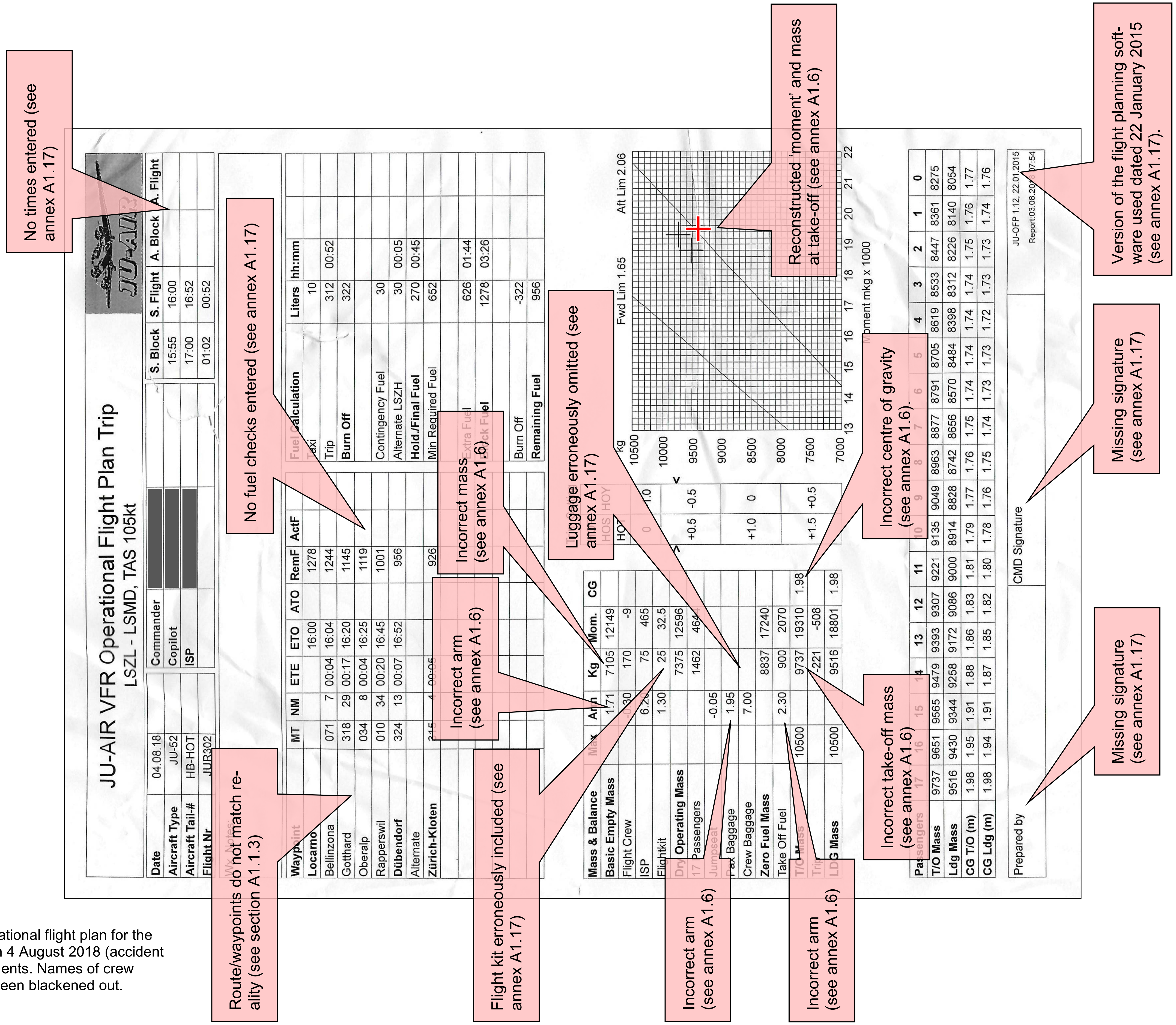

Figure 10: Operational flight plan for the HB-HOT flight on 4 August 2018 (accident flight) with comments. Names of crew members have been blackened out.

Contents

A1. Factual information

A1.5 Personnel information

A1.5.1 Pilot A

A1.5.1.1 General information

Person	Male, born 1955
Licence	Airline transport pilot licence aeroplane (ATPL (A)) according to the standards of European Union Aviation Safety Agency (EASA), initially issued by the Federal Office of Civil Aviation (FOCA) on 20 May 1992
Ratings	JU52, SEP (land) with flight instructor aeroplane (FI (A)), aerobatics (ACR), night flying (NIT)
Last proficiency check	14 March 2018
Last line check	7 April 2018
Medical fitness certificate	Class I, valid until 19 October 2018 Restriction: shall wear multifocal lenses and carry a spare set of [spectacles] (VML)
Last aviation medical examination	17 April 2018
Flight training commenced	1977

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

A1.5.1.2 Flight experience

Total	20,714 h
On the accident type	297 h (A)
As commander (CMD)	14,412 h
As CMD on the accident type	121 h (A)
During the last 90 days	90:02 h
On the accident type (B)	42:50 h
As CMD on the accident type	22:09 h
As co-pilot on the accident type	20:41 h
On single-engine aircraft (C)	47:12 h

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

(B) In the last two months prior to the accident flight, pilot A carried out a total of 33 flights on the accident type, 28 of which were with pilot B from the accident flight.

(C) Pilot A completed some of these flight hours as a member of a historic aircraft owners club.

A1.5.1.3 Periods of duty

Commencement of shifts in the 48 hours before the accident	2 August 2018: off duty 3 August 2018: 08:00 4 August 2018: 15:00
End of shifts in the 48 hours before the accident	2 August 2018: off duty 3 August 2018: 10:30
Total periods of flying duty in the 48 hours before the accident	3 August 2018: 2:30 h
Periods of rest in the 48 hours before the accident	from 3 to 4 August 2018: 28:30 h
Length of flying duty at the time of the accident	4 August 2018: 1:56 h

A1.5.1.4 Details of flying career

Pilot A began his military flight training in 1977. As a professional military pilot, from March 1978 he served in two flying squadrons, one of which with pilot B, in the surveillance unit (*Überwachungsgeschwader* – UeG) on ‘Hunter’ and F-5E ‘Tiger’ aircraft.

His annual performance reviews up until voluntarily leaving the Air Force in April 1984 each indicate a good overall appraisal as a squadron pilot and flight instructor. In 1981, a collision occurred during an air combat exercise (see section A1.5.1.7), in which pilot A was accused of failure to observe service regulations and physical injury resulting from negligence due to his lack of caution.

On 2 April 1984, pilot A left the UeG and attended the Swiss Aviation School (*Schweizerische Luftverkehrschule* – SLS) to become an airline pilot.

After his training and subsequent retraining course for the DC-9-81 (or MD-80) aircraft type, which he passed with a grading of ‘standard[1]’, he worked as a co-pilot on short-haul flights from 1984 to 1990. The recurring checks in the simulator and during scheduled flight duties do not indicate any abnormalities during this time; the respective overall evaluations are in the ‘standard’, and sometimes ‘high standard[2]’ range.

In 1991, he completed his retraining for the Airbus A310 with a grading of ‘standard’. In 1998, he upgraded to commander on the A320. Three years later, he also gained the type rating for the long-haul A330. All reviews during this period are graded as ‘standard’ or ‘high standard’. The recurring checks in the simulator and scheduled flight duties do not indicate any abnormalities either; all assessments are marked with ‘qualified[3]’.

Until 2010, pilot A was working on the short- and long-haul fleet of a major airline, and as of 2009 this also included the A340. In the final few years before his retirement on 28 March 2015, pilot A worked exclusively on long-haul flights on A330 and A340 aircraft. The regular checks in the simulator and scheduled flight duties are graded as ‘qualified’, and sometimes ‘high standard’. Remarks are repeatedly made about his *“high pace of work”* and his *“clear and rather firm management*

[1] ‘Standard’ refers to good performance that meets expectations.

[2] ‘High standard’ refers to very good performance that exceeds expectations.

[3] ‘Qualified’ refers to performance that meets expectations.

style". In the 2014 annual review, his knowledge was certified as being generally good, but superficial in places and could be improved.

Alongside his regular employment, pilot A had been working as an instructor in the simulator and on scheduled flights for his employer since October 1998. As he had been disregarding the employer's requirements relating to non-aeronautical aspects, his additional contract as an instructor was terminated at the end of May 2010.

In April 2013, pilot A gained the type rating for the Junkers Ju 52/3m (JU52) and from then on worked as a co-pilot on Ju-52 flights for Ju-Air. In 2015, with 176 hours of flight experience[4], he completed the transition to commander, meaning he could also act as CMD in the left-hand seat during flights from then on. All appraisals for line checks and proficiency checks are graded as 'standard' or 'high standard'. Recurring remarks graciously comment on the high level of consideration for passengers, noise and the environment that his choice of flight paths and adaptive flying style provided.

From August 2015, pilot A attended a 'Change of operator' course with another airline and then worked on A330 aircraft. The generally good performance evaluations did, however, include comments on the use of outdated call-outs as well as an increased number of 'divers' in the final approach, i.e. a final approach below the nominal glideslope. According to the airline, there had been repeated violations of a regulation and standard operating procedures (SOPs) that fell under the just culture[5] category of 'optimising violations'.

In addition to working for the two commercial air operators and Ju-Air, pilot A regularly served as a flight instructor on single-engine general aviation aircraft. As part of this job, he gave a detailed lecture on 'Flying in the mountains' during a refresher course at a flying club in 2018. In terms of flying tactics, the lecture illustrated, among other things, that ridges and crests should not be flown over at an angle of 90 degrees or when climbing, but should be flown over at an angle of 45 degrees with the possibility of performing a steep turn whilst in horizontal flight with sufficient safety altitude, or when descending (see section A1.17.6.2.3).

As a member of a historic aircraft owners club along with pilot B, he took passengers on sightseeing flights.

A1.5.1.5 Assessment by aeronautical colleagues

Those of his aeronautical colleagues who were interviewed described pilot A as a sociable, communicative and rather extroverted person with an easy-going demeanour. As regards his collaboration with others, he was perceived as approachable, honest and straightforward, as well as stubborn at times with a somewhat resolute tone.

His aeronautical skills were rated as average with dips in his performance. Furthermore, a partial lack of self-critique and a lack of attention to detail were noted in assessments. From an operational point of view, he was appraised of having rather diminished risk awareness, which was mainly expressed by the fact that he sometimes did not recognise potential dangers or did not seem to attach adequate importance to them.

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[4] Unlike with block hours, this figure does not include taxiing times before and after the flight.

[5] Just culture: An environment in which people feel free to report mistakes, which others within the organisation can learn from. In contrast to a blame culture, in a just culture, individuals are not punished or dismissed because of unintentional deviations from the rules. Rather, the cause of the error is sought.

A1.5.1.6 Previous flights in summer 2018

Out of the flights for which data is available between April 2018 up to and including the day of the accident, there are 6 radar recordings involving flight paths with a risk score of 8 to 10 (see section A1.18.4), in which pilot A was a member of the flight crew; 4 of these also involved pilot B from the accident flight.

A1.5.1.7 Collision during air combat

On 18 November 1981, a collision occurred in the Moutier (canton of Bern) region during a tactical[6] air combat exercise involving two Mirage III Ss (MSs) and two Tiger F-5Es (TEs) from the Swiss Air Force (*schweizerische Fliegertruppen*). Pilot A was involved as the pilot of one of the Tigers. During this air combat, pilot A succeeded in 'shooting down' one MS using cannon simulation. The pilot of this MS heard the 'shooting signal' from pilot A via the mutual radio channel, but assumed that his defensive manoeuvre had been successful and that he had not been 'shot down'. As a result, he did not perform the kill removal manoeuvre stipulated for a 'shot-down' aircraft. Pilot A, who had fired the 'shot', was subsequently left behind the MS, which he expected to perform a kill removal manoeuvre, and repeated his radio signal another two times. Firmly convinced that MS was now entering the kill removal manoeuvre, pilot A in the TE evidently took his eyes off the MS. A few seconds later, the two aircraft collided; both pilots were able to eject themselves from the aircraft.

As stated in the Military Justice's corresponding final report from 31 August 1982, neither of the two pilots who were directly involved had a comprehensive overview[7] of the situation immediately before the collision. According to the aeronautical assessment in said final report, pilot A's lack of caution was, to a certain, unquantifiable extent, the cause of the collision. His lack of caution consisted of taking his eyes off the MS without ensuring that the MS pilot would follow a flight path that would lead him away from his own trajectory.

The final report goes on to state that the conduct of pilot A was understandable from his point of view to a certain extent since, for one, only the mentioned MS could have been shot down and, secondly, the air combat continued. Therefore, if nothing else, the MS wingman could have benefited from a delay by manoeuvring into an optimal position in relation to pilot A. The tactical interest or intention to achieve the set goal, i.e. the successful combat against the MS patrol, contributed to pilot A momentarily lacking the basic caution required.

The case was closed on 4 October 1982.

A1.5.2 Pilot B

A1.5.2.1 General information

Person	Male, born 1956
Licence	Airline transport pilot licence aeroplane (ATPL (A)) according to the standards of European Union Aviation Safety Agency

[6] Unlike formal air combat exercises, tactical air combat exercises constitute missions, in which usually only the initial situation and the framework conditions are prescribed, but the course of the actual combat results from the pilot's conduct and manoeuvres, and cannot be foreseen in advance.

[7] According to the final report, the most important components of the 'overview' in air combat are as follows: visual contact with other aircraft or knowledge of their relative position and movements (or a mixture of visual contact and knowledge of relative positions); comprehensive radio communication techniques; spatial awareness (ability to understand positions conceptually and in terms of space as well as map out one's own movements and the flight paths of other aircraft); ability to adapt and react appropriately and swiftly to events and problematic situations.

	(EASA), initially issued by the Federal Office of Civil Aviation (FOCA) on 17 September 1992
Ratings	JU52, SEP (land), aerobatics (ACR), night flying (NIT)
Last proficiency check	13 March 2018
Last line check	12 May 2018
Medical fitness certificate	Class I, valid until 4 October 2018 Restriction: shall wear multifocal lenses and carry a spare set of [spectacles] (VML)
Last aviation medical examination	20 March 2018
Flight training commenced	1978

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

A1.5.2.2 Flight experience

Total	19,751 h
On the accident type	945 h (A)
As commander (CMD)	12,751 h
As CMD on the accident type	710 h (A)
During the last 90 days	60:45 h
On the accident type (B)	52:17 h
As CMD on the accident type	32:30 h
As co-pilot on the accident type	19:47 h
On single-engine aircraft (C)	8:28 h

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

(B) In the last two months prior to the accident flight, pilot B carried out a total of 41 flights on the accident type, 28 of which were with pilot A from the accident flight.

(C) Pilot B completed all of these flight hours as a member of a historic aircraft owners club.

A1.5.2.3 Periods of duty

Commencement of shifts in the 48 hours before the accident	2 August 2018: off duty 3 August 2018: 08:00 4 August 2018: 08:15
End of shifts in the 48 hours before the accident	2 August 2018: off duty 3 August 2018: 10:30
Total periods of flying duty in the 48 hours before the accident	3 August 2018: 2:30 h
Periods of rest in the 48 hours before the accident	from 3 to 4 August 2018: 21:45 h
Length of flying duty at the time of the accident	4 August 2018: 8:41 h

A1.5.2.4 Details of flying career

Pilot B began his military flight training in 1978. As a professional military pilot, from March 1980 he served in a flying squadron along with pilot A in the surveillance unit (*Überwachungsgeschwader* – UeG) on 'Hunter' and F-5E 'Tiger' aircraft.

His annual performance reviews up until voluntarily leaving the Air Force in April 1985 each indicate a good overall appraisal as a squadron pilot and flight instructor, as well as head flight instructor from 1983 onwards. The service records[8] for 1978 to 2003 also show consistently good performance reviews without any abnormalities.

On 2 April 1985, pilot B left the UeG and attended the Swiss Aviation School (*Schweizerische Luftverkehrschule* – SLS) to become an airline pilot.

After his training and subsequent retraining course for the DC-9-81 (or MD-80) aircraft type, which he passed with a grading of 'high standard', he worked as a co-pilot on short-haul flights from 1984 to 1989. The recurring checks in the simulator and during scheduled flight duties do not indicate any abnormalities during this time; the respective overall evaluations range from 'standard' to 'high standard'.

In 1991, he completed his retraining for the Airbus A310, which he passed with the grading of 'high standard'. In 1997, he aborted his upgrading to commander on the A320 at his own request. Out of the three options a) immediate re-entry, b) re-entry on the next course or c) returning as co-pilot on the A310, he chose the latter. A specially convened committee certified him as having a *"very high level of aspiration"*, but as *"dealing with his own mistakes in an immature manner"*. Approximately two years later, in May 1999, he qualified as a CMD on the A320.

Eight years later, he also gained the type rating for the long-haul A330. None of the recurring checks in the simulator and during scheduled flight duties indicate any abnormalities and all are marked with 'qualified'.

Until 2009, the CMD worked on the short- and long-haul fleet of a major airline; after gaining the additional A340 rating, he exclusively worked on long-haul flights until his retirement on 15 July 2015. Regular checks in the simulator and scheduled flight duties are marked with 'qualified', ranging from 'standard' to 'high standard' with good leadership conduct as a CMD and good intervention conduct towards the co-pilot.

In February 2004, pilot B gained the JU52 type rating and from then on worked as a co-pilot in Ju-Air flights. In 2008, with 235 hours of flight experience, he completed the transition to commander, meaning he could also act as a CMD in the left-hand seat during Ju-52 flights from then on. All of the appraisals regarding line checks or proficiency checks are graded as 'standard' or 'high standard'. In the context of final checks as a CMD, he was appraised as having a very high level of aspiration, which *"could also be a hindrance"*. Recurring remarks graciously comment on his prudent choice of flight paths with regard to noise and consideration for passengers.

In terms of general aviation, like pilot A, he was a member of a historic aircraft owners club.

[8] In accordance with the Ordinance on Military Controls (*Verordnung über das militärische Kontrollwesen* – VmK), a service record was kept for officers, in which not only personal data and information regarding military service were recorded, but also performance reviews.

A1.5.2.5 Assessment by aeronautical colleagues

Those of his aeronautical colleagues who were interviewed described pilot B as a quiet, friendly, reserved, reliable and rather introverted person who was very approachable when working together. As an experienced pilot with a great deal of knowledge and a very high level of aspiration and sense of duty, he is said to have worked meticulously and accurately, but did not communicate his thoughts much in flight.

His aeronautical skills were unanimously rated as above average. From an operational point of view, he exhibited a calculated readiness to take risks, i.e. he always considered potential alternatives or different routes, for example in the event of engine failure.

A1.5.2.6 Previous flights in summer 2018

Out of the flights for which data is available between April 2018 up to and including the day of the accident, there are 8 radar recordings involving flight paths with a risk score of 8 to 10 (see section A1.18.4), in which pilot B was a member of the flight crew; 4 of these also involved pilot A from the accident flight.

A1.5.3 Previous incidents involving pilots A and/or B

On 6 July 2013, the same flight crew flew over the Segnes pass in a similar manner in the sister aircraft HB-HOP during a climb approximately 30 m above ground. The altitude abeam the Martinsloch was 2,684 m AMSL (approximately 8,800 ft AMSL). At the time, pilot A occupied the right-hand seat as the pilot monitoring (PM), while pilot B was the pilot flying (PF) seated on the left. Further information can be found in section A.1.18.1.

On 6 July 2018, pilot A, acting as the CMD, flew together with pilot B over the city of Munich in HB-HOT at an altitude which, according to the competent authority of the government of Upper Bavaria, was "*for a long period considerably and continuously*" below the minimum required safety altitude of 300 m above ground (see section A1.17.1.18.6).

On 2 October 2015, an aircraft entered the airspace above the Oktoberfest festival in Munich without permission, with pilot B as the commander on board.

Further information on these and other incidents involving pilots A or B can be found in annex A1.17.

A1.5.4 Assessment

A1.5.4.1 Flying careers, flight experience and collaboration

At the time of the accident, both pilots possessed vast overall flight experience and their training on the accident type was sound and up to date. Pilot A joined Ju-Air in 2013 and successfully completed the transition to CMD just short of three years later. At the time of the accident, he had 297 flight hours and thus a good level of flight experience on the accident type. Pilot B joined Ju-Air back in 2004 and successfully completed the transition to CMD five years later. At the time of the accident, he therefore had 945 flight hours, meaning he had considerably more flight experience on the accident type.

There are significant parallels between the flying careers of the two pilots, from them joining the Swiss Air Force (*schweizerische Fliegertruppen*) to their transition to work as airline pilots at the same airline, to the models they flew on short- and long-haul flights. Moreover, the aeronautical skills of both pilots were rated good to very good by their respective examiners over all these years. A flat hierarchy can therefore be surmised between the two pilots due to the similarities in their experience and careers. In principle, this is a good basis for solid crew resource management (CRM)[9].

The paths of the two pilots crossed again and again: as professional military pilots serving in the surveillance unit (*Überwachungsgeschwader* – UeG) in the same flying squadron, within the same airline, and since 2013 in Ju-Air flight operations. They also showed a common interest as members of the same historic aircraft owners club. The two were also considered good friends by their colleagues. It can therefore be concluded that the two pilots not only knew each other well in their private lives, but also had great confidence in each other's flying skills.

In the last two months before the accident, pilots A and B carried out 28 flights together on the accident type. During these flights, they both acted as the pilot flying (PF) and pilot monitoring (PM) from the left-hand and right-hand seats. Operational framework of this kind can create the conditions for a certain degree of complacency. This is a state of satisfaction with one's own performance, coupled with a lack of awareness of upcoming problems or dangers.

Complacency and excessive mutual trust within a flight crew reduce mutual monitoring[10], which is an essential safety net in a two-person cockpit. In this investigated accident, the lack of a natural difference in their level of experience may have had an inhibitory effect on monitoring between the pilots, who both held the type rating as commanders.

A1.5.4.2 Human aspects

A1.5.4.2.1 General

Although the flying careers of the two pilots are similar and their capabilities at the individual stages of their careers are at a comparable level, the assessments of pilots A and B show certain differences in their characters which may have played a decisive role in the development and course of this investigated accident.

[9] Crew resource management: CRM was developed as training for flight crews based on the experience of numerous accidents in which poor collaboration in the cockpit was a causal factor. CRM is intended to raise awareness of the fact that, in addition to technical understanding on board an aircraft, human relations are also a critical factor for safe flight operations.

[10] Monitoring: This is generally defined as the active and meticulous observation of the flight path and aircraft systems, and the cross-checking of actions. Monitoring serves to detect deviations or improper operational activities early on and to make adjustments if necessary.

A1.5.4.2.2 Pilot A

His long-standing work as an instructor with the airline that employed him as an airline pilot was abruptly terminated as he had failed to comply with the employer's instructions relating to non-aeronautical aspects (see section A1.5.1.4). Furthermore, he failed to adhere to the syllabus of the flying club as a flight instructor during a trainee pilot's difference training on the Robin DR40 aeroplane. Knowing that, among other things, the specified 10 landings in different configurations had not been fulfilled, he allowed this trainee pilot to cross the Alps by himself twice for planned flights between Dübendorf and Locarno, and noted these on the training record as relevant training flights for 3 and 4 August 2018.

Behaviour that also failed to comply with provisions was demonstrated during the flight over the city of Munich in HB-HOT on 6 July 2018, which was carried out considerably below the minimum required safety altitude (see section A1.5.3). There is no doubt that pilot A had been familiar with this figure.

The same is true of the flight tactic principles when flying in the mountains, on which he gave a lecture during a refresher course in 2018. He was fundamentally familiar with the principles which state that ridges and crests should not be flown over at an angle of 90 degrees or when climbing, but should be flown over at an angle of 45 degrees with the possibility of performing a steep turn whilst in horizontal flight with sufficient safety altitude, or when descending. Nevertheless, the accident flight and previous flights in summer 2018 (see section A1.5.1.6) indicate that these principles were not always followed.

Repeated violations that fell under the just culture category 'optimising violations' during his employment with his other employer also indicate that he interpreted underlying rules his own way.

In the final report regarding the collision of 18 November 1981 in the Moutier (canton of Bern) region during a tactical air combat exercise in which an F-5E 'Tiger' collided with a Mirage III S, pilot A was accused of not being cautious enough when he momentarily took his eyes off the Mirage without ensuring that the Mirage pilot would follow a flight path that would lead him away from his own trajectory (see section A1.5.1.7).

In order to triumph as a pilot in air combat, a certain amount of fighting spirit or bravado is required. This is linked to a certain readiness to take risks[11]. Conversely, a fighter pilot who is always overcautious or overanxious when entering air combat will almost always lose and therefore cannot perform their task with the same level of success. In addition, it can earn them a bad reputation, i.e. it can make them be seen as inferior among the Air Force pilot community. During complex air combat involving fast-paced and often taxing sequences, there are moments when other factors prevail, such as the will to outmanoeuvre the other aircraft or to maintain a tactically favourable situation. In this context, one speaks of target fascination[12]. This is understood as too much willingness to take risks, as was shown by pilot A when he continued to perform a manoeuvre even without having a comprehensive overview of the situation immediately before the collision, as the Military Justice's final report states.

[11] Pilot A had completed his 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.

[12] Target fascination: This effect occurs when a person is so fixated on an object that they become unaware of anything else.

In light of aviation safety being top priority in military flight operations during peacetime, every pilot faces the challenge of finding the right balance between aspects of aviation safety and the requirements of realistic training. From the course of the accident, an increased willingness to take risks could be deduced for pilot A, which was ultimately a causal factor in the collision with the other fighter aircraft. Those of his aeronautical colleagues who were interviewed also confirmed that he exhibited diminished risk awareness, which was mainly expressed by the fact that he sometimes did not recognise potential dangers or did not seem to attach adequate importance to them.

A1.5.4.2.3 Pilot B

In 1997, pilot B aborted his upgrading to commander on the A320 at his own request. He was certified as having a very high level of aspiration, but also of dealing with his own mistakes in an immature manner. He declined the opportunity to resume the ongoing upgrade process and voluntarily returned to work as a co-pilot on the A310. A similar personal assessment was carried out as part of final checks as a CMD at Ju-Air, when he was appraised as having a very high level of aspiration, *"which could also be a hindrance"*.

The term 'level of aspiration'[13] encompasses the pursuit of a goal and the perceived difficulty in achieving said goal. It is human nature to maintain, lower or raise the current level of aspiration in each instance based on the latest performance result, i.e. success or failure, which depends on the discrepancy between the achievement of goals. The above-mentioned reaction of pilot B implies that – in response to his partial success – his level of aspiration remained the same or even increased during the upgrade process. Dealing with personal performance results can ultimately be debilitating and thus hinder training or work. The above relative clause relating to pilot B being appraised as having a very high level of aspiration during the final check is probably to be understood in this sense.

According to those of his colleagues who were interviewed, he exhibited a calculated readiness to take risks based on potential alternatives or different routes, for example in the event of engine failure. Being a rather introverted person, he did however not communicate his thoughts much in flight.

As the discussions on the morning of 4 August 2018 show (see section A1.1.2.5), pilot B was also familiar with the flight tactic principles when flying in the mountains, which state that ridges and crests should not be flown over at an angle of 90 degrees or when climbing, but should be flown over at an angle of 45 degrees with the possibility of performing a steep turn whilst in horizontal flight with sufficient safety altitude, or when descending. Nevertheless, the accident flight and previous flights (see section A1.5.2.6) indicate that these principles were not always followed.

A1.5.4.3 History of the flight

As there was no cockpit voice recorder (CVR) on board HB-HOT, the human aspects that would allow for a direct insight into pilot collaboration are not accessible. When HB-HOT travelled on a north-northeasterly heading approximately in the middle of the basin south-west of Piz Segnas – possibly to give passengers a spectacular view of the Martinsloch – the following human aspects may have played a role in the choice of lateral flight path and altitude:

[13] The level of aspiration is defined as the level of future performance in a familiar task which an individual, knowing their level of past performance in the task, explicitly undertakes to reach. Who a person chooses to play tennis against or which route they choose for their daily running training reflects their level of aspiration.

- Complacency: This state of satisfaction with one's own performance, coupled with a lack of awareness of upcoming problems or dangers, can lead to insufficient situational awareness, which prevents a person from intervening when necessary.
- Lack of monitoring: Excessive trust in the other person, potentially combined with complacency, can negatively influence monitoring. In this investigated accident, the lack of a natural difference in the level of experience between the two pilots may have had an additional inhibitory effect.
- Representativeness heuristic[14]: This mental tool for making decisions, especially under time pressure in unclear or uncertain situations, often brings the desired outcome, but can also misdirect a decision unfavourably. In this investigated accident, the choice of flying tactics may have been based on the experience of the many similar flights over ridges and passes, and the successful flight over the Segnes pass on 6 July 2013 (see sections A1.5.1.6 and A1.5.2.6). However, the fact that something has happened successfully many times, thus making it representative, does not make success more likely. This leads to the neglect of probabilities that are actually relevant (base rates), which is why people overestimate their ability to accurately predict an event.
- Reward learning[15]: The spectacular view of mountain landscapes that are almost close enough to touch may trigger enthusiasm, recognition or admiration (reward) from passengers, meaning this choice of flight tactic (behaviour) is likely to become more frequent in the future.
- Overconfidence[16]: This is usually contextual and not a personality trait. People tend to overestimate their abilities in tasks that are repetitive, simple and common, in this case navigating the Junkers Ju 52.
- Invulnerability[17]: Many people falsely believe that accidents happen to others, but never to them. They know accidents can happen, and they know that anyone can be affected. However, they never really feel or believe that they will be personally involved. Pilots who think this way are more likely to take chances and increase risk.

[14] A judgemental heuristic in which the probability of events is evaluated according to how closely they correspond to certain prototypes. Here, a decision is based on the frequently made and thus mentally represented multitude of experiences regarding a similar or the same situation (base rate).

[15] Reward learning describes learning by positive reinforcement: if a certain behaviour is followed by a pleasant situation in the form of a reward, this behaviour will present more often in the future.

[16] Overconfidence is a systematic manner of misjudging one's own ability and, like the representativeness heuristic, belongs to the category of cognitive distortion.

[17] As described in the 'Pilot's Handbook of Aeronautical Knowledge' published in 2016 by the FAA.

Contents

A1. Factual information

A1.6 Information on the aircraft

A1.6.1 General information

Registration	HB-HOT
Aircraft type	Ju 52/3m g4e
Characteristics	Three-engined commercial air transport aircraft with radial engines and two-blade fixed-pitch propellers, designed as a self-supporting low-wing monoplane in an all-metal construction and with tailwheel landing gear. Non-pressurised cabin.
Manufacturer	Junkers Flugzeug- und Motorenwerke AG, Dessau, Germany
Year of manufacture:	1939
Serial number	6595
Owner	Swiss Air Force, P.O. Box 1072, 8600 Dübendorf
Operator	*Verein der Freunde der Schweizerischen Luftwaffe* (Association of the Friends of the Swiss Air Force or VFL), Überlandstrasse 271, 8600 Dübendorf. The VFL operated the Ju 52 aeroplanes under the name Ju-Air
Operating hours, airframe	10,189:50 h (TSN[1])
Number of landings	8,783
Engines	Manufacturer: BMW Flugmotoren GmbH, Munich, Germany Type: BMW 132 A3, nine-cylinder radial engine

Left engine (no. 1)

Serial number:	67438
Year of manufacture:	1939
Operating hours:	5,687:14 h (TSN)
	946:50 h (TSO[2])

Centre engine (no. 2)

Serial number:	68842
Year of manufacture:	1939
Operating hours:	7,036:27 h (TSN)
	1,153:11 h (TSO)

Right engine (no. 3)

Serial number:	70578

[1] TSN: Time since new

[2] TSO: Time since overhaul

	Year of manufacture:	1939
	Operating hours:	8,228:00 h (TSN)
		457:49 h (TSO)
Propeller hubs	Manufacturer: Junkers Flugzeug- und Motorenwerke AG, Dessau, Germany	
	Type: Ju-PAK 9.20020.21, two-blade	
	Left propeller hub (no. 1)	
	Serial number:	3201
	Year of manufacture:	1939
	Operating hours:	Unknown (TSN)
		1,270:42 h (TSO)
	Centre propeller hub (no. 2)	
	Serial number:	30520
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN)
		489:29 h (TSO)
	Right propeller hub (no. 3)	
	Serial number:	32026
	Year of manufacture:	1939
	Operating hours:	10,058:52 h (TSN)
		41:39 h (TSO)
Propeller blades	Manufacturer: Avia-Propeller Ltd, Prague, Czech Republic	
	Type: Ju-PAK 9.20020.21 (-MT), remanufactured (see section A1.6.17.2.6)	
	Installed on left propeller hub:	
	Serial number:	Blade 1: RA-12004 Blade 2: RA-12005
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN) 1,270:42 h (TSO)
	Installed on centre propeller hub:	
	Serial number:	Blade 1: RA-12008 Blade 2: RA-12009
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN) 481:29 h (TSO)

	Installed on right propeller hub:	
	Serial number:	Blade 1: P-094 Blade 2: P-095
	Year of manufacture:	Unknown
	Operating hours:	41:39 h (TSN)
Max. permissible mass	Max. permissible take-off mass (see section A1.6.6)	10,500 kg
	Max. permissible landing mass	10,500 kg
Mass and centre of gravity	Based on the reconstruction, the aircraft's mass at take-off was 9,387 kg. Based on the reconstruction, the aircraft's mass at the time of the accident was 9,206 kg. Mass was within the permissible limits of the aircraft flight manual (AFM). Based on the reconstruction, the centre of gravity was outside the permissible limits of the aircraft flight manual (see section A1.6.6.4).	
Maintenance	The last interval inspection took place on 31 July 2018 at 10,187:50 operating hours. The Federal Office of Civil Aviation (FOCA) last inspected the aircraft on 6 April 2018. No complaints were found.	
Technical restrictions	The tech log contained no complaints. In contrast, the following three items were listed under 'Damage/faults/malfunctions' in the hold item list (HIL): "*1 Aircraft to be fuelled with AVGAS 100 LL only Fuel test* *2 LH + RH booster pumps have been deac tivated due to AVGAS operation only* *3 RH propeller 100 h blade nut retightening*" Item 1 and 2 were added to the HIL on 15 February 2007, and item 3 on 27 July 2018.	
Approved fuel quality	Aviation gasoline (AVGAS) 100 LL[3] or aviation fuel with an octane grade of 80/87 or higher. A service bulletin (SB) was issued by Ju-Air for its Ju 52 aircraft. This states that motor gasoline (MOGAS) compliant with European Standard (EN) 228, leaded or unleaded, containing no more than 1 % alcohol and with an octane	

[3] LL: Low lead

	grade of at least 95 RON[4] may be used for operation (see section A1.6.12.1.4). This SB also states that operation with a mixture of AVGAS and MOGAS is also permitted. However, since 2007, the aircraft type has been operated with AVGAS 100 LL only.
Fuel quality	Based on analysis, the fuel complied with the specifications for aviation gasoline AVGAS 100 LL.
Oxygen equipment	There was a small portable oxygen cylinder with three oxygen masks in the aft fuselage (galley).
Certificate of registration	Issued by FOCA on 16 December 2013, no. 6, valid until deleted from the aircraft register.
Certificate of airworthiness	Issued by FOCA on 7 June 2007, no. 2, valid until revoked.
Confirmation of inspection	Date of inspection: 6 April 2018
	Date of expiry: 13 April 2020
Operating specifications	Commercial
Approved operation	Visual Flight Rules (VFR) by day and night
MOPSC[5]	17 or 18[6]
Minimum flight crew	2 pilots, 1 ISP (in-flight service personnel)
Performance class	C[7]
Technical complexity[8]	Complex motor-powered aircraft

A1.6.2 History

The three Junkers Ju 52/3m g4e aircraft, registered as HB-HOP, HB-HOS and HB-HOT, operated by Ju-Air in 2018, were manufactured in Germany by state-owned armaments company Junkers Flugzeug- und Motorenwerke AG in 1939. That year, the Swiss Confederation, or rather the defence technology division of the Swiss Federal Military Department, procured these three Ju 52 aircraft for their

[4] RON: Research octane number – the octane number determined using the single-cylinder testing method in accordance with the Cooperative Fuel Research Committee (CFR) of the American Society of Automotive Engineers (SAE).

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

[6] The MOPSC, which – according to section 8.1.9.1.5 of OM-A – is supposed to be specified in section 6.6 of the AFM is in fact not explicitly stated there. In particular, the status of the seat usually occupied by the ISP (in-flight service personnel) was not clear.

[7] 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".*

[8] According to article 3 of EU Regulation 216/2008, a motor-powered aeroplane is considered a complex motor-powered aeroplane if it has a maximum certificated take-off mass exceeding 5,700 kg, or it is certified for a maximum passenger seating configuration of more than 19, or it is certified for operation with a minimum crew of at least two pilots, or it is fitted with one or more turbojet engines or more than one turboprop engine. HB-HOT met at least two of these criteria.

air defence corps[9]. HB-HOT, as it was later known, carried the Swiss military registration number A-702 at the time, and the other two aircraft were registered as A-701 and A-703. Although the three aircraft had been procured as so-called ‘classroom aircraft’[10] in 1939, over time they were also or primarily used for transporting military forces and cargo as well as for dropping paratroops. From the 1950s to 1960s, the air defence troops’ three Ju 52 aircraft were temporarily registered as civil aircraft for operations abroad – as HB-HOS, HB-HOT and HB-HOP. After this, the aircraft were reissued their military registrations. In 1981, the air defence corps decommissioned the three Ju 52 aircraft. A-702, later known as HB-HOT, had accumulated 3,545 operating hours at that time.

The VFMF [11] association was founded in 1979. In 1982, the VFMF began using A-701 as HB-HOS and A-703 as HB-HOP for commercial passenger flights from Dübendorf Air Base. In addition, as of 1985 A-702 was used as HB-HOT. For this purpose, the three aircraft had needed to be modified and converted for civilian use.

By this time, there were no longer any type certificate holders (TC holders) for the aircraft and engines. This meant that, already at this point in time, there was no longer a TC holder to support and establish fundamentals for guaranteeing the aircraft’s continued airworthiness.

The VFMF and the VF Flab [12] associations merged in 1997 to form the new Association of the Friends of the Swiss Air Force (VFL). Its purpose is the preservation of Swiss military aircraft and related equipment. Under the name Ju-Air, the VFL was responsible for the Ju 52 aircraft’s flight operations, aircraft maintenance and the continuing airworthiness management organisation (CAMO). The official documents of the certification and supervisory authority were each issued to the VFL (see annex A1.17).

A1.6.3 Certificates of airworthiness and aircraft category

A1.6.3.1 1985 certificate of airworthiness

In order for HB-HOT and its two sister aircraft to be used for civilian passenger flights, these three Ju 52 aircraft were transferred from the military to the civil aircraft register in the 1980s. To this end, the aircraft needed to be granted civil technical approval. This, in turn, required the aircraft to be assigned to an aircraft category. For FOCA, civil technical approval posed “*no major problem as the aircraft had already been civilly registered* [temporarily during their time in the air defence corps]”. In 1981, FOCA was of the opinion that there was “*nothing to prevent the aircraft from being assigned to the ‘Normal’ category*” on the basis that “*the aeroplane was at the time built in line with civilian certification specifications*”. On 21 August 1985, FOCA thus issued the first certificate of airworthiness (CofA) for HB-HOT, operated by Ju-Air. In the process, it classified HB-HOT in the ‘Standard’ aircraft category and ‘Normal’ subcategory. This certificate stated the following:

“This Certificate of Airworthiness is issued […] *pursuant to the Convention of 7th December, 1944 on International Civil Aviation* […]”

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9 The then air defence corps was renamed the Air Force on 1 January 1996.

10 Classroom aircraft were used by the Swiss air defence corps for training air observers on two-seater aeroplanes. For this purpose, they were fitted most notably with two worktables in the cabin.

11 VFMF: *Verein der Freunde des Museums der Schweizerischen Fliegertruppen* (association of the friends of the Swiss air corps museum)

12 VF Flab: *Verein der Freunde der Fliegerabwehrtruppen* (association of the friends of the air defence corps)

A1.6.3.2 2007 certificate of airworthiness

On 7 June 2007, FOCA replaced HB-HOT's 1985 certificate of airworthiness with a new one. According to this new certificate of airworthiness, the aircraft remained classified in the 'Standard' category and 'Normal' subcategory. The certificate of airworthiness declared once again that it had been issued "*pursuant to the Convention of December 7, 1944 on International Civil Aviation*". FOCA clarified to the STSB that a certificate of airworthiness issued "*in compliance with the Convention on International Civil Aviation of 7 December 1944*" also automatically complies with annex 8 of said agreement (ICAO annex 8).

According to FOCA, the reissue of the certificate of airworthiness on 7 June 2007 was "*part of a mass exchange of all on-board documents of aircraft on the Swiss aircraft register*".

A1.6.3.3 Airworthiness category and legal bases

As of 2011, European Regulation No. 216/2008[13] formed part of the bilateral air transport agreement between Switzerland and the European Union[14]. Annex II of this regulation 216/2008 defined certain categories of aircraft. These categories were necessary so that the applicability of the European regulations could be governed in greater detail based on the aircraft's classification. Ju-Air's Ju 52 aeroplanes exhibited the characteristics for two categories of said annex II:

- Category (a)(ii) ("*aircraft having a clear historical relevance*");
- Category (d) ("*aircraft that have* [previously] *been in the service of military forces*").

Being classified as (a)(ii) and (d) aircraft, as per the aforementioned annex II, Ju-Air's Ju 52 aeroplanes therefore also fell under annex II of European Regulation 216/2008.

Aircraft of categories (a)(ii) or (d) of annex II to European Regulation 216/2008 which are "*used for commercial air transportation*" were excluded from the scope of the European Regulations as per article 4 (4) and (5) of said regulation with regard to certification and maintenance, but not with regard to operation and equipment (see section A1.6.4). As of 2011, in Switzerland, the DETEC[15] Ordinance on the Airworthiness of Aircraft (VLL, SR *748.215.1*) served as the definitive set of rules for the certification and maintenance (continued airworthiness) of aircraft referred to in annex II.

Primarily for the development and manufacturing of aircraft, but also for the purpose of subsequent certification, aircraft are assigned to one of two airworthiness categories according to the VLL – standard or special:

[13] 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. European Regulation 216/2008 has since been repealed. It was succeeded by Regulation (EU) 2018/1139, which came into force in the EU on 11 September 2018 and in Switzerland on 1 September 2019. As a result, aircraft previously listed in annex II are now listed in annex I.

[14] Agreement on aviation between the Swiss Confederation and the European Community (SR *0.748.127.192.68*).

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

- Standard: Aircraft in the 'Standard' category must comply with the applicable European airworthiness directives.[16] Aircraft in the 'Standard' category are approved for operation as per the VLL by means of a certificate of airworthiness (CofA).
- Special: According to the VLL, aircraft which fail to or do not fully comply with the requirements of the 'Standard' category belong to the 'Special' category. For aircraft in the 'Special' category, permission to fly is granted via the issuance of a so-called 'permit to fly'.

According to the VLL, Ju-Air's Ju 52 aeroplanes should in principle have been assigned to the 'Special' category.

As Ju-Air's Ju 52 aircraft did not meet the European airworthiness requirements, it was not possible to issue these aeroplanes with standard certificates of airworthiness under European regulations. Instead, European Commission Decision C(2009) 7633 was applied and national standard certificates of airworthiness were issued for Ju-Air's Ju 52 aircraft (see section A1.6.5).

The HB-HOT entry in FOCA's aircraft register at the time of the accident in fact showed that the aircraft belonged to the 'Normal' airworthiness category. In the aircraft register, *"annex II"* was specified as the "*legal basis*", meaning annex II of European Regulation 216/2008.

A1.6.3.4 Findings

As part of this investigation, Ju-Air and FOCA were unable to provide any evidence or documents that confirm or suggest that HB-HOT or its sister aircraft at Ju-Air ever complied with the requirements of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention), or annex 8 of said agreement (ICAO annex 8). FOCA was also unable to clarify which requirements from the ICAO convention the corresponding entry in the certificate of airworthiness of 7 June 2007 specifically referred to. Nevertheless, FOCA itself concluded in summer 2019 and stated that Ju-Air's Ju 52 aircraft "*did not comply or rather had never complied*" with the requirements of the ICAO convention, or annex 8 of said agreement, that the classification in the 'Standard' category was incorrect and that this had "*never been questioned*" since the certificate of airworthiness was first issued in 1985.

In summary, it can be stated that:

- FOCA issued HB-HOT's 1985 certificate of airworthiness "*pursuant to the Convention of 7th December, 1944 on International Civil Aviation*". Neither FOCA nor Ju-Air were able to provide evidence for this certification.
- FOCA renewed the 2007 certificate of airworthiness without reviewing the framework and without relevant evidence.
- After European Regulation 216/2008 came into force, "*annex II*" was added to the classification of HB-HOT in the aircraft register.

A1.6.4 Exemptions concerning equipment for commercial air transport operations

A1.6.4.1 Applications by the air operator

The requirements concerning equipment for aircraft used in commercial air transport were outlined in the JAR[17]-OPS regulations between 1997 and 2006. As

[16] Certification specifications CS-23 and CS-25, in particular, are considered European airworthiness directives.

[17] JAR: Joint aviation requirements. After the civil aviation authorities merged to form the Joint Aviation Authorities (JAA), Switzerland was a member of the JAA from the late 1990s until 1 December 2006. The JARs were the JAA's set of rules and regulations.

Ju-Air's Ju 52 aircraft failed to meet several of these requirements, in February 2004, Ju-Air requested for FOCA to grant exemption for the following 15 requirements:

- JAR-OPS 1.640 (b)(2): Landing lights
- JAR-OPS 1.645: Windshield wipers
- JAR-OPS 1.650 (n): Power failure warning
- JAR-OPS 1.650 (d): Airspeed indicators
- JAR-OPS 1.652 (j): Two independent static pressure systems
- JAR-OPS 1.652 (k): Heated pitot system
- JAR-OPS 1.652 (l): Standby attitude indicator
- JAR-OPS 1.670: Airborne weather detecting equipment
- JAR-OPS 1.710: Cockpit voice recorder
- JAR-OPS 1.730 (a)(4): Shoulder harness
- JAR-OPS 1.735 (a): Internal doors and curtains
- JAR-OPS 1.780 (a)(1): Protective breathing equipment
- JAR-OPS 1.800: Marking of break-in points
- JAR-OPS 1.815 (3): Emergency lighting
- JAR-OPS 1.1255: Flight deck security

Two such applications are presented in the following excerpts: one application to waive the use of two independent static pressure systems and another to waive the use of a cockpit voice recorder (CVR).

At the time, Ju-Air explained the reasoning behind its application to FOCA for an exemption for JAR-OPS 1.652 (j), two independent static pressure systems, as follows:

"*The JU-52 have been designed and manufactured according to applicable certification rules which do not require two independent static pressure systems. A retrofit with the equipment would create various challenges in respect of the structural engineering works.*

The JU-AIR JU-52 operation, however, is restricted to VFR only and has been performed for the recent decades with the above mentioned installation and not experiencing any difficulties in relation to it. A retrofit seems, therefore, out of proportion considering the gain of safety compared to the effort and uncertainties involved in the installation."

Ju-Air justified the reasoning behind the application for an exemption for JAR-OPS 1.710, cockpit voice recorder (CVR), as follows:

- *"The installation of a CVR requires an electrical power supply from the existing electrical system. The JU-52 as well as the DC-3 electrical systems are supplied by a set of batteries and by the engine-driven DC-generators.*
- *A CVR would have to be electrically supplied from one of the available electrical buses. The respective bus is buffered by a 12 V 20 Ah battery and would have – in order to allow for continuous operation of the CVR – have to remain operational even in the case of a major electrical failure, thus providing emergency lighting, navigation, communication and instrumentation for the required period*

of time. An additional power demand caused by a CVR is not desired since the DC generators only feed electrical energy to the electrical system when the engines run considerably above idle power. The aircraft ground operation takes place with engines running at idle RPM, thus feeding all electrical systems exclusively with battery power. The resulting unnecessary draft of electrical emergency power during the typically lengthy ground operation would cause a reduction of the safety margins in the case of an electrical main bus failure.

- *The crashworthy mechanical installation of the CVR in the area below the rear part of the cabin requires enforcement of the aircraft's structure. This would add – not mentioning the cost of the project – weight to the rear structure of the aircraft. The center of gravity would therefore move further aft and loading to the full passenger complement would be impossible.*
- *In order to supply the CVR with the required audio signals a major redesign of the audio system would be required. The CAM (Cockpit Area Microphone) channel could not be provided in a satisfactory quality due to the noise of the aircraft.*
- *The installation of a CVR requires a large financial investment into the vintage aircraft. The permanent decrease in payload due to the shift of the center of gravity to the aft of the aircraft would reduce the full passenger complement. The readability of the recorded data seems questionable due to the high cockpit noise.*

Summing up these arguments, the gain of CVR data in the case of an accident or incident compared to the trade off in flight safety and commercial margins does not seem to justify this modification."

A1.6.4.2 Approval of exemptions by FOCA

On 15 April 2004, FOCA approved all 15 applications submitted by Ju-Air. The exemption permits applied to the entire fleet of, at the time, four Ju 52 aircraft.

In 2008, the version of the JAR-OPS rules dating 1 January 2005 were used as a basis to supplement European Regulation 3922/91[18] with European Regulation 1899/2006[19]. This amendment included in particular annex III, which contained common technical requirements and administrative procedures applicable to commercial transportation by aeroplane. Annex III of European Regulation 3922/91 came into force in the EU on 16 July 2008. In 2012, these rules were transferred into European Regulation 965/2012[20]. Throughout this amendment of the legislation, the content of the rules remained largely, but not entirely, identical. Despite this, the 15 exemptions granted and the new regulations were not reviewed or reassessed by FOCA when the legislation was amended. In particular, the requirement applicable since 2012 of being equipped with a terrain awareness warning system (TAWS) as per CAT.IDE.A.150 of European Regulation 965/2012 was not recognised (see annex A1.17).

Whilst in the days of JAR-OPS, FOCA was allowed to "*grant exemptions from some of these requirements* [JAR-OPS] *in justified cases, in particular to avoid*

[18] 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.

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

[20] 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.

cases of hardship or to stay abreast of technical developments”, this was not so feasible after 2006 for the relevant requirements of the European regulations. At this time, according to article 8 (3) of European Regulation 3922/91, and later according to article 14 (6) of European Regulation 216/2008, no such exemptions from the applicable regulations could be granted or tolerated without proof of an equivalent level of protection/safety and without completion of a process involving the European Commission and EASA. However, FOCA continued to tolerate derogation from the applicable regulations in accordance with the exemptions granted in 2004 without proof of an equivalent level of protection/safety and without the process involving the European Commission and EASA having been completed. FOCA justified its tolerance to the STSB with a letter from the European Commission dated 2 December 2014. The Office understood this letter to FOCA “*as covering all derogations from the operational rules resulting from the design of the JU-52 without additional specific exemption approval (for each individual derogation)*.” In its letter, however, the European Commission approved of Ju-Air’s commercial air transport 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) (see section A1.6.5).

Subsequently, Ju-Air’s Ju 52 aircraft were not fitted with the following equipment or systems according to the European Regulation 965/2012 for several years until and including 4 August 2018, meaning they did not achieve the level of safety required for commercial air transport:

- CAT.IDE.A.115 (b)(2): Landing lights;
- CAT.IDE.A.120: Equipment to clear windshield;
- CAT.IDE.A.125 (a)(2) and CAT.IDE.A.130 (c): Equipment of indicating when the supply of power to the required flight instruments is not adequate (power failure warning);
- CAT.IDE.A.130 (e): Equipment of annunciating to the flight crew the failure of the heated pitot system;
- CAT.IDE.A.130 (f): Two independent static pressure systems;
- CAT.IDE.A.130 (i): Standby equipment of measuring and displaying the aircraft’s attitude;
- CAT.IDE.A.150 (b): Terrain Awareness Warning System (TAWS);
- CAT.IDE.A.160: Airborne weather detecting equipment;
- CAT.IDE.A.185: Cockpit Voice Recorder (CVR);
- CAT.IDE.A.205 (a)(5) A seat belt with upper torso restraint system on each flight crew seat and on each observer seat in the cockpit;
- CAT.IDE.A.205 (a)(6): A seat belt with upper torso restraint system on each seat for the minimum required cabin crew;
- CAT.IDE.A.245: Protective breathing equipment for the crew;
- CAT.IDE.A.260: Marking of break-in points;
- CAT.IDE.A.275: Emergency lighting.

A1.6.5 Exemption regulation for obtaining an air operator certificate

A1.6.5.1 Initial situation

For commercial air transport (CAT) operations, such as those conducted by Ju-Air, the air operator must hold an air operator certificate. For an air operator certificate, on the other hand, the operated aircraft are required to possess a certificate of airworthiness (CofA) in line with the requirements of European regulations. Since 2012, this results from ORO.AOC.100 (c)(2) of European Regulation 965/2012, before 2012 from OPS 1.180 (a)(1) of European Regulation 3922/91, supplemented in this respect by European Regulation 1899/2006. The Ju 52 aircraft did not possess a certificate of airworthiness in accordance with the requirements of the European regulations but they were issued with a national standard certificate of airworthiness (see section A1.6.3.3). The following two sections set out the relevant information.

A1.6.5.2 European Commission Decision C(2009) 7633

European Regulation 3922/91, supplemented in this respect by Regulation 1899/2006, gave European Community member states the option to derogate from the European regulations subject to certain conditions. The air transport agreement, which made the European aviation regulations applicable to Switzerland as well, provided Switzerland with the option of derogating from the rules under certain circumstances. Article 8 of European Regulation 3922/91 specifically permitted member state authorities to derogate from the common technical requirements and administrative procedures, provided that "*a safety level equivalent to that attained by the application of the common technical requirements and administrative procedures* [...] *can be achieved by other means*". The aforementioned article 8 also specified the relevant administrative procedure: a member state intending to derogate from the common technical requirements and administrative procedures must notify the European Commission of its intention and state "*the reasons therefor and the conditions laid down in order to ensure that an equivalent level of safety is achieved*". The European Commission is then to decide whether the derogation proposed by the member state may be applied. If it is decided that it may, the European Commission communicates its decision to all member states. In line with the fundamental concept of the European single market, all member states are then entitled to apply the relevant measures.

In Germany, Deutsche Lufthansa Berlin-Stiftung conducted commercial air transport operations using a Ju 52 aircraft. Thus, OPS 1.180 (a)(1) of European Regulation 3922/91, supplemented in this respect by European Regulation 1899/2006, could not be complied with. This rule states that an air operator certificate may only be granted and remains valid only when a standard certificate of airworthiness has been issued for the aircraft operated in accordance with European Regulation 1702/2003. The Ju 52 belonging to Deutsche Lufthansa Berlin-Stiftung did not possess such a certificate of airworthiness. Germany therefore approached the European Commission on 12 September 2008 and requested permission to derogate from said rule.[21] For the Ju 52 aircraft concerned, the measures that Germany intended to take to achieve an equivalent level of safety were as follows:

- Certificate of airworthiness as per annex 8 (ICAO annex 8) of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention);

[21] At the same time, Germany also requested permission to derogate from OPS 1.180 (a)(1) for a number of other historic aircraft, including a Douglas DC-3 and an Antonov AN-2.

- Continuing airworthiness by maintenance organisations which hold permits in accordance with annex II (part 145) of European Regulation 2042/2003;
- Regular review of procedures for continuing airworthiness by the authorities.

The European Commission subsequently concluded that the measures specified by Germany would ensure an equivalent level of safety. In its Decision C(2009) 7633, the European Commission communicated its approval of derogation from OPS 1.180 (a)(1), subject to the conditions proposed by Germany, as follows[22]:

Article 2: "*Germany may, by derogation from OPS 1.180 (a)(1) of Regulation (EEC) No 3922/1991, issue an Air Operator's Certificate* […] *for the operation of aircraft of the type Junkers Ju52* […]."

Article 5 (1): "*The aeroplanes subject to the derogations described under Articles 1 to 4 shall have a certificate of airworthiness issued in accordance with national rules and meeting the requirements of Annex 8 to the Convention on International Civil Aviation, signed in Chicago on 7 December 1944.*"

Article 5 (2): "*The operators concerned by the derogations described under Articles 1 to 4 shall comply with Regulation (EC) No 2042/2003 or have in place equivalent continued airworthiness and maintenance arrangements approved by the competent national Authority.*"

Article 5 (3): "*The operations concerned by the derogations described under Articles 1 to 4 shall be conducted in full compliance with all provisions of Regulation (EEC) No 3922/91 which are not covered by these derogations.*"

In addition, the Commission specified in article 6 that a certificate issued in accordance with this decision should state "*that it has been issued in accordance with this decision by way of derogation from Regulation (EEC) No. 3922/91*". In its decision, the European Commission also stated that the envisaged derogations were "*necessary in order to maintain the commercial air transport operations of the aircraft concerned*". It goes on to state that, "*The alternative to the derogations related to the standard certificate of airworthiness would be to cease commercial operations or to undertake the effort to be issued a standard certificate of airworthiness in accordance with Regulation (EC) 1702/2003* [...]. *However, the cost of such certification would be excessive, if not prohibitive, and disproportionate in the light of the ensured level of safety.*"

During this investigation, the Commission was unable to provide any evidence or documents that confirm or suggest that an equivalent level of safety could indeed be achieved by using the approved measures. Furthermore, the Commission was unable to state which requirements for a certificate of airworthiness "*meeting the requirements of Annex 8 to the Convention on International Civil Aviation* […]" it understood as needing to be concretely fulfilled.

A1.6.5.3 Application of Decision C(2009) 7633 by Switzerland

In a letter dated 10 December 2009, FOCA notified the European Commission with regards to article 8 (3) of Regulation 3922/91 of its intention to permit the air operator Ju-Air, with its four Ju 52 aircraft, to derogate from OPS 1.180 (a)(1). When doing so, FOCA referred to European Commission Decision C(2009) 7633 of 14 October 2009. In its letter dated 10 December 2009, FOCA listed the following

[22] Decision C(2009) 7633 also concerned similar exemption permits granted to Austria, the United Kingdom and Malta by the European Commission.

measures which it intended to take to ensure an equivalent level of safety and which were comparable with the measures taken by the German authorities:

- National standard certificate of airworthiness as per annex 8 (ICAO annex 8) of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention);
- Continuing airworthiness by maintenance organisations, which hold permits in accordance with annex II (part 145) including annex I (part M) of European Regulation 2042/2003. Furthermore, it was noted that Ju-Air was approved as a continuing airworthiness management organisation (CAMO);
- Annual airworthiness inspection by the regulatory authority.

FOCA concluded its reasoning by stating that, with these measures, Ju-Air's Ju 52 aircraft would meet the same safety requirements as aircraft used in commercial air transport operations which are not listed in annex II of European Regulation 216/2008.

There is no written response available from the European Commission to the Swiss authorities.

On 30 September 2014, FOCA wrote to the European Commission and EASA. In this letter, FOCA stated that, based on article 6 (2) of European Regulation 965/2012, it intended to maintain this derogation for the four Ju-Air Ju 52 aircraft in future under the conditions covered by Decision C(2009) 7633, which FOCA communicated to the European Commission on 10 December 2009.

The European Commission wrote to FOCA on 2 December 2014 acknowledging receipt of the above-mentioned letter. In said letter, the Commission clarified its understanding that the flight operations for which FOCA had applied or sought exemption would be carried out in full compliance with European Regulation 3922/91 ('EU-OPS') with the exception of OPS 1.180 (a)(1), and that the derogation from OPS 1.180 (a)(1) was covered by European Commission Decision C(2009) 7633. Based on this observation, the Commission and EASA concluded that the envisaged derogation did not differ from the previous derogation that had already been authorised.

A1.6.6 Mass and centre of gravity

A1.6.6.1 Previous developments relating to maximum permissible take-off mass

The sales documentation and the operating instructions of Junkers Flugzeug- und Motorenwerke from 1939 specified a maximum flight mass of 10,000 kg for the Ju 52/3m g4e classroom aircraft, which applied to serial numbers 6580 (later HB-HOS), 6595 (later HB-HOT) and 6610 (later HB-HOP).

In September and October 1939, a Swiss delegation took performance measurements using one of the three Ju 52/3m g4e aircraft ordered by Switzerland (see section A1.6.10.5). The flights were carried out with a mass of 10,000 kg.

A maximum flight mass of 10,500 kg was listed in the Junkers Flugzeug- und Motorenwerke takeover deed of 4 October 1939.

The military pilot's manual from 1948 specified a maximum flight mass of 10,500 kg.

HB-HOT's first civilian-aircraft flight manual, issued on 9 August 1985, also specified a maximum flight mass of 10,500 kg. Since then, there has been no known change in the maximum flight mass.

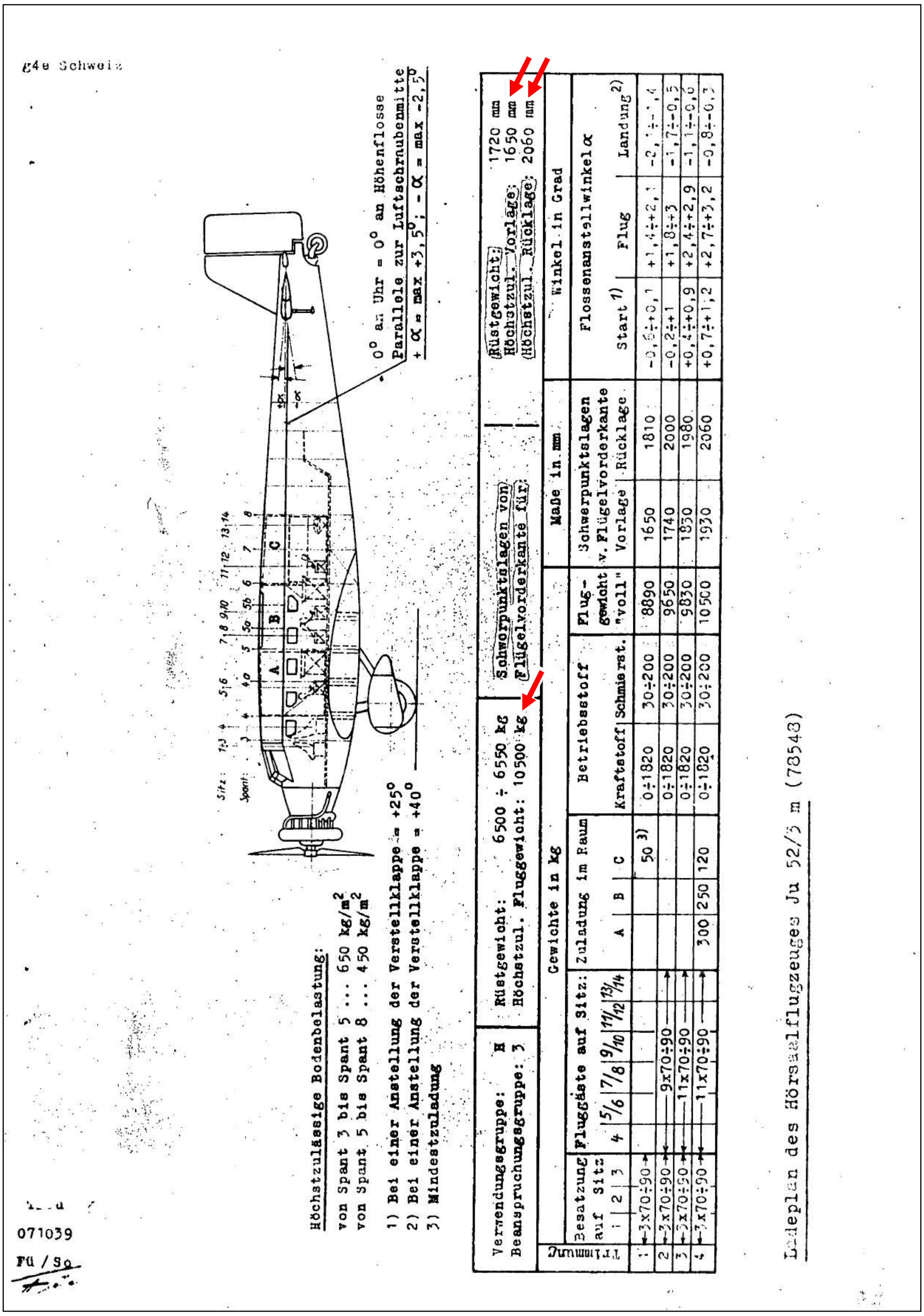
A1.6.6.2 Developments relating to operation and centre of gravity determination

A1.6.6.2.1 1939 to 1981

When the three Ju 52/3m g4e aircraft were procured in Germany in 1939, the philosophy there regarding the loading of (Ju 52) aircraft was different to that of today – at least this is what is suggested by historical documents obtained and sighted from archives during the investigation. Nowadays, it is the task of every flight crew (or, for an airline, usually the task of a dispatch service) to themselves determine an aircraft's flight mass and centre of gravity and to keep these within the defined limits based on information in the flight manual – in particular information on the arms. The philosophy in Germany in 1939, however, seemed to have been that flight crews loaded and refuelled their aircraft primarily for 'standard loading operations', following an accurately defined 'loading plan'. There were other loading plans, including for the use of 'cargo transport aircraft', 'passenger aircraft', 'paratroopers and airborne troops aircraft' or 'classroom aircraft'. These had previously been drawn up by the aircraft manufacturer's engineers, taking into consideration all limits for flight mass and centre of gravity. Observing the loading plans for loading and refuelling was meant to ensure that the flight mass and balance remain within the permissible limits. Only in the second instance, i.e. For 'unforeseen unique instances' of load distribution, did crews of German Air Force Ju 52 aircraft have the option of "*determining a new centre of gravity and comparing whether this lies within the permissible limits using the* [...] *weight and moment tables* [in the loading regulations]." These loading instructions also included information on arms for the aircraft's various loading areas. In contrast to the civilian loading plans written by Junkers Flugzeug- und Motorenwerke AG, which could be exported abroad, the loading instructions were military service regulations of the German Air Force and "*for official use only*".

When the three Ju 52/3m g4e aircraft were handed over to the Swiss Confederation, a loading plan drawn up by Junkers Flugzeug- und Motorenwerke AG for the use of 'classroom aircraft' was supplied (see figure 1). This loading plan was part of the operating instructions[23] supplied by Junkers and specified the maximum permissible flight mass (10,500 kg) and permissible balance limits (maximum of 1,650 mm forward and 2,060 mm aft, measured from the leading edge of the wing). This loading plan was subsequently signed off by a department of the Swiss military administration and provided to the air defence corps as the 'TD 9560' loading plan (see figure 2). Although the air defence corps provided its Ju 52 pilots with the 'TD 9560' loading plan, investigation by the STSB revealed that it was evidently not used by the pilots. It could not be proven that loading plans were provided to Swiss air defence pilots for other purposes. There was also evidently no known alternative system for determining the mass and centre of gravity, as was the case with the loading instructions in Germany. Instead, the Swiss Ju 52 aircraft were loaded, refuelled and operated by the air defence corps based on experience passed on informally. Load sheets were not completed. As anecdotal examples show, the limits for flight mass and balance were regularly ignored by the Swiss air defence corps during operations.

[23] In the 1980s, Ju-Air acquired multiple versions of the 'Ju 52/3m g4e operating instructions for Switzerland' from September 1939, along with the aforementioned 'loading plan for classroom aircraft'.



Trimmung	Gewichte in kg: Besatzung auf Sitz 1 | 2 | 3	Fluggäste auf Sitz: 4, 5/6, 7/8, 9/10, 11/12, 13/14	Zuladung im Raum A	B	C	Betriebsstoff: Kraftstoff	Schmierst.	Flug-gewicht "voll"	Maße in mm: Schwerpunktslagen v. Flügelvorderkante: Vorlage	Rücklage	Winkel in Grad: Flossenanstellwinkel α: Start 1)	Flug	Landung 2)
1	3x70÷90				50 3)	0÷1820	30÷200	8890	1650	1810	-0,6÷+0,1	+1,4÷+2,1	-2,1÷-1,4
2	3x70÷90	9x70÷90				0÷1820	30÷200	9650	1740	2000	-0,2÷+1	+1,8÷+3	-1,7÷-0,5
3	3x70÷90	11x70÷90				0÷1820	30÷200	9830	1830	1980	+0,4÷+0,9	+2,4÷+2,9	-1,1÷-0,6
4	3x70÷90	11x70÷90	300	250	120	0÷1820	30÷200	10500	1930	2060	+0,7÷+1,2	+2,7÷+3,2	-0,8÷-0,3

Figure 1: Loading plan supplied to the Swiss Confederation in 1939. The red arrows point to information regarding the maximum permissible centres of gravity and maximum permissible flight mass. Source: “*Betriebsanweisung Ju 52/3m g4e*” (operating instructions).

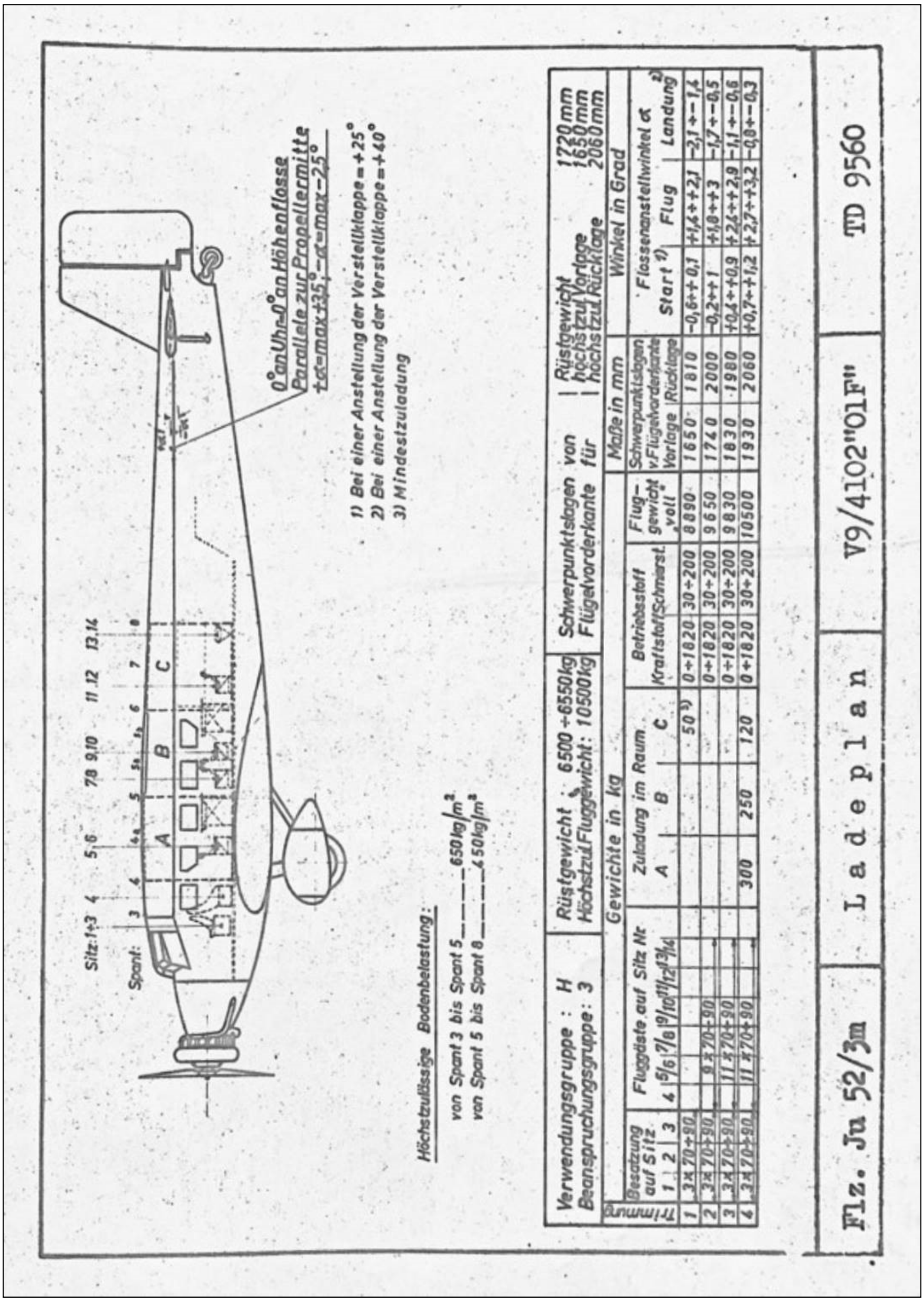


Figure 2: 'TD 9560' loading plan, drawn up by a department of the Swiss military administration, which was provided to the air defence troops and their pilots.

A1.6.6.2.2 1982 onwards

For the transferral of the three Ju 52 aircraft from the air defence corps to Ju-Air, Ju-Air first needed to create an aircraft flight manual (AFM) based on civilian features and approved by the Federal Office of Civil Aviation. To a large extent, the content of the operating instructions supplied by Junkers in 1939 (see section A1.6.6.2.1) was used to create the first edition of the AFM from 1982 and the subsequent revisions. However, the Junkers and ‘TD 9560’ loading plans, both drawn up for the use of the Ju 52 as a classroom aircraft, could no longer be used. Firstly, a loading plan for the use of the aeroplane as a classroom aircraft was not applicable to the Ju-Air aircraft now fitted with airline seats. Secondly, the ‘loading plan philosophy’ was no longer common in the aviation industry. Only the maximum permissible flight mass (10,500 kg) and the permissible balance limits (maximum of 1.65 m forward and 2.06 m aft) were transferred to the AFM for the ‘Mass and centre of gravity’ section. The arm values for the various stations[24] within the aircraft had to be ascertained using measurements taken on the aircraft.

The development of the AFM from 1982 until its last revision on 1 June 2017 could be partially reconstructed based on archived documents. The AFM, which had initially been created only for HB-HOS, the first Ju-Air aircraft, also applied to the sister aircraft HB-HOP and HB-HOT when they later joined the Ju-Air fleet. Milestones in the development of the AFM:

- The first AFM was created in 1982 and was approved by FOCA. What exactly it covered is unknown.
- As of January 1983, the AFM included information for calculating the centre of gravity. The authors were clearly aware of the different arms of the various fuel cells. There was relevant information at two locations within the AFM: On the “*Weight and CG determination for flight*” page and in the “*Fuel & loading tables*”. According to the “*Fuel & loading tables”*, cells 1 to 3 (referred to elsewhere as cells I to VI, one of each in the left- and right-hand outer wings) had an arm of 2.30 m, cells 4 (referred to elsewhere as cells VII, one in the left-hand and one in the right-hand outer wing) had an arm of 3.20 m. The rear underfloor storage compartment was not mentioned in the AFM until at least January 1983.
- As of no later than February 1986, the AFM included a “*Payload moment table*” which referred to the rear underfloor storage compartment[25] as “*cabin cargo*” with an arm value of 1.95 m. Next to this, the comment “*Same values as in PAX ROW 3*”[26] was added. “*PAX ROW 3*” was also listed with an arm value of 1.95 m in this table. It can be seen from the station plan in this edition of the AFM that, together, seats 5 and 6 form row 3 (see figure 3).
- As of no later than December 1986, there was no longer any difference in the arms for the various fuel cells on the “*Weight and CG determination*” page in the AFM. However, there were still differences in the “*Fuel & loading tables*”. As of no later than this time, this page also included a diagram, from which the setting of the horizontal-stabiliser trim for take-off is to be taken. According to this diagram, the necessary setting of the horizontal-stabiliser trim depends only on the take-off mass (see figure 4).

[24] In relation to the calculation of the mass and balance of an aircraft, ‘stations’ are understood to be all of the points within the aircraft at which a load is placed when refuelling and loading cargo or boarding passengers. These include, most notably, passenger and crew seats, fuel cells and cargo or luggage compartments. For the centre of gravity calculation, each station is assigned an arm value, i.e. a distance from a defined reference point (datum).

[25] For the aircraft supplied to the Swiss Confederation in 1939, the area used by Ju-Air as rear underfloor storage was not intended by the manufacturer as storage space for luggage, but as a passageway to a ventral and foldable machine gun rack for military use. To this end, this compartment was equipped with a ladder. However, when the Ju 52/3m was originally designed in 1932, it was intended as a civilian aircraft for transporting passengers and freight. In this variant, the areas below what referred to as the ‘main usable area’, i.e. the passenger cabin, were already being used to store luggage.

[26] ‘PAX ROW 3’ refers to the third row of passenger seats (row 3), counted from front to back.

- As of no later than January 1998, the rear underfloor storage compartment was marked in the station plan diagram as 'cabin cargo' with an arm value of 1.95 m. Although there was a 'cabin cargo' entry in the "*Weight and CG determination*" table at the time, there was no arm value.
- As of no later than January 2005, the rear underfloor storage compartment was recorded on the "*Mass and CG determination*" page (previously "*Weight and CG determination*") as 'cabin cargo' with an arm value of 1.95 m (see figure 4). In the same table, an arm value of 2.3 m was now also stated for the fuel.
- The "*Fuel & loading tables*" from 1983 remained unchanged in the AFM issued in January 2005, as well as in the latest edition of the AFM from June 2017.

Re-measurements taken as part of the investigation on one of HB-HOT's sister aircraft revealed that the rear underfloor storage compartment begins 2.72 m behind the reference datum[27] and ends 3.58 m behind it. The centre of the rear underfloor storage compartment is therefore 3.15 m behind the reference datum. The rear underfloor storage compartment is situated approximately in line with row 5 consisting of seats 9 and 10 (see figure 3).

In addition, the arm values for the various fuel cells, as they have been included at various points in the AFM since 1983, were verified as part of the investigation on the sister aircraft. Both values – 2.30 m for cells 1 to 3 (I to VI) and 3.20 m for cells 4 (VII) – were correct (see figure 5).

In 2005, the "*Mass and CG determination*" page from the AFM served as a basis for the programming of the flight planning software 'JU-OFP'.

When Ju-Air commenced operations in 1982, all of its pilots were former military Ju 52 pilots from the air defence corps. The flight instructor who was to retrain the pilots for civilian flight operation on the aircraft type had also previously been a military Ju 52 pilot. According to this flight instructor, the topics of load distribution and the calculation of the centre of gravity were not discussed as part of this retraining. This flight instructor also stated that they all agreed that this was not necessary due to the flying experience the aspiring Ju-Air pilots had gained during their time with the air defence corps or civil aviation companies.

[27] The reference datum from which all arms are measured is an imaginary plane vertical to the longitudinal axis of the aircraft, which runs through the leading edge of the wing at the root.

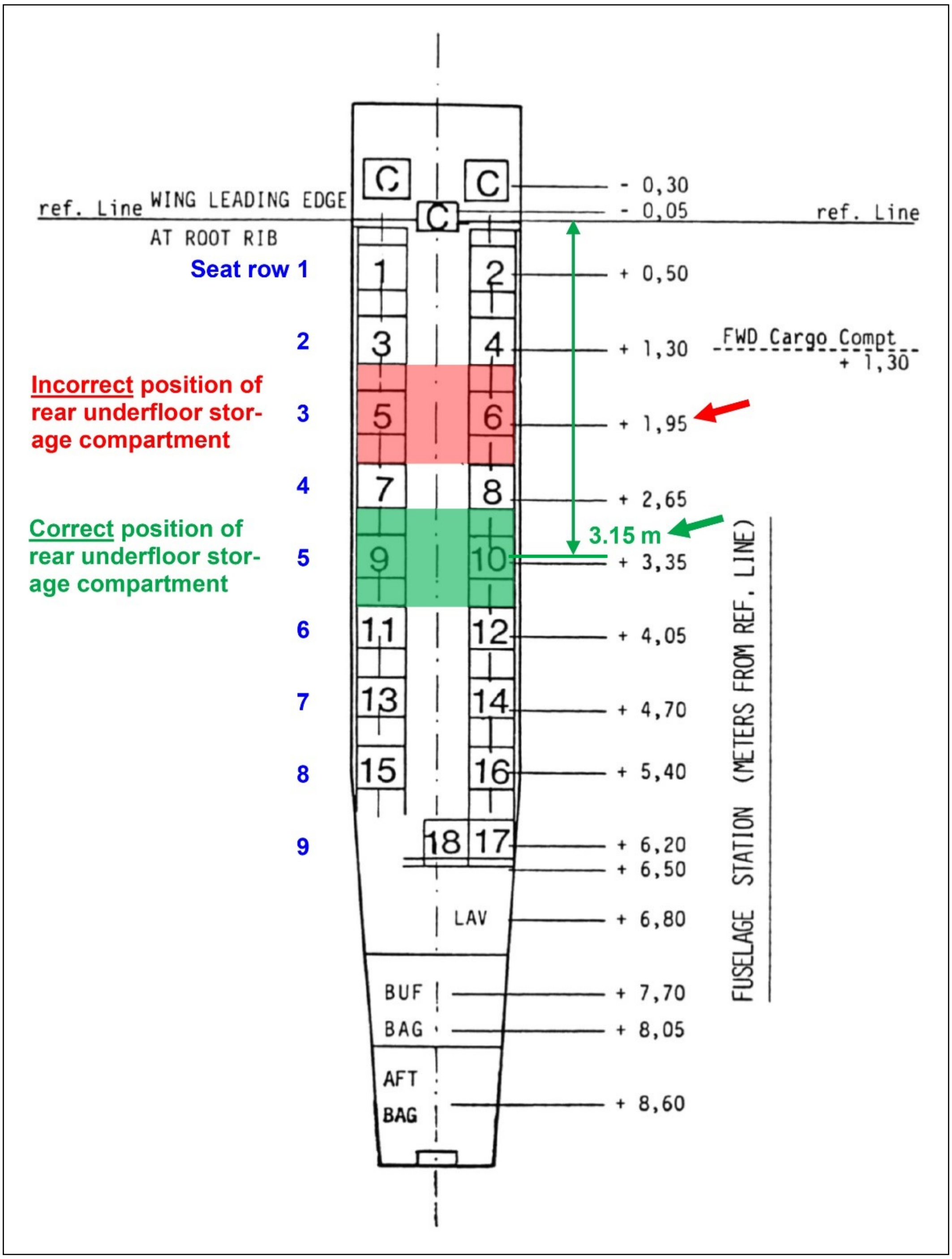


Figure 3: Station plan taken from the AFM from February 1986, with annotations by the STSB in blue, red and green.

The passenger cabin seats are numbered 1 to 18 in black

The seat rows are numbered 1 to 9 in **blue** from front to back

The (at the time incorrectly assumed) position of the rear underfloor storage compartment (cabin cargo) is marked in **red** with an arm value of 1.95 m for seat row 3

The correct position of the rear underfloor storage compartment is marked in **green** with the correct arm value of 3.15 m determined during the investigation

Source of station plan: Ju-Air AFM from 1986.

PAYLOAD CALCULATION		example max PAX Payload	Moment
JUMP SEAT	-0.05	0	0.0
ROW 1	0.50	184	92.0
ROW 2	1.30	184	239.2
ROW 3	1.95	184	358.8
ROW 4	2.65	184	487.6
ROW 5	3.35	184	616.4
ROW 6	4.05	184	745.2
ROW 7	4.70	184	864.8
ROW 8	5.40	184	993.6
ROW 9	6.20	92	570.4
FWD CARGO	1.30		0.0
CREW LUGGAGE	1.30	30	39.0
CABIN CARGO	1.95		0.0
PAX LUGGAGE	1.95	170	331.5
LAVATORY	7.00		
BAGGAGE	8.05		
AFT BAGGAGE	8.60		
FLIGHT KIT klein #	1.30	25	32.5
Motorendecken #	1.95	12	23.4
PAYLOAD		1801	5394.4

\# Flight Kits siehe Kapitel 6.10

BASIC EMPTY MASS	meters from reference	Maß kg	Moment mkg
see M&B record	Ø 1.75	Ø 7200	Ø 12850
Crew 2x92 kg	-0.30	184	-55.2
ROW9 F/A 68 kg	6.20	68	421.6
Flight Kit groß	1.30	75	97.5
DRY OPERATING MASS	Ø 1.73	Ø 7500	Ø 13300
PAYLOAD		1801	5394.4
ZERO FUEL MASS	Ø 2.01	9301	Ø 18695
FUEL (1715 l)	2.30	1235	2840.5
RAMP MASS	2.04	10536	21535.5
Taxi + Run up 50 l	2.30	36	82.8
TAKE OFF MASS	2.04	10500	21452.7

MAX TAKE OFF AND MAX LANDING MASS	between **1.65** and **2.06**	**10'500**	between **17325** and **21630**

TRIMSETTING				
7-8	8-9	9-10	10-10.5	TOW TONS
TRIM				
0	+0.5	+1.0	+1.5	**HB - HOP/S/T**
-1.0	-0.5	0	+0.5	**HB - HOY**

Figure 4: Excerpt from the "*Mass and CG determination*" page of the AFM from January 2005. Incorrect values which were transferred to the JU-OFP flight planning software are indicated in red. The bottom right-hand corner shows the table, from which the setting of the horizontal-stabiliser trim for take-off is to be taken depending on the take-off mass (Take-Off Weight – TOW). Source: Ju-Air AFM from 2005.

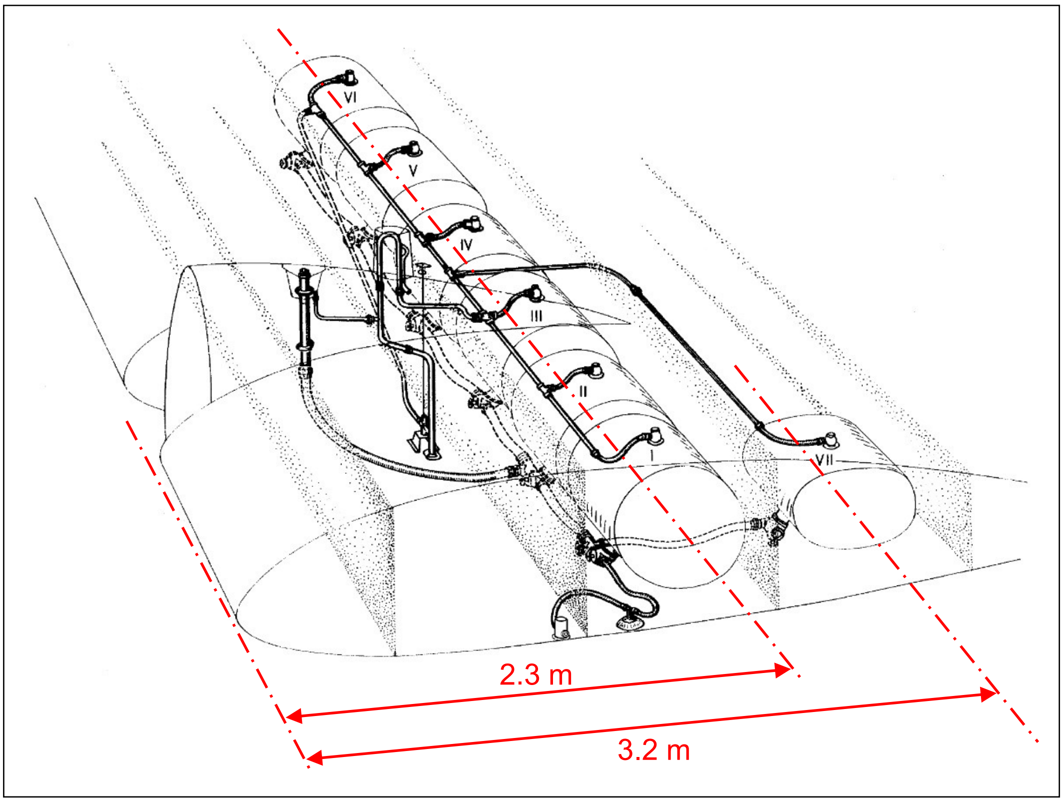


Figure 5: Diagram showing fuel cells I to VII in the right-hand outer wing. View from the root of the wing outwards. Direction of flight to the left. Engine is not shown. The different arm values for cells I to VI (2.3 m) and VII (3.2 m) have been added in red. Source: Ju-Air AFM from 2017, dimensioning by the STSB.

A1.6.6.3 Applicable limits for mass and centre of gravity

According to the ‘Operating limits’ section of Ju-Air’s Ju 52 AFM, the following limits were applicable for mass and centre of gravity:

- Max. permissible flight mass: 10,500 kg
- Rearmost permissible centre of gravity: 2.060 m behind the reference line
- Foremost permissible centre of gravity: 1.650 m behind the reference line

The reference line was defined as the “*vertical tangent to the leading edge of the wing at the root*”.

A1.6.6.4 Mass and centre of gravity for the 2018 Locarno adventure tour

Pilot A, the person responsible for flight preparations, created the OFP for the outbound and return flights on the morning of 3 August 2018 (see annex A1.1). To do this, he used the flight planning software ‘JU-OFP’ on a computer in the briefing room at the Air Force Center. Creating an OFP for a flight also involves calculating the mass and balance for the flight in question.

The OFP for the outbound flight and the OFP for the accident flight were secured from the wreckage of HB-HOT. When examining these OFPs, it stood out that the table used to calculate the mass and centre of gravity had not taken into account the passengers’ and ISP’s luggage (together approximately 120 kg in reality, or 239 kg when calculated using standard values), whilst 25 kg had been included for a flight kit which was not actually on board. Both of these factors led to the presumed centre of gravity being further forward.

During the investigation, the aircraft's mass and balance were reconstructed as it must have been at various points in time during the 2018 Locarno adventure tour. In addition, diligent flight preparation by the pilots was simulated using flight planning software. The following table compares these scenarios against the values from the OFP taken from the wreckage and the corresponding limits.

	According to the operational flight plan (OFP) from the wreckage		Simulation of diligent flight preparation		Reconstruction of actual situation		Limits (see section A1.6.3.3)	
	Mass	Centre of gravity	Mass	Centre of gravity	Mass	Centre of gravity	Maximum flight mass	Rear centre of gravity limit
Take-off from Dübendorf 3 August	9,965 kg	1.99 m	10,180 kg	2.00 m	9,714 kg	2.098 m	10,500 kg	2.060 m
Take-off from Locarno 4 August	9,737 kg	1.98 m	9,858 kg	1.99 m	9,387 kg	2.077 m		
Entry into accident basin	–	–	–	–	9,206 kg	2.071 m ([28])		

Table 1: Comparison of various scenarios for mass and centre of gravity.

Green means that the relevant limit has been observed

Red means that the relevant limit has not been observed

For the reconstruction of the actual situation for take-off from Dübendorf on 3 August 2018, the values for mass and centre of gravity corresponded to a 'moment' (mass × arm) of 20,375 kg×m (see annex A1.1, figure 9, OFP1, red cross).

For the reconstruction of the actual situation for take-off from Locarno on 4 August 2018, the values for mass and centre of gravity corresponded to a 'moment' of 19,499 kg×m (see annex A1.1, figure 10, OFP2, red cross).

The calculations for the simulation of diligent flight preparation are based on the following assumptions and values in particular:

- Mass and arm of the basic aircraft, i.e. when empty, based on values recorded in the flight planning software, but not true to reality;
- Standard masses for the crew and passengers based on values recorded in the flight planning software and OM-A;
- Standard person/seat allocation based on values recorded in the flight planning software, OM-A and the AFM;

[28] The arms for all people, storage compartments and fuel cells, mass for the people, and mass for the fuel were calculated using an assumed tolerance of ±10 cm, ±2.5 kg and ±10 % respectively, which produced the following: The extreme values calculated for the centre of gravity, which could only occur in the unlikely event of all values shifting in the same direction, are 2,032 m and 2,111 m. According to a Monte Carlo error calculation and based on the above assumptions, the centre of gravity was >2,060 m with a probability of >99.5 %, i.e. behind the rearmost permissible centre of gravity position.

- Standard masses for the luggage belonging to the crew and passengers based on values recorded in the flight planning software and OM-A;
- Identical arm for all passenger luggage based on the value recorded in the flight planning software and the AFM, but not true to reality;
- Identical arm for all crew luggage based on the value recorded in the flight planning software, but not true to reality;
- No flight kit based on the situation found at the accident site;
- Fuel density of 0.71 kg/l based on the value recorded in the flight planning software;
- Arm for the total remaining fuel, independent of the fuel remaining, based on the value recorded in the flight planning software and on the AFM, but not true to reality.

The calculations for the reconstruction of the actual situation are based on the following assumptions and values in particular:

- Mass and arm of the basic aircraft, i.e. when empty, based on the applicable weight sheet;
- Realistic masses for crew and passengers based on information from relatives;
- Realistic person/seat allocation based on reconstruction using photos and videos; one person per seat;
- Masses for luggage belonging to the crew and passengers based on the weight of the luggage taken from the accident site (totalling 121 kg);
- Realistic arm for the luggage found in the rear underfloor storage compartment based on the re-measurement of a sister aircraft;
- Arm for the luggage found in the front rear storage compartment based on the AFM;
- No flight kit based on the situation found at the accident site;
- Fuel density of 0.72 kg/l based on the AFM;
- Real arms for the different fuel cells based on the re-measurement of a sister aircraft (and confirmed by section 6.7 of the AFM);
- Realistic distribution of the remaining fuel among the various cells based on modelling of the fuel tank system;[29]
- Average fuel consumption based on the AFM.

It can be concluded from table 1 and the underlying assumptions and values that:

- HB-HOT's centre of gravity was outside the permissible range at all times between its take-off from Dübendorf on 3 August 2018 and the accident on 4 August 2018.
- Even with the pilots conducting diligent flight preparation, they could not have noticed that the centre of gravity was outside the permissible range. This is due to the incorrect values recorded in the flight planning software and, in turn, to some extent the incorrect values in the AFM.

[29] Modelling of the fuel tank system and of the cell emptying regime was based on the simplified assumption that all 14 cells lie horizontally and are cuboidal, but differ in base area and height, and are vertically tiered following the inclination of the top of the wing. In reality, the cells are shaped rather like sloped, elliptical cylinders. The simplifications between the model and reality are considered permissible for the purpose in question.

A1.6.6.5 Shifting of the centre of gravity by passengers

For the accident flight, simulations were created to determine how the balance would have been affected if certain passengers had moved further back in the aircraft.

Scenario 1: the passenger weighing 99 kg, who was sitting in the front row, goes to the toilet. Result: the centre of gravity shifts backwards by approximately 7 cm.

Scenario 2: the passenger weighing 99 kg, who was sitting in the front row (rear-facing seat), moves to the access door level with row 9 for a view down through the window, which is blocked by the wing from their seat. Result: the balance shifts backwards by approximately 6 cm.

Scenario 3: the passenger weighing 92 kg, who was seated in seat row 4, moves to the access door level with seat row 9 for a view down through the window, which is blocked by the wing from their seat. Result: the centre of gravity shifts backwards by approximately 4 cm.

The problem that the balance can shift backwards by several centimetres in such scenarios and thus fall outside the permissible limits was not addressed in OM-B or the AFM.

In the images and video footage available that had been captured from inside HB-HOT, there was no evidence of anyone moving within the aircraft or not sitting in their seat between the period when the aeroplane entered the basin south-west of Piz Segnas and up to the beginning of its downward spiral trajectory. The video footage revealed that, in particular, the heaviest person on board the aircraft (99 kg) was in their seat in the front row until impact.

A1.6.7 Navigation equipment

Ju-Air's Ju 52 aircraft were fitted with equipment and displays for conventional radio navigation (VOR and DME) as well as a GPS device. However, navigation in the mountainous terrain was carried out by visual clues – either using paper charts or knowledge of the terrain from memory.

HB-HOT's equipment included one copy of each of the following charts and reference books:

- ICAO aeronautical chart, 1:500,000 ("*Switzerland Liechtenstein, Aeronautical Chart ICAO, GND – FL 195, 47th edition, 2018 MAR 29*");
- Military aeronautical chart, 1:500,000 ("*Mil Airspace Chart, 2018 MAR 29*");
- Area chart for Geneva and Zurich, 1:250,000 ("*Zurich Area / Geneva Area, Area Chart ICAO, 1:250,000, GND – FL 195, 9th edition, 2018 MAR 29*");
- 'VFR Manual' from commercial provider Jeppesen including approach and aerodrome charts for Switzerland and surrounding countries.

The first three charts mentioned above covered the area surrounding the accident site. At the scene of the accident, these three charts were found neatly folded in the cockpit pocket provided for the storage of these charts.

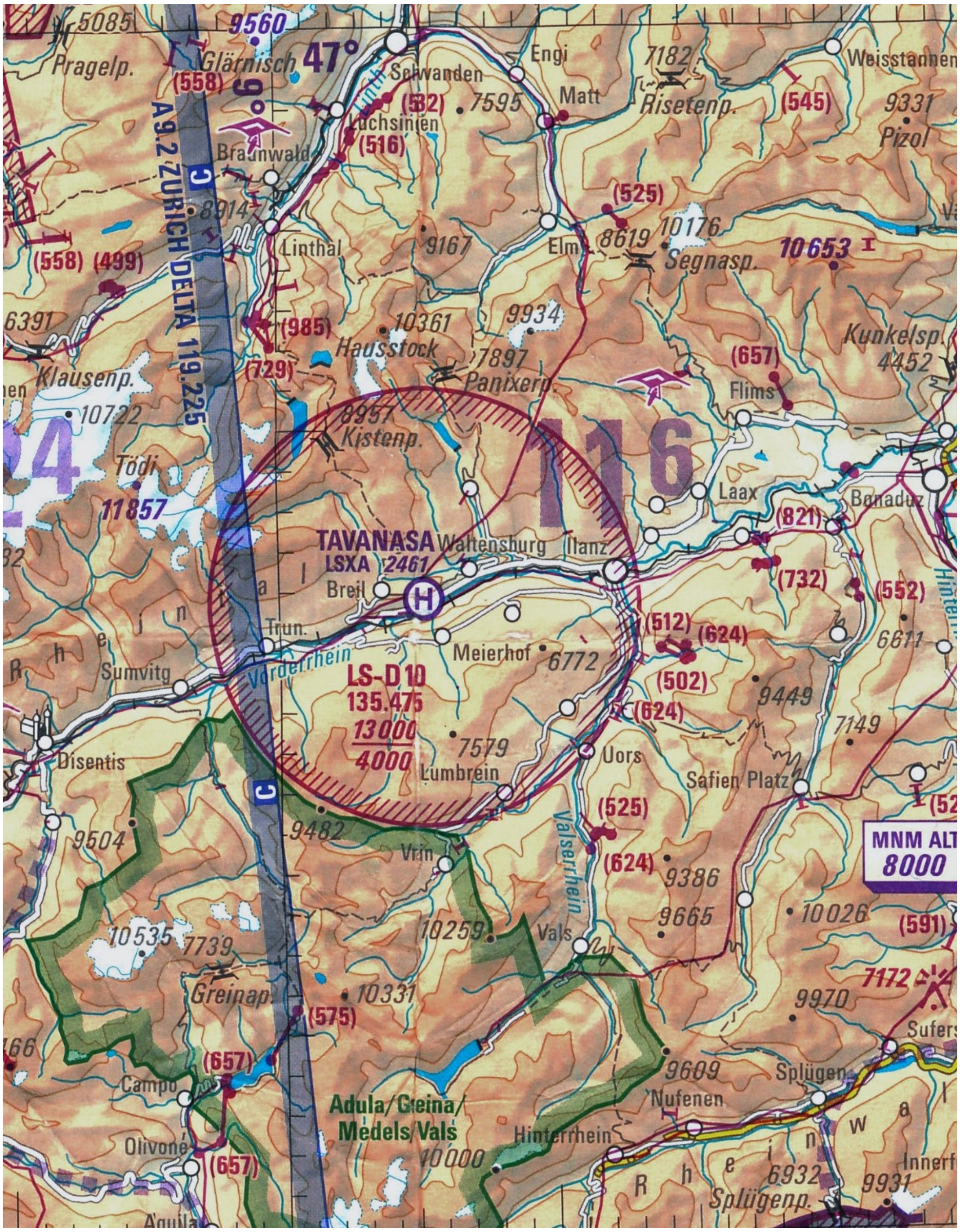


Figure 6: Excerpt (not to scale) from the ICAO aeronautical chart, 1:500,000, on board HB-HOT. Altitude information is given in feet.

HB-HOT's equipment did not include copies of the aeronautical information publication (AIP) of Switzerland, the official VFR Manual for Switzerland (published by Skyguide) or the official VFR-Guide for Switzerland, and these were not on board the aircraft. As specified in section 8.1.14 of OM-A, one copy of the AIP, the VFR Manual and the VFR-Guide should have been on board.

The GPS device that was installed in Ju-Air's Ju 52 aircraft only had a small display. The device was not primarily intended for navigational purposes, but served predominantly to maintain the scheduled flight time.

A1.6.8 Structural features

A1.6.8.1 General information

The type Ju 52/3m g4e aeroplane was developed in Germany as a three-engined aircraft by Junkers Flugzeug- und Motorenwerke AG and had its maiden flight in 1932. The aircraft was made predominantly of Duralumin[30], whilst important connecting pieces were made of high-strength steel. Light cast metal components as well as connection bolts and turned parts made of standard steel were also used in the construction of the aircraft. The Ju 52/3m g4e is an all-metal aircraft, which features an airframe covered in corrugated sheet panelling attached using snap head rivets (solid rivets).

The Ju 52/3m g4e, registered as HB-HOT, originally procured by the Swiss Army as a classroom aircraft, was converted to a passenger aircraft in 1985.

A1.6.8.2 Fuselage

The fuselage consists of four spar caps with fuselage frames perpendicular to the longitudinal axis. The partitioning frames of the fuselage are veed out.

Corrugated sheet metal attached using snap head rivets, which is partially reinforced by stringers, serves as panelling. The fuselage and the centre wing are firmly connected to each other. The ends of the three main, load carrying spars (spars I, II and III) and the auxiliary spar (spar IV) in the centre wing each bear two halves of the ball joints, known as ball sockets, to which the two outer wings are attached.

Both the vertical stabiliser, using four ball joints, and the adjustable horizontal stabiliser are fixed to the end of the fuselage.

The control components in the main usable area are installed in a channel that is easily accessible through hatches. All inspection hatches and covers on the fuselage are attached using quick-release fasteners or countersunk bolts.

A1.6.8.3 Wing

The self-supporting wing of the Ju 52/3m g4e consists of a centre wing and two outer wings. The centre wing is connected to the fuselage to form a single unit. The outer wings are trapezoidal and consist of a fixed main wing and an adjustable auxiliary wing. The outer part of the auxiliary wing is the aileron, and the inner part is the flap. The outer wings are removable, which makes it easier to inspect the inside of the wing and the control components.

The wings are connected to spars I, II, III and IV in the centre wing using eight ball joints (see figure 7). The fuel cells are integrated into the wing and are accessible through hatches on the underside of the outer wings. The spars are composed of a lower and an upper spar tube, which are connected to one another using stiffeners. The spars are connected to each other with cross bracings and struts. The connection points are called joints. The spars consist of several tubes, which are joined together and tapered in diameter towards the wing tip. The spars form a torsion box together with the ribs and the shear-resistant corrugated sheet panelling.

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[30] Duralumin is an aluminium alloy that is stronger and harder than pure aluminium.

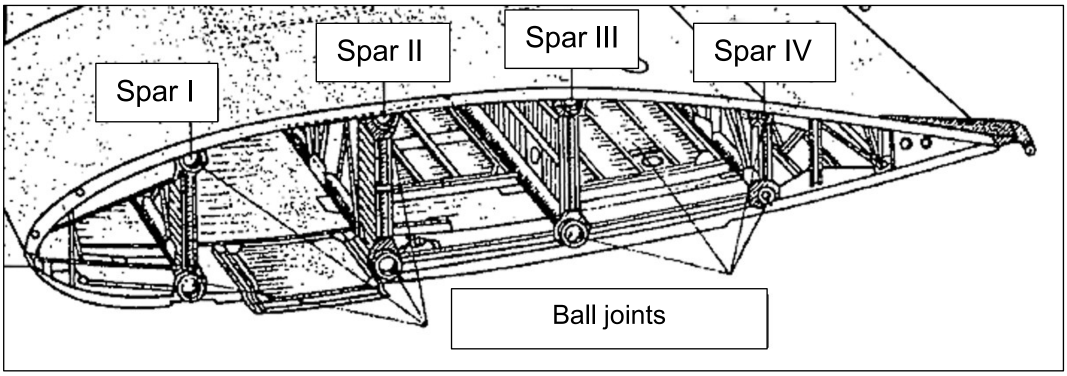
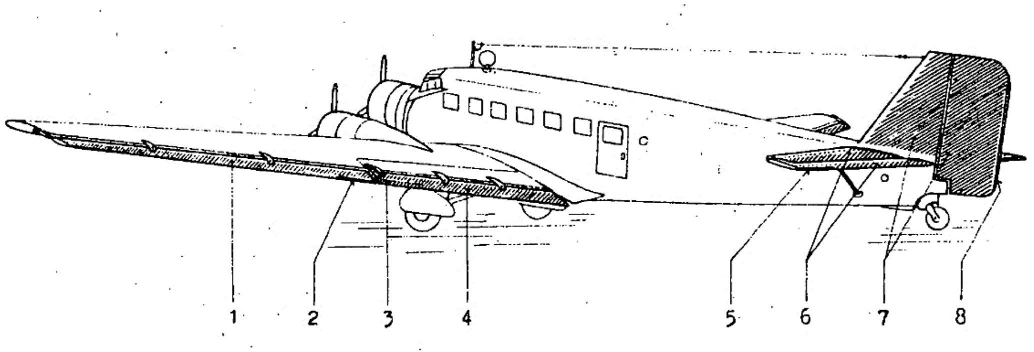


Figure 7: Outer wing including spars and ball joints. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4 Control surfaces

A1.6.8.4.1 General

The control surfaces comprise the horizontal stabiliser (see figure 8), vertical stabiliser, ailerons and adjustable flaps.



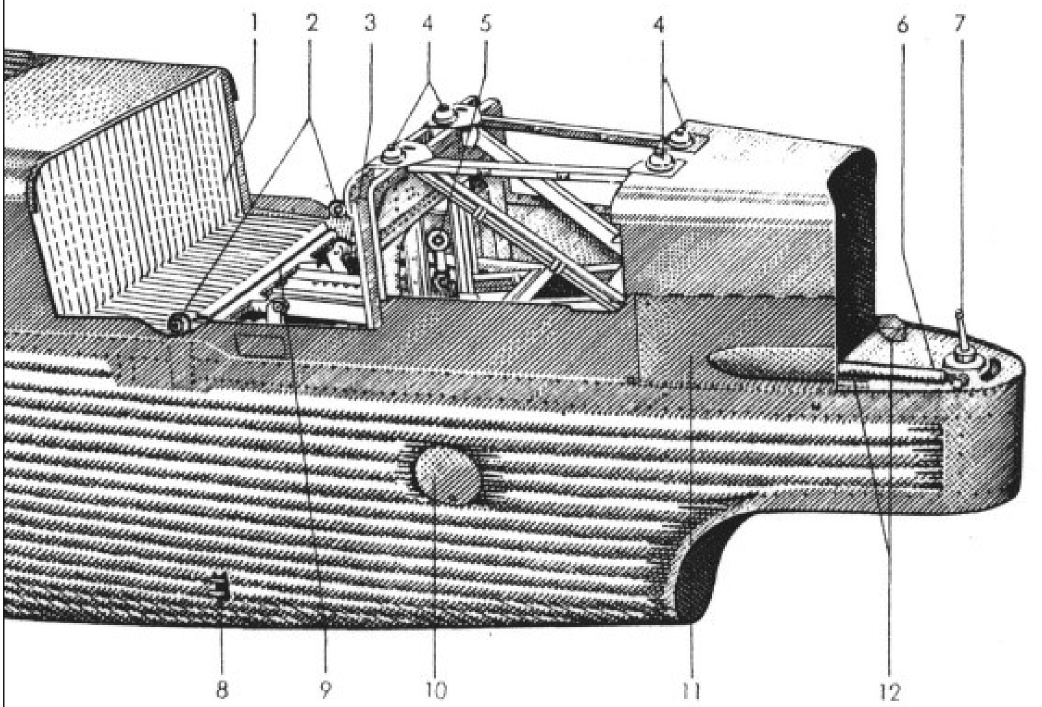
1) Aileron = outer adjustable flap
2) Trim tab for aileron
3) Trim tab for flap
4) Inner adjustable flap
5) Elevator trim tab
6) Horizontal stabiliser
7) Vertical stabiliser
8) Rudder trim tab

Figure 8: Overview of the control surfaces: Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4.2 Horizontal stabilisers

The horizontal stabilisers, which are covered with corrugated sheet panelling, are attached to fuselage frame 8 using two ball bushings (see figure 9, (2)) and each feature a support strut on the respective side of the fuselage. Their angle can be adjusted within a range of +/- 3 degrees. In the centre of each stabiliser, an adjustment spindle (5) is engaged via a push-pull rod.

The horizontal stabilisers are adjusted from the cockpit using a hand wheel. A scale at the end of the fuselage and an indicator on the left-hand side of the cockpit display the angle set for the stabilisers.



1) Aft fuselage frame 8a
2) Opening with ball bushings for horizontal stabiliser
3) Aft fuselage frame 9
4) Ball joint for vertical stabiliser
5) Push-pull rod of the adjustment spindle for horizontal stabiliser
6) Push-pull rod for rudder
7) Bolt for rudder mounting
8) Bracket for horizontal stabiliser support strut
9) Aft fuselage frame 8
10) Hatch with quick-release fastener
11) Hatch with hinge and pin
12) Rudder stop

Figure 9: Mounting of the empennage. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4.3 Elevators

The elevators are covered with corrugated sheet panelling. Each elevator with partial weight compensation is mounted onto three brackets on the respective horizontal stabiliser. Deflections of the elevators are limited in the cockpit by stops on the control column. Both elevators feature trim tabs on the outer trailing edge, which serve to trim small differences in the empennage components.

A1.6.8.5 Controls

A1.6.8.5.1 General

The controls consist of elevator, rudder and aileron controls as well as flap adjustment.

The flaps and ailerons are referred to as the auxiliary wing. The entire structure, including the outer wings, is also referred to as a 'double wing' construction.

The rudder and elevator trim tabs are used to trim the respective stabilisers and are set during maintenance test flights. The aileron trim tabs counterbalance the control force around the longitudinal axis of the aircraft. The flap trim tabs are automatically deployed when the flaps are activated. The aileron and flap trim tabs can only be adjusted on the ground.

The movements from the actuating elements are transferred to the control surfaces using push-pull rods, cables, chains, bevel gears, universal shafts and adjustment spindles. The connecting linkages can be set; the control cables must have the correct pretension.

A1.6.8.5.2 Elevator control

The actuating element for elevator control is the control column in the cockpit. The movement of the control columns is transferred to the elevators purely mechanically using levers, joints, push-pull rods and cables.

The elevator control is set according to set-up diagrams in the operating instructions (see figure 10).

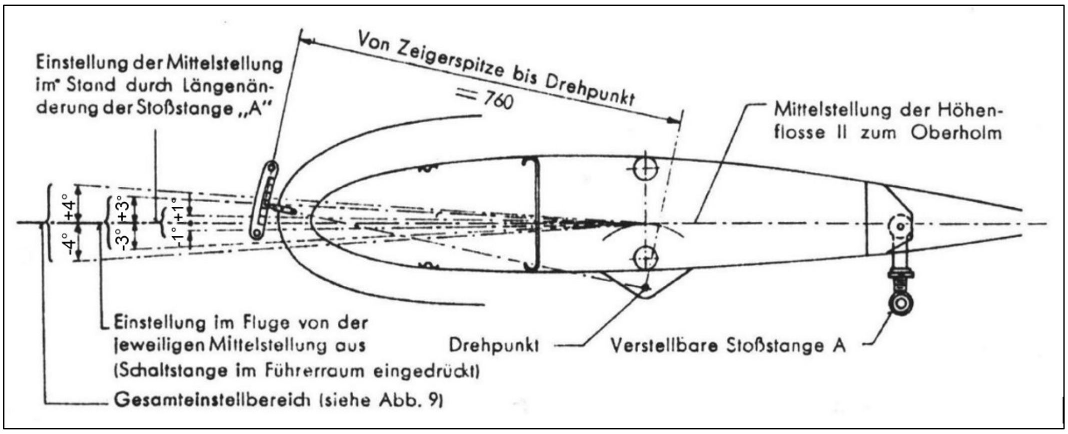


Figure 10: Set-up diagram for horizontal stabiliser. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.5.3 Rudder control

The rudder is operated using a pair of foot pedals, which transfer the pilot's inputs via a bevel gear and other mechanical elements.

A1.6.8.5.4 Ailerons

The ailerons are operated using the hand wheel on the control column in the cockpit. The control input is transferred purely mechanically via joints, push-pull rods and transmission levers.

A1.6.8.5.5 Auxiliary-wing and horizontal-stabiliser adjustment

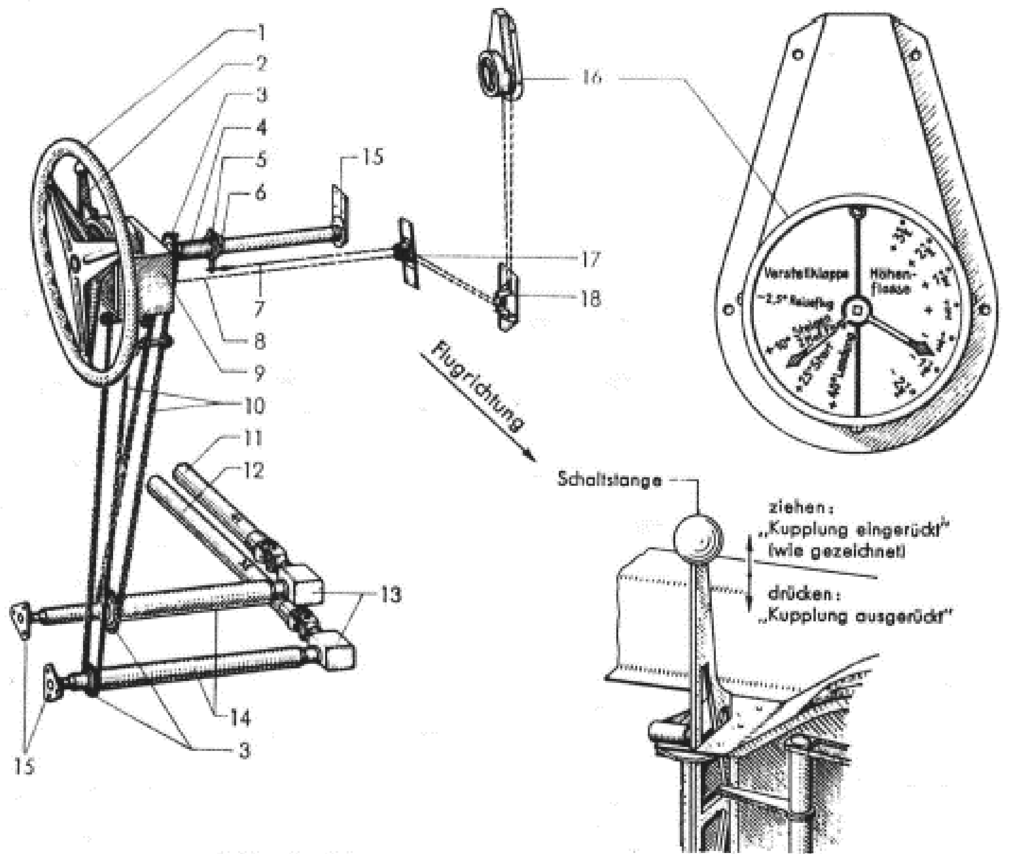
The auxiliary wings, consisting of the flaps and ailerons, as well as the horizontal stabiliser, are adjusted using the device shown in figure 11. It is operated using the hand wheel (1) next to the left-hand pilot seat and transfers the input adjustments via sprockets (3), chains (10), sprocket shafts (14), bevel gears (13), universal joint shafts (11) and (12), push-pull rods with pendulum guide and bell cranks.

The auxiliary-wing adjustment mechanism includes a safety device consisting of a spring assembly and an oil shock absorber. The safety device has the following function: If the dynamic pressure becomes too high when the auxiliary wing is at an angle, the reaction force in the actuating rods becomes greater than the strength of the spring assembly. As a result, the piston in the cylinder of the oil shock absorber slides back until an equilibrium is established between the spring strength and dynamic pressure. The angle of the auxiliary wing is thereby reduced. The oil shock absorber's cylinder thereby has a damping effect and compensates for sudden movements of the flaps.

When the control rod (2) is engaged, the auxiliary wing and horizontal stabiliser are adjusted together when the hand wheel (1) is operated. The control rod can be engaged with the flaps and horizontal stabiliser in any position. When the flaps and horizontal stabiliser are engaged in the zero position, the deflections are as follows:

Flap:	42° = 39°30' downwards + 2°30' upwards
Aileron:	14°30' = 12° downwards + 2°30' upwards
Horizontal stabiliser:	3°30' (for landplanes and seaplanes)

where the hand wheel (1) must make approximately 10½ turns. When the control rod (2) is disengaged (pushed in), the hand wheel can make 18 turns, adjusting only the horizontal stabiliser within a range of +/- 3 degrees. It is not possible to adjust the auxiliary wings alone.



1) Hand wheel
2) Control rod
3) Sprocket
4) Spindle shaft
5) Stop nut
6) Stop pin
7) Cable for horizontal stabiliser position indicator
8) Cable for flap position indicator
9) Control box
10) Chain
11) Universal joint shaft for stabiliser adjustment
12) Universal joint shaft for flap activation
13) Bevel gear
14) Sprocket shaft
15) Mounting
16) Indicator
17) Diverter pulley
18) Cable guide lever

Figure 11: Auxiliary-wing and horizontal-stabiliser adjustment. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

There is an indicator on the left-hand wall in the cockpit (see figure 11, (16)), which displays the position of the flaps and the horizontal stabiliser in degrees. The display is transmitted via cables (7 and 8), which are linked to the stop nuts (5) on spindle shaft (4). The cables (7 and 8) guided over pulleys (17) each engage with a lever for guiding the cable (18) and thus adjust the indicator's spring-loaded needles. In addition, there is another indicator at the end of the fuselage, from which the horizontal stabiliser position can be read.

The horizontal-stabiliser adjustment spindle (see figure 12) is incorporated in the fuselage frame (9). It is adjusted from the cockpit using a hand wheel (see figure 11 (1)), which transfers the inputs via a shaft (15) with a universal joint (14). The horizontal-stabiliser adjustment dimensions, as per the limit positions and zero position of the stabiliser, can be learned from figure 12. The relevant adjustment is made using the push-pull rod sleeve (1) and the locknut (2).

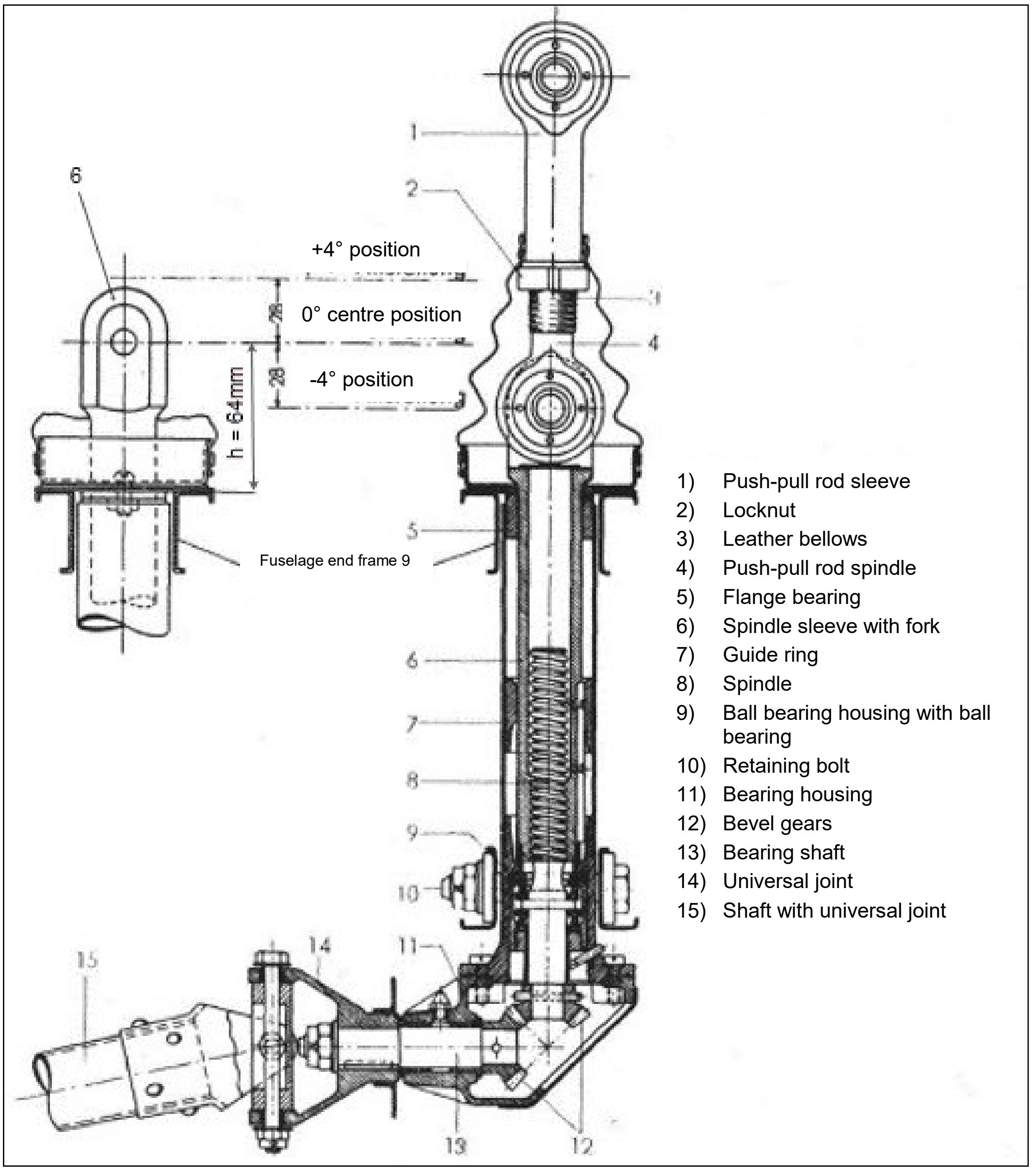


Figure 12: Horizontal-stabiliser adjustment spindle. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

When installing the horizontal-stabiliser adjustment spindle, the spindle sleeve is set to the correct position in line with the operating instructions. With this setting, the distance between the fuselage frame and the point of connection with the horizontal stabiliser (hole in the spindle sleeve's fork) is 64 mm (= h). In this position, the pitch of the horizontal stabiliser and the indicator in the cockpit are then adjusted to an angle of 0 degrees.

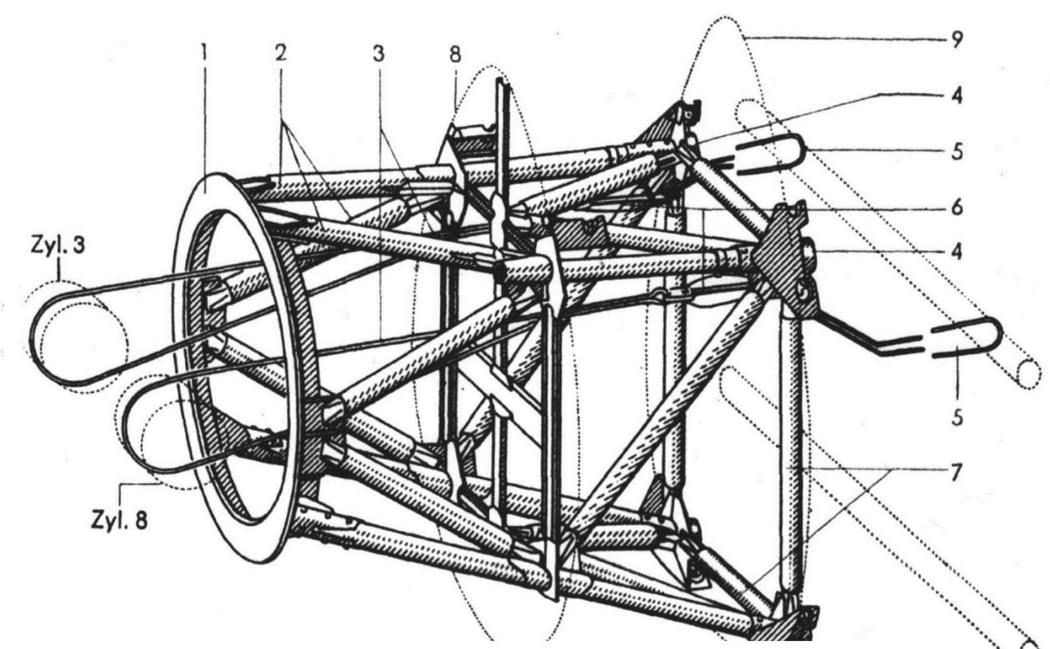
It should be ensured that the spindle sleeve with fork (6), in which the spindle rotates, is almost completely filled with grease at all times.

As specified in section 6.5.1 of the aircraft flight manual (AFM), the horizontal stabiliser must be adjusted based on the take-off mass prior to each flight. These values were also presented in the operational flight plan (OFP).

A1.6.8.6 Engine frame

The engine frames for the three engines are each mounted to the respective outer wing and fuselage connection frame using four ball joints (see figure 13 for the frame used for the left and right engines). They consist of the engine mount including tubular struts, the firewall and safety cables.

The engine mount, to which the engine is fitted, is riveted to the struts of the tubular frame using gusset plates. There are ball joints at the four rear ends of the struts for attaching the engine frame to the respective outer wing and fuselage connection frame.



1) Engine mount
2) Tubular frame
3) Engine safety cable
4) Ball joint
5) Bracket for attaching safety cable to upper spar I
6) Expansion rod
7) Tubular struts of the connection frame
8) Firewall
9) Outer wing connection frame

Figure 13: Engine frame for the left or right engine respectively. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.9 Engines

A1.6.9.1 General

HB-HOT was installed with BMW 132 A, series 3 aircraft engines manufactured by BMW Flugmotorenbau GmbH in Munich. These are air-cooled nine-cylinder radial engines built under licence based on a Pratt & Whitney Aircraft Co. (USA) design that was modified by BMW based on their own experience from 1928 onwards.

The engine is equipped with a supercharger and a carburettor; the auxiliary equipment is mounted on the back of the engine. The propeller is driven directly by the engine's crankshaft. The design of this engine mainly makes use of the metric system.

BMW produced these engines until the end of the Second World War.

The information on the engine is based on the 1938 manufacturer's description and operating instructions for the air-cooled BMW 132 A3 aircraft engine.

A1.6.9.2 Cylinders

The nine air-cooled cylinders are bolted to the crankcase in a star shape. The cylinders consist of a thin-walled steel barrel with cooling fins and a cast aluminium-alloy cylinder head. The cylinder head also features numerous cooling fins. It is bolted onto the barrel when warm. The diameter of the bore when new is 155.56 to 155.60 mm; the wear limit is 155.80 to 155.90 mm. According to the operating instructions, a cylinder must be replaced with a new component when the wear limit is reached. The manufacturer also states that it is not permitted to re-bore the cylinder.

A1.6.9.3 Cam discs

The intake and exhaust valves of the radial engine are controlled by the cams on cam discs using a series of tappets, push-pull rods and rocker arms.

The cam disc for the exhaust valves and the disc for the intake valves each have four cams.

The cam discs are part of the cam drum. The cam drum is driven by the crankshaft via a gear transmission; it rotates in the opposite direction to the crankshaft at ⅛ of the crankshaft's speed. Each valve is actuated one after the other by the four cams.

A1.6.9.4 Magnetos

The air-fuel mixture is ignited in the cylinder by two spark plugs located in the cylinder head. The voltage required for this is supplied by two magnetos, which are mounted on the auxiliary equipment carrier of each individual engine. In each case one spark plug from each cylinder is connected to one of the two magnetos, so that – even if one magneto fails – proper ignition is guaranteed. However, the engine speed must not drop by more than 50 rpm.

A coupling is fitted between the gearbox in the auxiliary equipment carrier and the magneto to prevent damage to the gearbox in the event of a blockage in the magneto. As part of service bulletin no. 1025, four steel cams were soldered onto the sleeves of these couplings (see section A1.6.17.2.7). These generate the pulses in the proximity switches for the electronic tachometers.

The magnetos are designed for a nine-cylinder engine. The ignition sequence is determined in the magneto. In normal operation, the magneto permanently works in early ignition mode.

A1.6.9.5 Carburettors

A1.6.9.5.1 General

The BMW 132 A3 engine is fitted with a dual carburettor manufactured by Pallas with the part number NAY-9 A (see figure 14). This design is based on a licence from Stromberg and features the following:

- Fuel efficiency regulation
- Altitude control regulation
- Accelerator pump

These systems ensure that the engine receives the correct fuel mixture to ensure good efficiency at low cylinder temperatures under various working conditions and in different flight situations.

Since the nozzle setting suitable for proper operation of the engine has been determined as a result of extensive testing, modifications should only be made when sufficient test data are available to assess the nature and extent of the modification with certainty.

The purpose of the fuel efficiency regulation is to adjust the fuel mixture when cruising at medium load in order to achieve efficient fuel consumption; this same system also allows the engine to operate at high load for a short period of time without unacceptable increases in cylinder temperature by enabling more fuel to be used.

The altitude control mechanism adjusts the air-fuel mixture to the most efficient consumption, in order to counteract the mixture becoming richer as altitude increases.

The accelerator pump ensures that when the butterfly valve is opened quickly, and the engine speed increases accordingly, the required larger quantity of fuel enters the carburettor's air funnel.

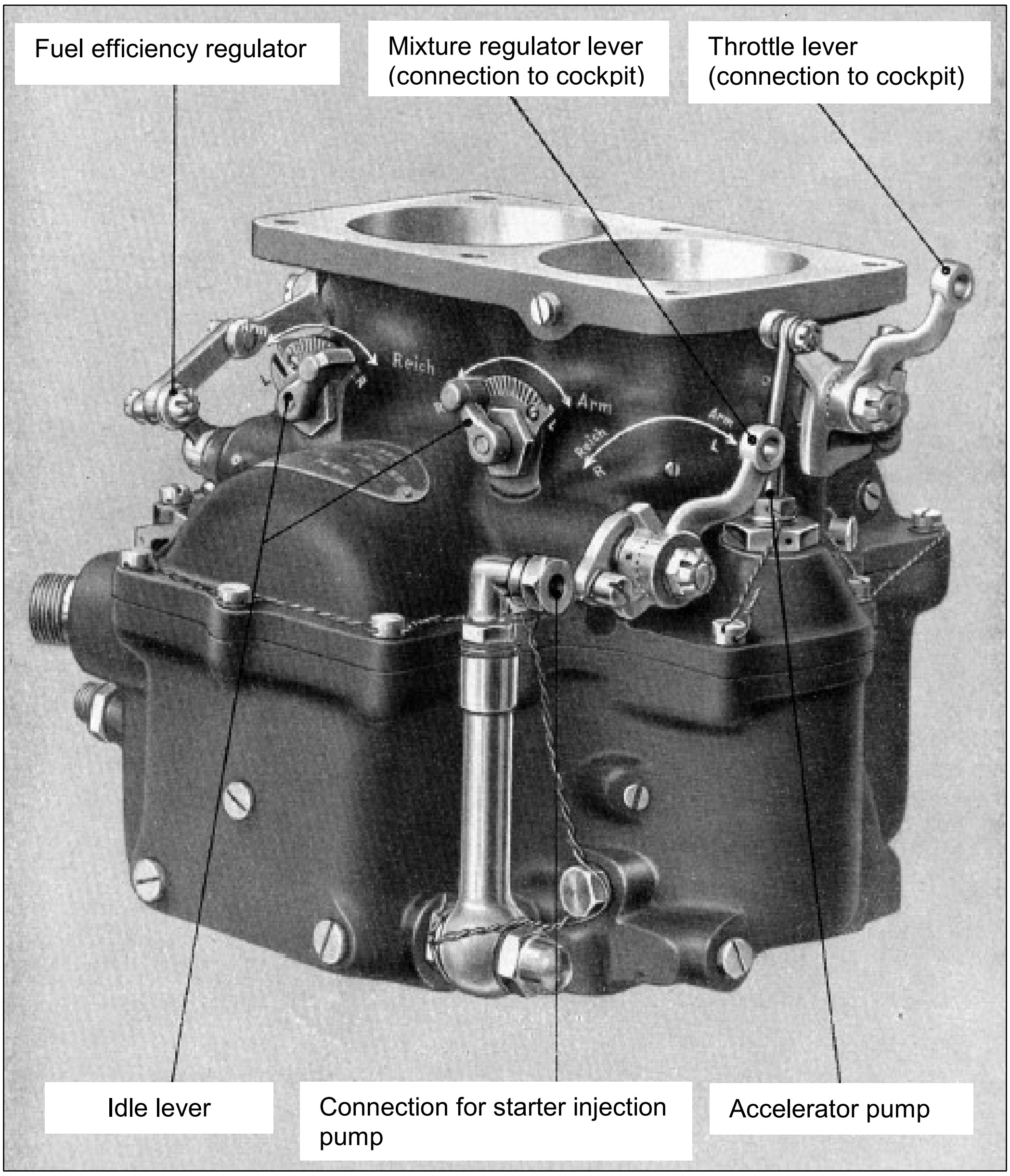


Figure 14: Pallas dual carburettor. Source: "*Betriebsanleitung des BMW-132-A3-Motors*" (instruction manual).

A1.6.9.5.2 Accelerator pump

In order to supply the engine with the larger quantity of fuel required when the engine speed is rapidly increased, the carburettor is equipped with an accelerator pump.

The accelerator pump is located in the lower part of the carburettor and consists of a pump cylinder in which a piston moves vertically. The lift rod of the piston is connected to the throttle lever by a linkage. The accelerator-pump piston's stroke from the 'fully closed' to 'fully open' throttle positions is about 24 mm.

A1.6.9.5.3 Adjusting the idle air-fuel mixture

The idle air-fuel mixture and idle engine speed are adjusted at the carburettor when the engine is warm. The air-fuel mixture is adjusted to be as rich as possible. The idle engine speed is set using the adjusting screw on the butterfly valve lever. Further basic settings on the carburettor are not possible.

A1.6.9.6 Supercharger

A1.6.9.6.1 General

The air-fuel mixture produced in the Pallas dual carburettor is drawn into a supercharger via an oil-heated preheater and fed to the individual cylinders under pressure. The supercharger is a single-stage turbo compressor with a radial design.

A1.6.9.6.2 Functionality

The supercharger shaft is driven by the rear end of the crankshaft via a transmission gear. This increases the speed of the supercharger shaft to 10 times the engine speed. A reliably functioning supercharger is essential for safe engine operation. The selection, lubrication and sealing of the high-speed rolling bearings for the supercharger shaft must be suitably exacting.

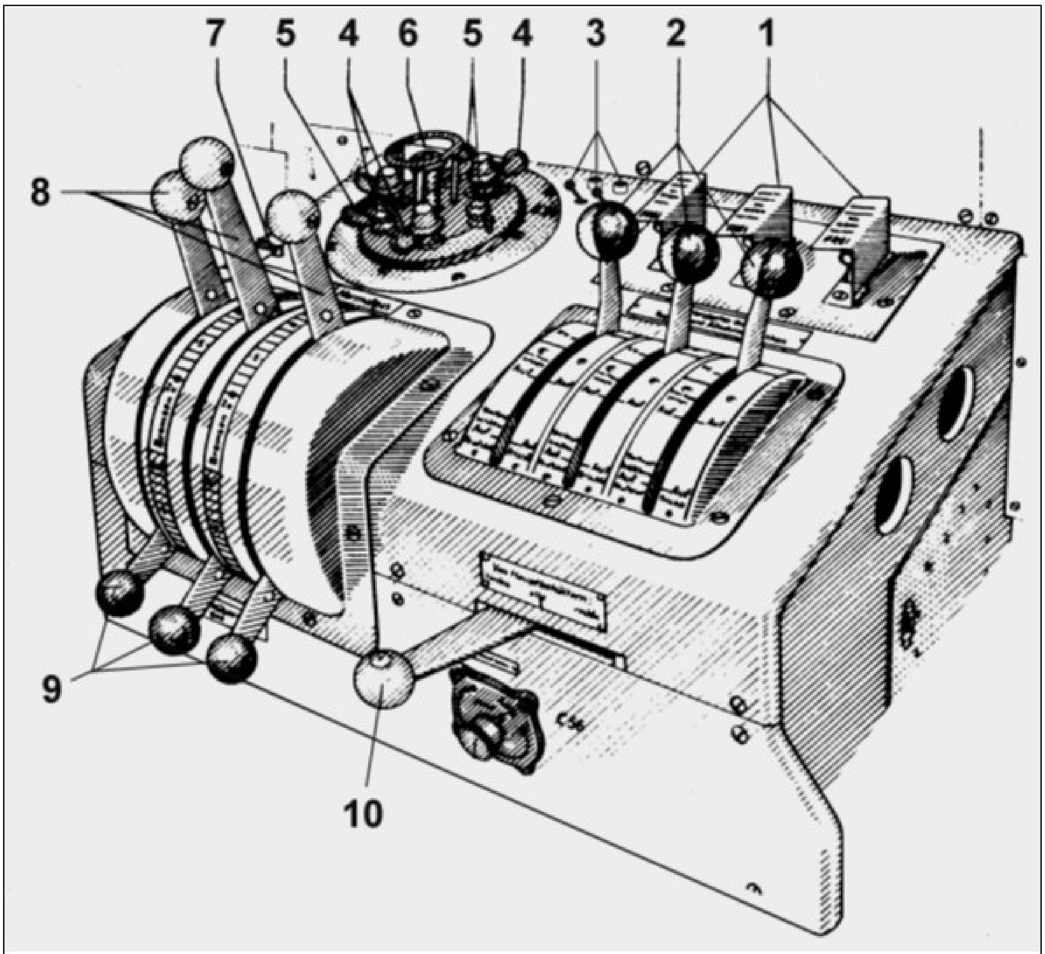
A1.6.9.7 Engine power controls

A1.6.9.7.1 General

The levers, switches, knobs and hand wheels required to operate the engines are located on the control panel (see figure 15) in the centre of the cockpit, to the left and right of it and on the equipment panel.

The main throttle levers (8) and high-altitude throttle levers (9) are located on the left-hand side of the control panel.

When set to ‘on’, the full-throttle limiter (7) restricts the travel of the main throttle lever (8), and when set to ‘off’ it allows the lever to travel fully.



1) Starter switch
2) Valve-battery lever (oil-fuel selector)
3) Booster-pump switch and lights
4) Ignition switch
5) Early/late ignition adjuster
6) Main ignition switch
7) Full-throttle limiter
8) Main throttle levers
9) High-altitude throttle levers
10) Fuel cell selector

Figure 15: Control panel for the Ju 52/3m g4e. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

From the control levers and hand wheels mounted in the cockpit, the movement is transmitted to the engines, switching units, etc. by linkages consisting of rods and cables.

The travel of the three main throttle levers as well as the three high-altitude throttle levers is transferred to the butterfly valve and the carburettor's mixture control via a system of rods, joints and bell cranks.

When removing rods, the adjustable rod ends must not be changed in length. If this has been done, the linkage must be readjusted so that the positions of the control levers on the cockpit control panel correspond to the positions of the end levers.

A1.6.9.7.2 Main throttle lever and its adjustment

The carburettor's butterfly valve is actuated via adjustable linkages using the main throttle lever on the control panel. With the butterfly valve fully open, the power output at a CINA[31] normal atmosphere of 0 (760 mm Hg, 15°C) is 725 PS at 2,050 rpm. As the engine is subject to excessive thermal stress when the butterfly valve is fully opened at altitudes below 900 m AMSL, it may only be operated with a fully-opened[32] butterfly valve in exceptional cases. For this reason, the travel of the main throttle lever is limited by a full-throttle limiter. When the full-throttle limiter is set to ‘on’, the main throttle lever cannot travel to its full extent (see figures 16 and 17). On the other hand, when set to ‘off’ the main throttle lever can travel to its full extent and the butterfly valve can be opened fully. This is called the full-throttle position. The travel of each main throttle lever is limited by adjustable stop bolts.

The full-throttle limiter on Ju-Air aircraft could be secured in the ‘on’ position using a copper wire and a lead seal. Turning the full-throttle limiter to ‘off’ breaks the seal. The aircraft manufacturer never provided for such a safety device. According to Ju-Air, this safety device had been installed since about 1995 to monitor the pilots, as the full-throttle limitation had been repeatedly deactivated. Each broken seal had to be recorded in the tech log and justified by the pilot.

According to the operating instructions, there is a mark on the carburettor for correctly adjusting the main throttle lever with the full-throttle limiter set to ‘on’. With the throttle not fully opened, the engine speed should not exceed 1,965 rpm at a CINA standard atmosphere of 0. When passing the limit stop, the engine should deliver the short burst of increased power at 2,050 rpm below 900 m AMSL and the short burst of power at 2,050 rpm above 900 m AMSL.

[31] CINA: *Commission Internationale de Navigation Aérienne*, International Commission for Air Navigation (ICAN). CINA was replaced by the International Civil Aviation Organisation (ICAO).

[32] When the butterfly valve is fully open, the valve is at an angle of 10 degrees from vertical.

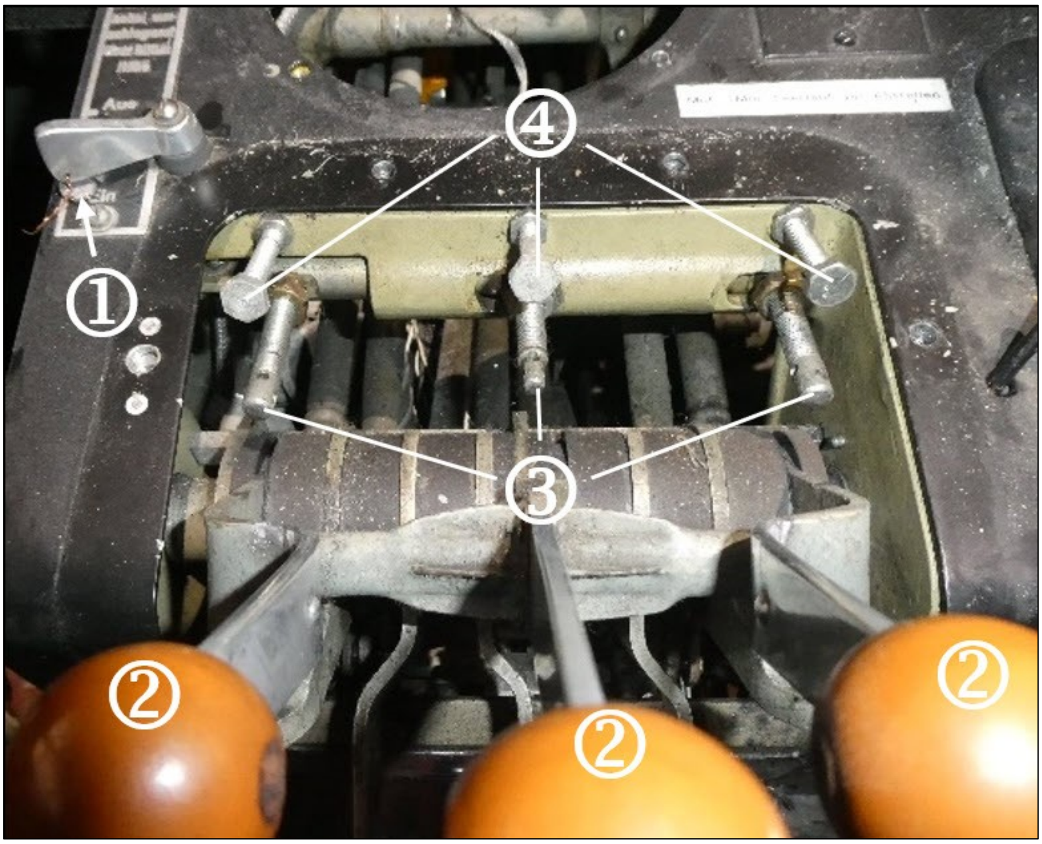


Figure 16: Full-throttle limiting mechanism in the ‘on’ position. Full-throttle limiter with lead-sealed wire lock (1); main throttle levers (2); stop bolts for full-throttle limiting (3); stop bolts for full throttle (4).

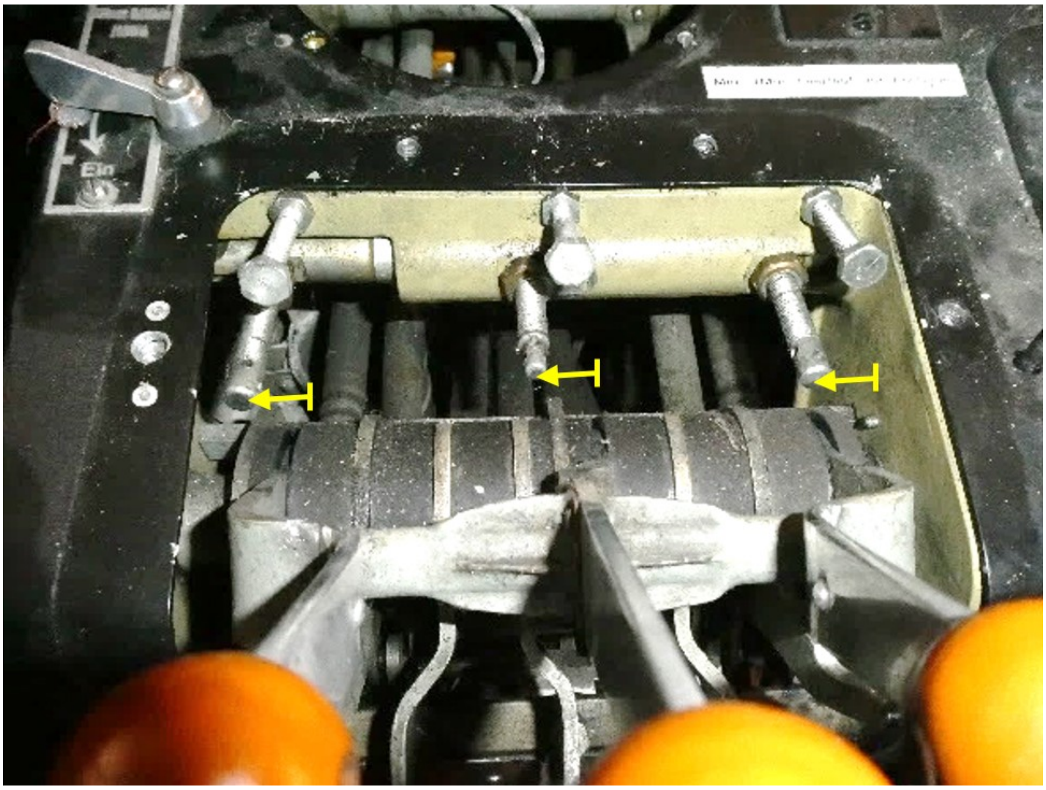


Figure 17: Full-throttle limiting mechanism in the ‘off’ position. Stop bolts for full-throttle limitation are moved to the left (yellow arrows).

A1.6.9.7.3 Altitude control regulation and its adjustment

With increasing altitude, i.e. decreasing air density, the air-fuel mixture becomes richer. In order to avoid an excessive increase in fuel consumption, the carburettor is fitted with altitude control regulation.

The altitude control regulation is operated by the pilots using the high-altitude throttle levers.

When adjusting the high-altitude throttle, it has to be ensured that the corresponding high-altitude throttle lever on the control panel is in the 'rich mixture' position when the adjustment lever on the carburettor is in the 'R' position, i.e. rich.

A1.6.10 Engine power

A1.6.10.1 Performance data terms defined by the manufacturer

The following information on the engine is based on the 1938 manufacturer's description and operating instructions for the air-cooled BMW 132 A3 aircraft engine:

"All power output values in PS are to be understood as the useful power available at the propeller shaft.

I. Full power Normal 0

is the net power the engine delivers at a CINA standard atmosphere of 0, i.e. air pressure of 760 mm Hg and + 15 °C, at full-throttle and for the maximum permissible operating speed (short-burst speed), if the engine were allowed to run at such high loads. (In urgent cases, it may be used for the BMW 132 A for take-off as a short burst of increased power up to a maximum duration of 1 minute).

II. Operational power outputs

are the maximum net power ratings permitted for certain specified operating modes. They are limited

1. *by the charging pressures given for the operating mode and the respective flight altitudes.*
2. *by the maximum engine speed selected for the operating mode and/or by the attainable take-off speeds in horizontal flight whilst maintaining the prescribed charging pressures below the short-burst power altitude with a fixed-pitch propeller.*

For flight operations, the following marginal power operating modes have been defined.

a) *Short-burst power is the maximum power drain permitted for the flight operation. It may only be used for the shortest possible time (maximum 5 minutes) during take-off and in case of an urgent need of power.*

b) *Increased continuous power is permitted only when necessary for accelerated climbing and in special cases, but must be limited to a maximum of 30 minutes.*

c) *Continuous power is the maximum permissible continuous load on the engine.*

d) *Recommended cruise power is the power level at which the engine operates most efficiently in terms of both fuel consumption and service life.*

III. Full-power altitude is the altitude at or above which the engine is permitted to run with the throttle fully open when at normal atmosphere. However, except for short bursts of power, the full power possible at this altitude can only *be fully utilised for engine speeds below this level with a freely variable propeller.*

IV. *Take-off engine speeds are those speeds which are reached in horizontal flight at altitudes below the short-burst power altitude at the relevant stipulated charging pressures and normal atmosphere with a fixed-pitch propeller."*

A1.6.10.2 Performance data from the engine manufacturer

The BMW 132 A3 engines are designed as high-altitude engines with enlarged air nozzles. Operation of the engine with fully opened butterfly valve and at 2,050 rpm is only permitted starting at an altitude of 900 m AMSL and for a maximum period of five minutes when using a fixed-pitch propeller. This is called short-burst-power operation. As the engine is subject to excessive thermal stress when the butterfly valve is fully opened at altitudes below 900 m AMSL, it may only be operated in this range with a fully-opened butterfly valve in exceptional cases (see table 2). The engine manufacturer has defined corresponding limit values for the maximum engine speeds in the different operating modes depending on the flight altitude (see figure 18).

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,965	2,050
Increased continuous power up to 30 minutes	1,890	1,975
Continuous power	1,850	1,930
Cruise power	1,785	1,860

Table 2: Power limits according to engine manufacturer.

According to the engine manufacturer's specifications, the engine's power output is 725 PS at 2,050 rpm. This is valid at a fully opened butterfly valve and CINA normal atmosphere at sea level (760 mm Hg, 15 °C). This power is called short-burst increased power and may be used in urgent cases for take-off as a short burst of increased power for up to a maximum of one minute.

The engine delivers 660 PS with the butterfly valve fully open at an altitude of 900 m AMSL at normal atmosphere (684 mm Hg, 9 °C). For this, the engine speed is 2,050 rpm. This output is referred to as short-burst power.

The engine manufacturer has defined the permissible deviations for power and engine speeds as follows:

Power: + 4 % to – 2 % Speed: +/- 2 %

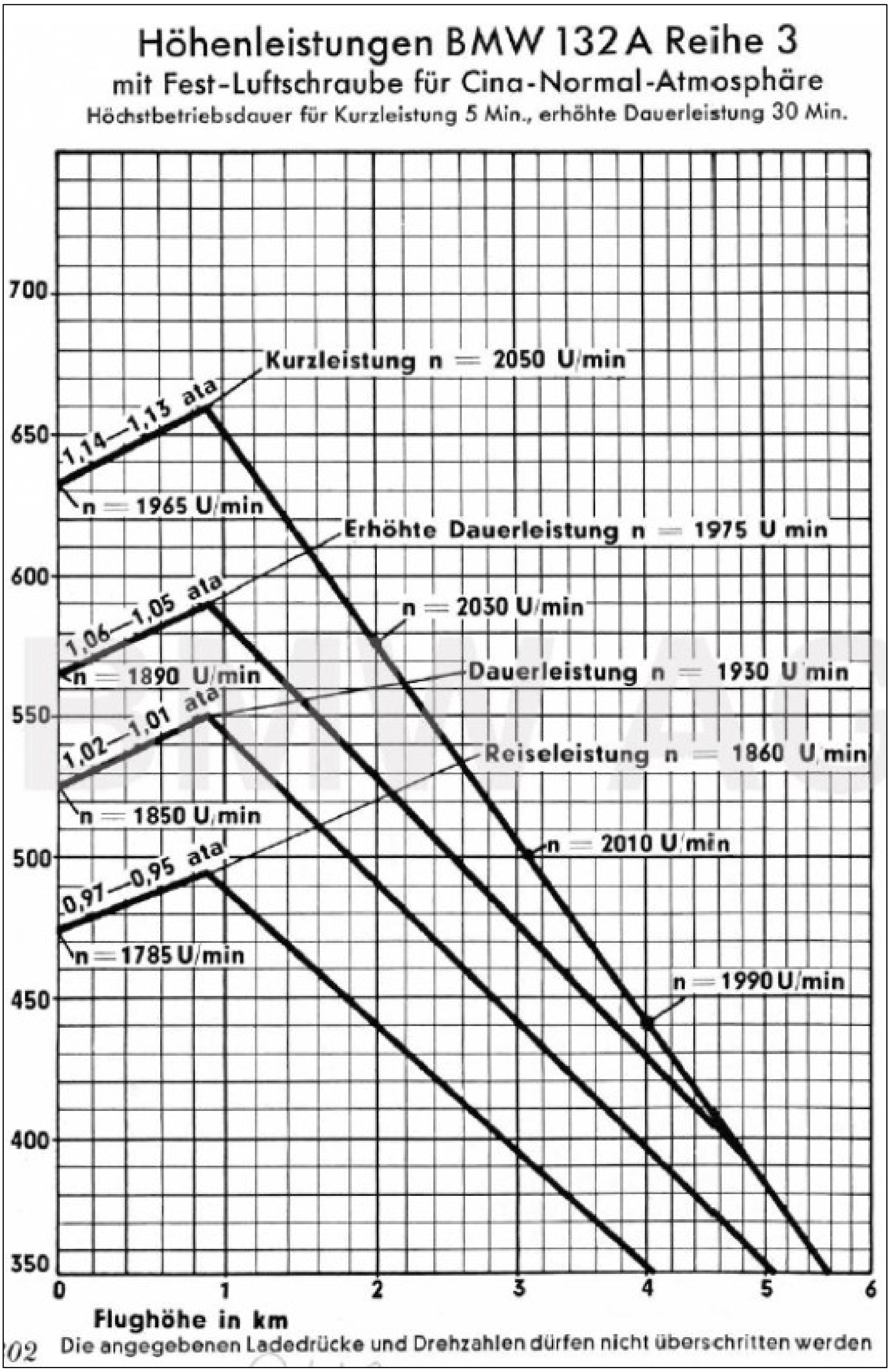


Figure 18: Altitude performance for the BMW 132 A3 aircraft engine. Source: "*Betriebsanleitung des BMW-132-A3-Motors*" (instruction manual).

A1.6.10.3 Guidelines for the inspection of engines

In 1937, the then Reich Minister of Aviation published the test data for the BMW 132 A3 engine via the aircraft testing institute on an engine test stand. According to these specifications, the following must be demonstrated when testing the engine on the test bench:

Power description	Power	Duration
Short-burst increased power	725 PS at 2,050 rpm	5 minutes
Short-burst power	660 PS at 1,990 rpm	15 minutes
Increased continuous power	590 PS at 1,925 rpm	105 minutes
Continuous power	520 PS at 1,850 rpm	–

Table 3: Engine test data for use in verification inspections.

During this test, the charging pressure, the specific fuel consumption and, for increased continuous power, the specific amount of lubricant consumed should also be measured. Limit values were defined for the measured data.

The above performance data refer to performance at CINA standard atmosphere. In places where the above values are not achieved despite a fully opened butterfly valve, the measured value can be calculated based on normal conditions.

For full power – which in the above list corresponds to the short-burst increased power of 725 PS – the aircraft testing authority specified a power tolerance of +/- 2.5 % and an engine speed tolerance of + 100 to - 60 rpm.

A1.6.10.4 Performance data from the aircraft manufacturer

A1.6.10.4.1 Operating data table

On the left-hand side of the fuselage in the cockpit, there was an operating data table with the permissible operating values (see table 4). These were supplied by the aircraft manufacturer in 1939.

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,950	2,050
Increased continuous power up to 30 minutes	1,900	1,975
Continuous power	1,850	1,930
Cruise power	1,775	1,850

Table 4: Values from the Junkers operating data table from 1939.

A1.6.10.4.2 Engine speeds in flight operation

In section 10, 'Flight operation', of the operating instructions for the Ju 52/3m g4e, the following information is given regarding engine speeds during the various flight phases:

"Take-off

[…]

Stop lever for main throttle on the left-hand side of the control panel set to 'on'.

Accelerate at a good pace until the 'up' stop.[33]

1-minute power, engine speed n = 2,050 rpm.[34]

[…]

After 1 minute back off the throttle to 30-minute power:

Engine speed n = 1,950 rpm[35] *at alt. = 0–900 m*

n = 2,050 rpm[36] *at alt. = over 900 m.*

Climb

[…]

After completing 1-minute power, switch to 30-minute power.

[…]

Cruise

Best altitude for cruising flight approximately 1,000 m

Engine speed at continuous power n =1,925 rpm

Engine speed in cruise flight n =1,850 rpm.

Cruising speed

V_a[37] *= 240 km/h at an altitude of 500 m*

V_a *= 220 km/h at an altitude of 2,500 m*

V_a *= 175 km/h at an altitude of 5,000 m*

[…]

I. Engine failure

In the event of one engine failing, there is enough power to continue the flight. Please note the following points:

[…]

3. *Open the main throttle levers of the healthy engines to full-throttle, regardless of altitude."*

The permissible operating values of the engines are marked on the display units by red lines or by luminous material.

---

33 Here it is to be understood that the throttle levers must be moved 'up' until the full-throttle limit is reached.

34 If necessary, the limit stop can be disengaged to use the maximum speed of 2,050 rpm for one minute.

35 Short-burst power up to five minutes at an engine speed of 1,950 rpm, as per the operating data table.

36 Short-burst power up to five minutes at an engine speed of 2,050 rpm, as per the operating data table.

37 V_a: Indicated airspeed

A1.6.10.5 Verification flights during acceptance of the aircraft

In a total of four flights between 29 September and 4 October 1939, a Swiss delegation measured the performance of one of the three Ju 52/3m g4e aircraft ordered at the airfield in Dessau where Junkerswerke was based. Based on previous inspection flights with the two aircraft bearing serial numbers 6580 (later HB-HOS) and 6595 (later HB-HOT), the aircraft with serial number 6580, which was assessed as less powerful, was designated as the aircraft to be used during the performance measurements.

The performance flights were carried out with a mass of 10,000 kg. The three propellers had the following pitches:

Left propeller	Centre propeller	Right propeller
21°	20.5°	21°

The performance flights included in particular:

- Horizontal speed close to ground level
- Climb to service ceiling
- Take-off and landing measurements

In summary, the following performances were measured:

Altitude [m AMSL]	Climbing time [min.]
0–1,000	4.7
0–2,000	9.3
0–3,000	15.2
0–4,000	24.6
0–5,000	42.2

Table 5: Logged climbing times during acceptance.

Climbing measurements with flap position set to 11 degrees:

Flying altitude	Indicated airspeed	Climbing speed	Engine speed left engine	Engine speed centre engine	Engine speed right engine
[m AMSL]	[km/h]	[m/s]	[rpm]	[rpm]	[rpm]
1,000	155	3.55	1,760	1,835	1,790
2,000	153	3.10	1,770	1,840	1,790
3,000	152	2.25	1,770	1,835	1,800
4,000	145	1.40	1,760	1,830	1,760
5,000	142	0.60	1,760	1,820	1,760

Table 6: Logged climbing measurements during acceptance.

Maximum speed at 1,000 m AMSL:

- v_{max} 271 km/h

Take-off and landing measurements:

- Length of take-off run until lift-off: 293 m
- Distance required to standstill after landing: 351 m

Further informative performance data taken from the extensive flight logs are listed below.

Speed measurements taken at 150 to 180 m AMSL with various engine speeds:

Engine speed [rpm]	V_a [km/h]
1,450	160
1,650	200
1,860	250

Table 7: Logged speeds at different engine speeds

A1.6.10.6 Performance data in the aircraft flight manual

A1.6.10.6.1 General

The aircraft flight manual *(*AFM) written by Ju-Air was based on the manufacturer's operating instructions for the aircraft. At the time of the accident, the AFM with revision 11 dated 1 June 2017 was valid.

A cover sheet dated 1 December 1997 had been inserted into section 10, 'Flight operations', of the operating instructions, stating:

"*The original information is purely informative. The mandatory procedures can be found in the current manuals, such as the AFM, FOM, MOE and the aircraft maintenance programme.*"

A1.6.10.6.2 Operating data table

The permissible operating values were published in section 5.8.2, 'Operating data table', of the AFM (see table 8).

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,950	2,050
Increased continuous power up to 30 minutes	1,900	1,975
Continuous power	1,850	1,925
Cruise power	1,750	1,850
Throttled glide	–	max. 2,250

Table 8: Values from the operating data table in the AFM.

A1.6.10.6.3 Engine speeds in flight operation

In sections 3, 4 and 5 of Ju-Air's AFM, revision 11 dated 1 June 2017, the following information regarding engine speeds in the various flight phases is given:

"*4.10.6 Take-off*

[…]

After the brake is released by the PIC, the pilot flying (PF) pushes the throttle levers forward slightly, so that all 3 engines develop power evenly without stuttering.

He then increases the output smoothly up to max. 1,800 rpm.

[…]

4.10.7 Climb

After lift-off, increase speed V_2 (flaps at 10 degrees) and reduce engine speed to 1,750 rpm (PIC) at the same time. For light aircraft or noise sensitive areas (e.g. Dübendorf) 1,700 rpm is sufficient.

[…]

The PF instructs the PNF to retract the flaps and to set the desired engine speed (1,700–1,750 rpm). The PNF retracts the flaps and synchronises the desired engine speed.

[…]

5.7 Cruising flight

The best altitude for cruising flight is approximately 3,000 ft AMSL

Engine speed at continuous power	*1,850 rpm*
Engine speed at cruise power	*1,750 rpm*

Cruising speed

V_a = 200 km/h at an altitude of 500 m

V_a = 170 km/h at an altitude of 2,500 m

V_a = 140 km/h at an altitude of 5,000 m

4.11.9 Cruise flight check

1.	*PNF*	*Engine speed as per PF's instruction*	*1,650–1,750 rpm set and synchronise*

[…]

3.7.4 Engine failure in flight

1.	*PF*	*Throttle lever of the failing engine*	*Idle*
2.	*PF*	*Engine speed of engines still running*	*Increase, 1,750–1,800 rpm (depending on requirements)*

[…]"

A1.6.10.7 Inspection of engines after major overhaul

A1.6.10.7.1 General

Between 2010 and 2016 the three engines, which were mounted on HB-HOT at the time of the accident, had been subjected to a major overhaul, carried out by Naef Flugmotoren AG. After an overhaul, the engine was brought to a company in Germany for inspection on the test bench. The measured values from the test run, which lasted several hours, were recorded in a test log and evaluated by the tester.

The test run carried out did not meet the specifications listed in section A1.6.10.2.

The test log was not self-explanatory, units were incorrect or missing. The log was not filled out completely.

In parts, the evaluation of the measured data was incomprehensible or wrong.

The logs did not contain any references or information on test requirements or tolerances.

The test results did not indicate whether the test requirements were met.

A1.6.10.7.2 Test results of the engines

After the respective major overhaul at Naef Flugmotoren AG, a performance test with fully open butterfly valve was carried out on the engines by a company in Germany. For the test of the right engine dated 28 June 2016, the engine was fitted with a different carburettor. From the logged measurements, the STSB has determined the following performance values based on the calculation formulas (modalities) given by the engine manufacturer:

	Actual engine speed[1)] [rpm]	Actual power[2)] [PS]	Actual power[3)] [PS]	Test run date
Left engine	1,996	666	606	12 Oct. 2010
Centre engine	2,030	711	647	17 April 2013
Right engine 1st test run 2nd test run	 2,038 2,027	 708 698	 644 635	 27 June 2016 28 June 2016

Table 9: Determined performance values for the engines during the test run after the respective major overhauls.

1) Target engine speed: 2,050 rpm

2) Target power: 725 PS at CINA standard atmosphere (760 mm Hg, 15°C)

3) Target power: 660 PS at 900 m AMSL (684 mm Hg, 9°C)

A1.6.10.8 Static test runs before and after maintenance work

During the period from 14 May 2018 to 26 July 2018, Ju-Air carried out maintenance work on HB-HOT's three engines on several occasions; this included static engine test runs. Prior to the work commencing, all three engines were subjected to a static pre-inspection test run (see table 10). After completing the work, the engine on which maintenance work had been carried out was subjected to a static post-inspection test run.

The engine speeds were measured with the main throttle lever in the following positions.

- Position until full-throttle limit, i.e. full-throttle limit 'on'
- Full-throttle position, i.e. full-throttle limit 'off'
- Idle position

The values measured during the respective static test runs were recorded in a static test log. The target values and their tolerances of the variables to be measured were neither stated on the test log nor in other static test documents.

Depending on the habit of the person, the engine speed values were read and recorded using the digital values indicated on the tachometers or the dials. Below are the engine speeds recorded during the static test runs with the full-throttle limiter set to 'on' and 'off'.

		Engine speed [rpm]		
Date	**Full-throttle limiter**	**Left engine**	**Centre engine**	**Right engine**
14 May 2018 Pre-inspection test	On	1,750	1,760	1,730
	Off (full-throttle)	1,880	1,870	1,840
25 May 2018 Post-inspection test	On	1,770	1,760	1,740
	Off (full-throttle)	1,900	1,880	1,860
18 June 2018 Pre-inspection test	On	1,750	1,770	1,750
	Off (full-throttle)	1,880	1,880	1,880
22 June 2018 Post-inspection test	On	–	–	1,710
	Off (full-throttle)	–	–	1,820
23 July 2018 Pre-inspection test	On	1,770	1,760	1,710
	Off (full-throttle)	1,890	1,860	1,810
26 July 2018 Post-inspection test	On	1,800	–	–
	Off (full-throttle)	1,910	–	–

Table 10: Recorded static-test engine speeds from the last three months before the accident.

A1.6.10.9 Technical inspection flights

A1.6.10.9.1 General

The Ju-Air maintenance organisation exposition (MOE) contains the following provisions regarding technical inspection flights:

"*2.24.2 Technical inspection flights with aircraft*

Technical inspection flights shall be arranged by the operations manager or their deputy, either using a standard flight programme or establishing a separate programme for specific checks.

Only persons directly involved in the purpose of the flight may be carried on inspection flights involving exceptional risks or flight manoeuvres."

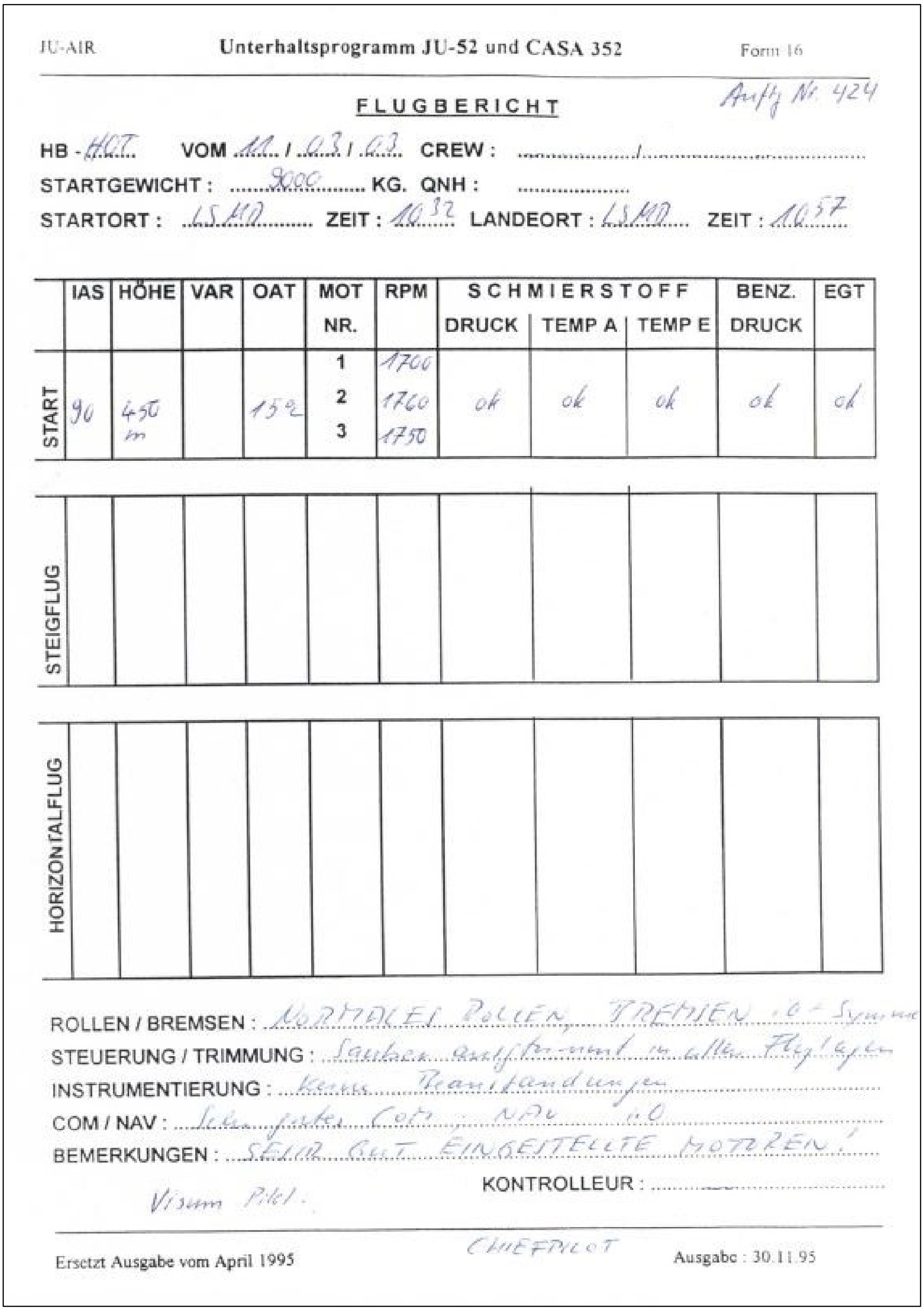
Under work preparation on the cover sheet of the maintenance checklists for the interval inspections, "*C. AVOR, 5th test flight*" is listed. Over the last few years, the cover sheets have usually had a check mark for 'test flight', 'n/a' or nothing at all.

The technical files only included two HB-HOT inspection flight reports for the last 15 years. These test flights were carried out after major repair work.

A1.6.10.9.2 Inspection flight on 11 March 2003

This inspection flight was performed after repair work on the horizontal stabiliser (see section A1.6.16.2.4). The flight lasted 25 minutes, essential parameters were not recorded during this flight (see figure 19).

The pilot had written the following under ‘Remarks’ on the flight report: “*Very well-tuned engines!*”



JU-AIR Unterhaltsprogramm JU-52 und CASA 352 Form 16

Auftr. Nr. 424

FLUGBERICHT

HB - HOT VOM 11 / 03 / 03 CREW : ..../............

STARTGEWICHT : 9000 KG. QNH : ....

STARTORT : LSMD ZEIT : 10 32 LANDEORT : LSMD ZEIT : 10 57

	IAS	HÖHE	VAR	OAT	MOT NR.	RPM	SCHMIERSTOFF DRUCK	SCHMIERSTOFF TEMP A	SCHMIERSTOFF TEMP E	BENZ. DRUCK	EGT
START	90	450 m		15°	1 2 3	1700 1760 1750	ok	ok	ok	ok	ok
STEIGFLUG											
HORIZONTALFLUG											

ROLLEN / BREMSEN : NORMALES ROLLEN, BREMSEN i.O. + Symm...

STEUERUNG / TRIMMUNG : Sauber ausgetrimmt in allen Fluglagen

INSTRUMENTIERUNG : Keine Beanstandungen

COM / NAV : Sehr gute Com, NAV i.O

BEMERKUNGEN : SEHR GUT EINGESTELLTE MOTOREN!

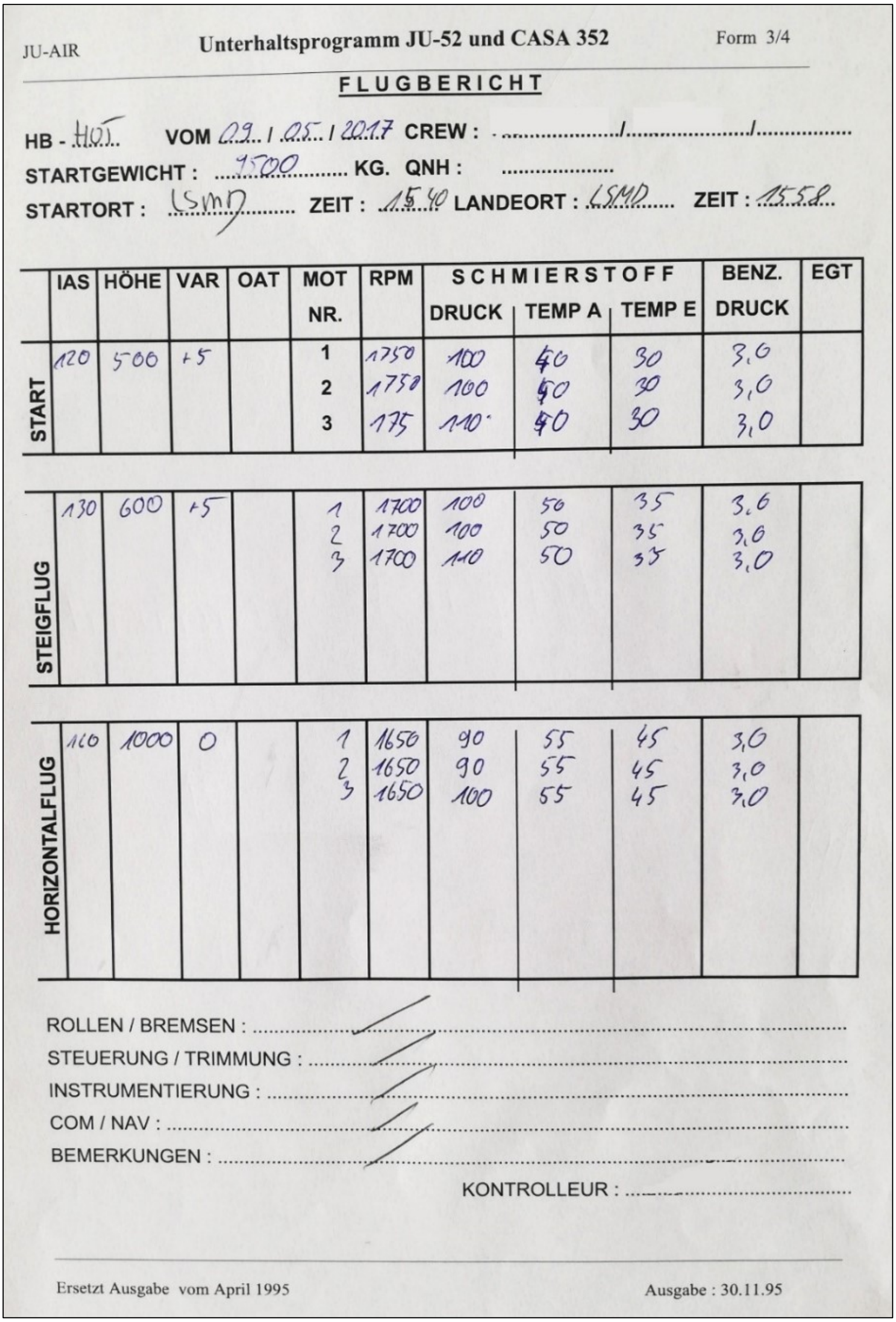
Visum Pilot. KONTROLLEUR : ....

Ersetzt Ausgabe vom April 1995 CHEFPILOT Ausgabe : 30.11.95

Figure 19: Test flight report from 11 March 2003. Names of persons removed by the STSB. Source: Technical records HB-HOT.

A1.6.10.9.3 Inspection flight on 9 May 2017

This inspection flight was performed after repair work on a wing spar (see section A1.6.16.2.3). The flight lasted only 18 minutes and essential parameters were not recorded (see figure 20). According to the log, relevant systems such as the flight controls, trim, brakes, etc. were not checked.


JU-AIR | Unterhaltsprogramm JU-52 und CASA 352 | Form 3/4

FLUGBERICHT

HB - HOT VOM 09 / 05 / 2017 CREW : .... / .... / ....

STARTGEWICHT : 9500 KG. QNH : ....

STARTORT : LSMD ZEIT : 15.40 LANDEORT : LSMD ZEIT : 15.58

	IAS	HÖHE	VAR	OAT	MOT NR.	RPM	SCHMIERSTOFF DRUCK	SCHMIERSTOFF TEMP A	SCHMIERSTOFF TEMP E	BENZ. DRUCK	EGT
START	120	500	+5		1	1750	100	40	30	3,0	
					2	1750	100	50	30	3,0	
					3	175	110	50	30	3,0	
STEIGFLUG	130	600	+5		1	1700	100	50	35	3,0	
					2	1700	100	50	35	3,0	
					3	1700	110	50	35	3,0	
HORIZONTALFLUG	160	1000	0		1	1650	90	55	45	3,0	
					2	1650	90	55	45	3,0	
					3	1650	100	55	45	3,0	

ROLLEN / BREMSEN : ....

STEUERUNG / TRIMMUNG : ....

INSTRUMENTIERUNG : ....

COM / NAV : ....

BEMERKUNGEN : ....

KONTROLLEUR : ....

Ersetzt Ausgabe vom April 1995 | Ausgabe : 30.11.95

Figure 20: Test flight report from 9 May 2017. Names of persons removed by the STSB. Source: Technical records HB-HOT.

A1.6.10.10 Evaluation

A1.6.10.10.1 General

This section analyses the development in performance of the BMW engines from the Ju 52/3m g4e aircraft delivery to the Swiss air defence corps in 1939 up until the time of the accident. The effects on flight performance were also examined.

A1.6.10.10.2 Available engine power

In order to create a basis for the following consideration, the performance measurements that were determined at the Junkerwerke airfield in Dessau (57 m AMSL) during four flights between 29 September and 4 October 1939 were used. Among other things, the horizontal speed at ground level was determined.

The performance flights were carried out with a mass of 10,000 kg. The three BMW 132 A3 engines were practically new and the propellers had a pitch of 21 degrees.

In horizontal flight at 150 to 180 m AMSL, the following values were achieved at that time:

Engine speed [rpm]	Speed [km/h]
1,450	160
1,650	200
1,860*	250*

Table 11: Logged speeds at different engine speeds.

The values marked with an * are comparable with the values for cruise flight mentioned in section 10, ‘Flight operations’ of the operating instructions for Ju 52/3m g4e aircraft:

“At an altitude of 500 m, at 1,850 rpm, speed V_a = 240 km/h”.

Between 2010 and 2016 the three engines, which were mounted on HB-HOT at the time of the accident, had been subjected to a major overhaul, carried out by a maintenance organisation. Afterwards, a company in Germany carried out a performance test on the engines with the butterfly valve fully open. On the test stand, the engine was operated with a brake propeller.

As the test results show, none of the three engines reached the target speed of 2,050 rpm during the test runs. For full power – which corresponds to the short-burst increased power of 725 PS – the aircraft testing authority specified a power tolerance of +/- 2.5% and an engine speed tolerance of + 100 to - 60 rpm. Thus, all of the engines were within the speed tolerance during the test run after the major overhaul, but only the centre engine was within the power tolerance.

The engine manufacturer, however, stated a power tolerance of + 4 % to – 2 % and an engine speed tolerance of +/- 2 %. Thus, the left engine was outside the speed tolerance during the test run after the major overhaul. Only the centre engine was just within the power tolerance.

During the period from 14 May 2018 to 23 July 2018, Ju-Air carried out maintenance work on HB-HOT’s three engines on several occasions. After completing the work, the engine was subjected to a static test run.

With the butterfly valve fully open, the engine should reach a speed of 2,050 rpm.

	Test runs after major overhaul			Static test run measurement (HB-HOT)	
	Date	rpm[1)]	PS[2)]	Date	rpm
Left engine	12 October 2010	1,996	666[3)]	23 July 2018	1,890
Centre engine	17 April 2013	2,030	711[3)]	23 July 2018	1,860
Right engine	28 June 2016	2,027	698[3)]	23 July 2018	1,810

Table 12: Comparison of the test run and static-test values.

1) Target speed = 2,050 rpm under CINA standard conditions (760 mm Hg, 15°C)

2) Target power at 2,050 rpm = 725 PS under CINA standard conditions

3) Power determined by the STSB from the logged torque measurements

As can be seen from the table above, this speed was not achieved on the three HB-HOT engines during the test runs after the major overhauls, nor during the static test run on 23 July 2018. The engine speeds determined during the static test runs are markedly below the target value of 2,050 rpm.

There is quite a large period of time between the test runs after the major overhauls and the static test run on 23 July 2018. In the meantime, the maintenance team had carried out several repairs on the three HB-HOT engines (see section A1.6.16.3). The factors listed below may have had an influence on the different measurement results:

- Condition of the engines;
- Adjustment of the control linkage between the main throttle lever and the carburettor;
- Properties of a brake propeller versus an aircraft propeller;
- Different atmospheric conditions;
- Different engine speed measuring devices.

A1.6.10.10.3 Available flight performance

Table 13 below compares the flight performance of the Ju 52/3m g4e in 1939 with that in the years 2017 and 2018. In each case the airspeeds in cruising flight were compared. It stands out that HB-HOT was able to reach higher airspeeds at comparable engine speeds in 1939 than it was prior to the accident. The following variables may potentially explain the difference:

- Lower engine power than when originally tested;
- Propeller pitch of 21 degrees as opposed to 19 degrees;
- Propeller efficiency of the reproduction propellers;
- Increased aerodynamic drag of the aircraft.

Operating instructions from 1939		Acceptance flights dating September/ October 1939		Ju-Air AFM, rev. 11, dated 1 June 2017		Inspection flight on 9 May 2017		Flight past Mount Rigi on 3 August 2018		Comparative HB-HOS flight in October 2017	
Cruising speed at 1,850 rpm		Cruising speed at 1,860 rpm		Cruising speed at 1,750 rpm		Cruising speed at 1,650 rpm		Cruising speed at ~1,750 rpm		Cruising speed at ~1,700 rpm	
Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h
500	240	< 500	250	500	200	500	–	500	–	500	–
1,000	–	1,000	–	1,000	–	1,000	160	1,000	–	1,200	150
2,500	220	2,500	–	2,500	170	2,500	–	1,800	150	2,500	–
5,000	175	5,000	–	5,000	140	5,000	–	5,000	–	5,000	–
Propeller pitch 21 degrees				Propeller pitch 19 degrees							

Table 13: Comparison of flight performance.

When comparing the cruising speeds from the inspection flight on 9 May 2017 and the cruising speeds from the comparative flight of HB-HOS in October 2017, with the indicated airspeed during the flight past mount Rigi, it can be seen that the figures shown are in fact plausible.

A1.6.11 Propellers

When the Ju 52/3m g4e was delivered in 1939, the engines were fitted with two-blade fixed propellers made of Duralumin labelled with Ju-PAK. These propellers rotate clockwise. They had a diameter of 2.9 m and were set at a pitch of 21 degrees.

The original pitch for the propeller blades of 21 degrees changed over the years. Ju-Air's AFM, rev. 0 dated 1 October 1982, mentions a setting of 17 degrees. According to Ju-Air's documentation, the propellers were operating at a pitch of 19 degrees at the time of the accident. This was also indicated in the current version of the AFM.

Due to corrosion and wear, the original propeller blades had to be replaced. However, as original blades were no longer available, new blades based on service bulletin no. 1045 (see section A1.6.17.2.6) were produced from 2000 onwards. The original hubs have been reconditioned for reuse several times (see section A1.6.16.3.5).

A1.6.12 Systems

A1.6.12.1 Fuel systems

A1.6.12.1.1 General

In each outer wing there is a group of fuel containers, consisting of seven aluminium cells that are connected to each other by branch lines. Cells no. I to VI are connected in series and installed between spar II and spar III, the additional cell no. VII is installed between spar III and spar IV (see figure 21). The contents of each group of containers is indicated by a mechanical display. According to the operating instructions, the total capacity is 2,400 litres. In contrast, the AFM lists a volume of 2,500 litres.

The fuel is delivered by fuel pumps, which are driven by the respective engine via a bevel gear and a remote shaft.

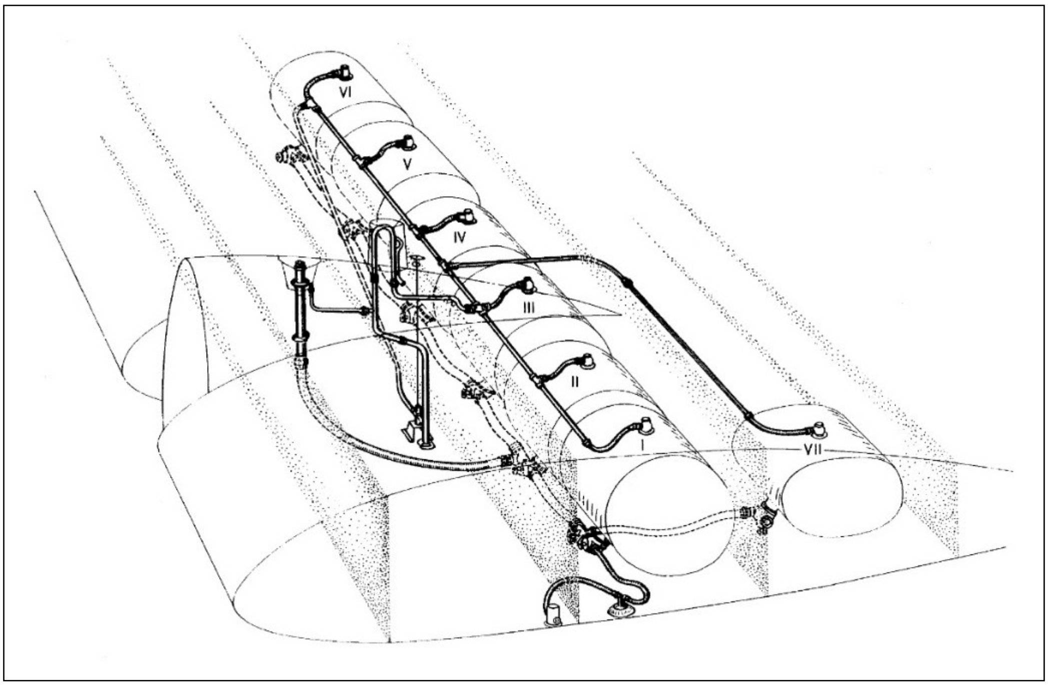


Figure 21: Fuel cell assembly in the right-hand outer wing. Source: Ju-Air AFM from 2017.

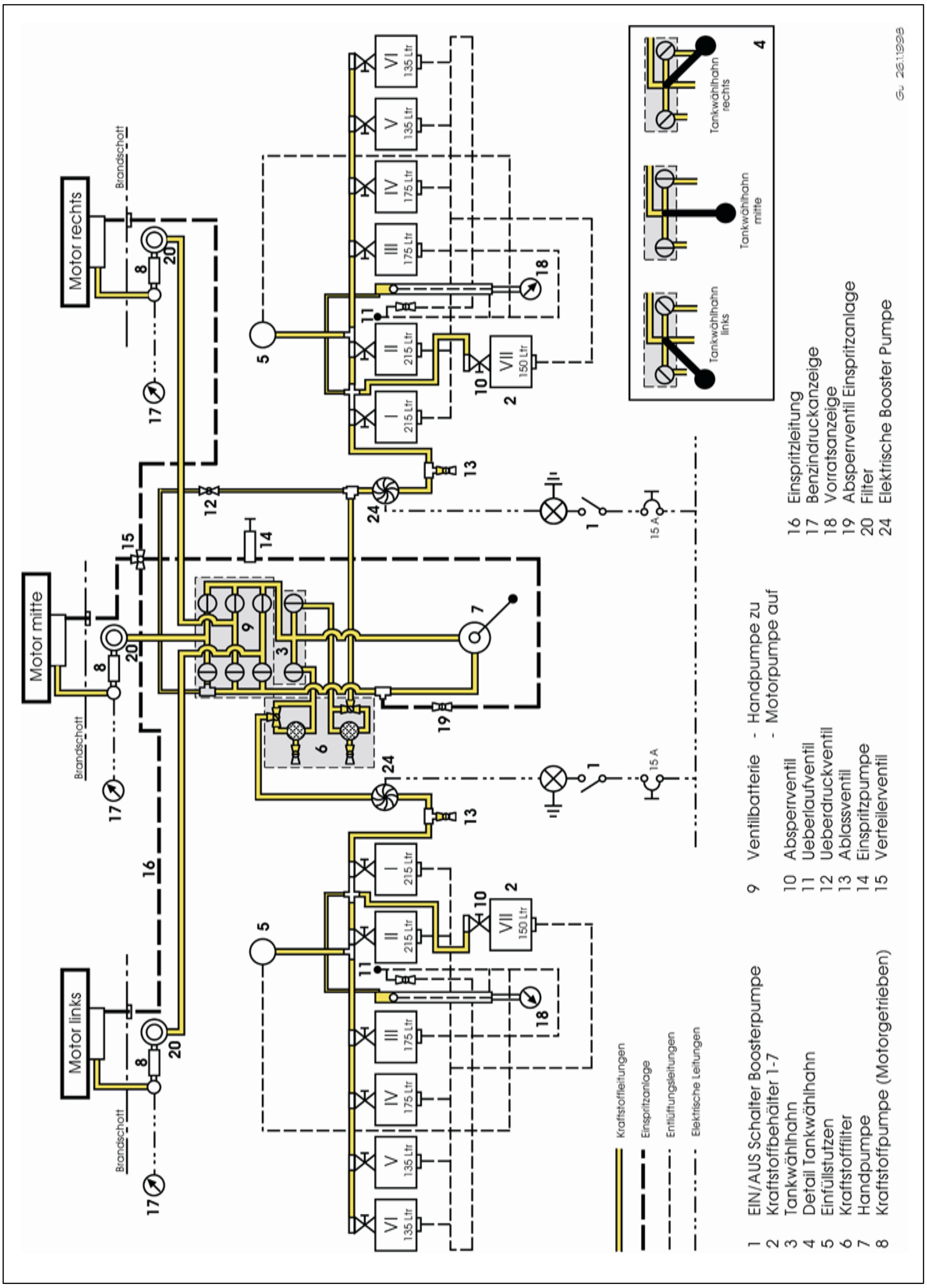


Figure 22: Diagram showing the fuel system. Source: Ju-Air AFM from 2017.

A1.6.12.1.2 Fuel filter

Each outer wing is fitted with a fuel filter (see figure 22, (6)). After the fuel has passed the filter, it is fed to the engine by an engine-driven fuel pump (8). The pressure is measured using a fuel pressure indicator (17). If necessary, the injection line (16) is activated when the engine is started.

A1.6.12.1.3 Fuel valve battery

A valve battery with seven connections between the lines is connected to distribute the fuel coming from the fuel cells to the engine systems (see figure 22).

The valve battery consists of a housing divided into four chambers. Each of these chambers feature two spring-loaded valves. These can be adjusted using a cam disc. All of the line connections and five valves are labelled on top of the housing. The fuel flow is regulated using control levers located in the cockpit. The levers allow the valve for fuel flow from the cells or fuel flow from the hand pump to be selected for the respective engine. The cam disc's third position results in these two valves not being actuated, or closed.

A1.6.12.1.4 Installation of electric fuel pumps

Based on service bulletin no. 1043, two electric fuel pumps (booster pumps) were installed in HB-HOT in August 1997 due to the use of MOGAS. These pumps were switched on when the outside air temperature reached 25 °C or more, in order to counteract the potential for fuel vaporisation. According to the hold item list (HIL), MOGAS was no longer used as of 15 February 2007 and the electric fuel pumps were deactivated. However, these remained installed in the fuel system. As such, the fuel flowed through a bypass integrated in the pump. The only measure taken was to lock the circuit breakers (CBs) in the off position using a cable tie and label the switches for the respective electric fuel pumps on the control panel as "*Inop.*".

Among other places, the electric fuel pumps have continued to be mentioned in the system descriptions and instructions for normal and abnormal operation in the current version of the AFM as if this system were still active. Furthermore, the pumps were listed in the minimum equipment list (MEL) as well as in the checklist for pilots of Ju-Air's Ju 52 aeroplanes dated 6 March 2017.

For example, the electric pumps were mentioned in section 9, "*Low fuel pressure*", of the checklist (see figure 23).

LOW FUEL PRESSURE / DREHZAHLABFALL

1. PNF Boosterpumpen LH und RH .... ein
2. PNF Gemischregulierungen .... auf entsprechende (Höhengas) .... Höhe stellen

ACHTUNG ! Tankwählhahn-Stellung
Mitte .... Boosterpumpen LH und RH ein
Rechts .... nur Boosterpumpe RH ein
Links .... nur Boosterpumpe LH ein
Bei Ausfall einer Boosterpumpe werden auf Stellung Mitte von der noch laufenden Boosterpumpe pro 10 Minuten ca 100 Liter Treibstoff in den anderen Flügel transferiert. (Der Ausfall einer Boosterpumpe trotz funktionierender Stromversorgung ist nur durch die entstehende Unbalance der Treibstoffanzeige feststellbar).

BOOSTERPUMPENWARNLAMPE LH/RH resp Treibstoff UNBALANCE

1. PNF Tankwählhahn .... auf Seite der noch laufenden Boosterpumpe resp den Flügel mit tieferem Benzinstand stellen
2. PNF Ausgefallene Boosterpumpe .... aus

falls sich Fuel press wieder normalisiert hat (unter 5000 ft resp OAT < 25 °C)

1. PNF Boosterpumpen .... aus
2, PNF Gemischregulierung .... zu (ganz nach unten)
3. PNF Tankwählhahn .... auf Seite mit höherem Treibstoffvorrat (Vorrat ausgleichen)

Figure 23: Extract from section 9 of Ju-Air's checklist.

The fact that maintenance was no longer carried out on the pumps meant that there was a risk that the fuel flow rate would be reduced. The condition of the pumps examined confirms that they had not been maintained for years (see annex A1.12). Components and systems installed in an aircraft must be maintained, otherwise the airworthiness of the aircraft can no longer be assured.

The files revealed that the two fuel pumps had been installed in HB-HOT for 4,239 operating hours since the last major overhaul. This means that the intended interval of 2,500 operating hours for a major overhaul was considerably exceeded. Therefore, these components were not airworthy.

The deactivation of the fuel pumps was not carried out consistently. The documents have not been adjusted to accurately reflect the state of the aircraft for over ten years. It is difficult to understand that this circumstance was accepted by both the flight crews and FOCA. The example indicates that the maintenance organisations and the flight operations team were not working in a coordinated manner.

In the HIL, the deactivation of the electric fuel pumps was mentioned as follows:

"*1 Aircraft to be fuelled with AVGAS 100 LL only*
Fuel test

2 LH + RH booster pumps have been deactivated due to AVGAS operation only"

This entry has existed since 2007. As a matter of principle, complaints noted in the HIL must be resolved within a defined period of time. For systems that are permanently deactivated, the HIL is the wrong instrument.

These processes indicate a lack of quality awareness and that Ju-Air staff obviously did not have the necessary expertise.

A1.6.12.2 Lubrication system

Each engine has its own lubrication system. The oil is circulated by a suction and pressure gear pump, which is driven by the engine. The lubricant is drawn from the respective engine's oil tank by the pump and fed under pressure to the individual points of lubrication. In each lubricant supply line, there is a shut-off valve which is coupled to the fire valves. In addition, there is an oil filter element (fine-mesh sieve), which – due to its design – is unable to filter the oil for fine particles and wear debris. A magnet is mounted in the filter housing cover. This magnet is intended to catch and hold magnetic metal particles. Such accumulated metal particles can provide valuable information on the condition of an engine. Nowadays cockpits are fitted with warning lights for these particle detectors, however, this was not the case with HB-HOT.

The oil filter has no bypass valve. This can lead to the oil circulation system failing if the filter element becomes blocked. There is also no system to indicate a clogged oil filter.

To regulate its temperature, the lubricant in the return line is led over the coolers via a changeover tap.

An electrical pressure gauge system, with display instruments incorporated into the cockpit's instrument panel, is installed to monitor the supply of lubricant.

Each engine has a built-in oil pressure warning light which lights up when the oil pressure drops below 3 bar.

The temperature of the lubricant is measured at the inlet and outlet using electrical thermometers and is displayed on instruments in the cockpit's instrument panel.

A1.6.12.3 Pitot-static system

The airspeed indicators, the altimeters, the variometers and the altitude encoder for the transponder are connected to the pitot-static system. All of these devices are connected in parallel. This means that the system is not redundant.

The airspeed indicator system consists of the pitot tube, the airspeed indicators and the associated lines.

To prevent the risk of icing, the pitot tube is electrically heated. However, there was no warning indicator for pitot tube heating failure.

HB-HOT had only one pitot tube system. The airspeed indicators for the pilot and the co-pilot were connected to the same pitot tube, without any redundancy. It was therefore not possible to identify any inaccurate readings through cross comparison.

The basic principle of operation of the airspeed indicator system is as follows (see figure 24): The pitot tube (1) transmits the dynamic pressure via the pressure line (2) to the display unit's measuring cell (6). The measuring cell links to the needle via a mechanism, which gauges the respective dynamic pressure and thus indicates the speed of the aircraft in relation to the surrounding air on the dial. The display unit has a second connection to the port for static-pressure compensation (4).

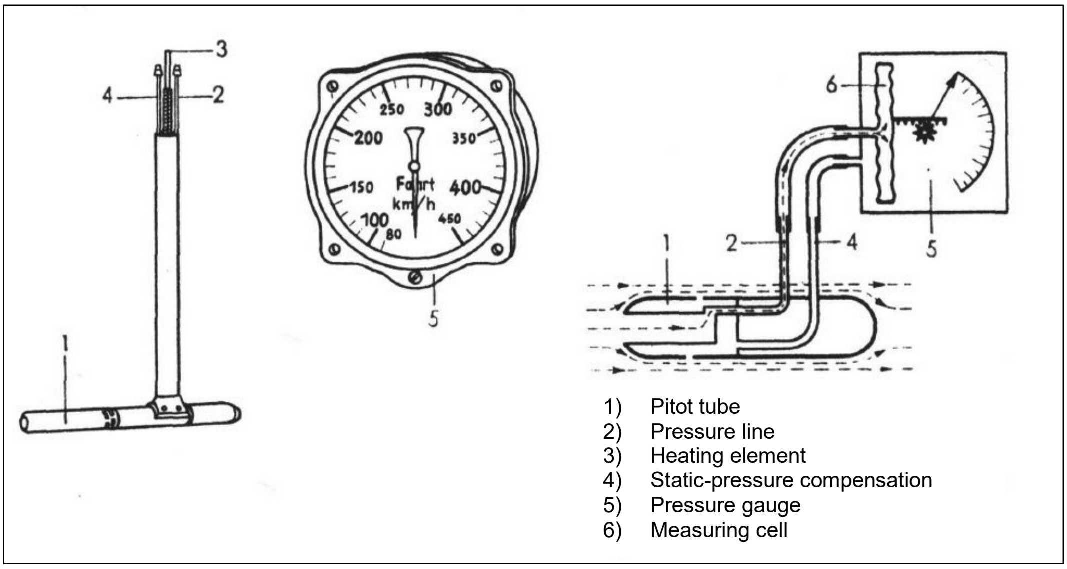


Figure 24: Airspeed indicator system. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

Dynamic pressure is taken from the pitot tube, which on Ju 52/3 g4e aircraft extends from the leading edge of the left outer wing (see figure 25).

Figure 25: Arrangement of the pitot tube with red cover on sister aircraft HB-HOS.

The static pressure is also taken from the pitot tube (see figure 26). In the cockpit, there is also an emergency intake for static pressure.

In the rearmost part of the pitot tube, the pressure line has a diameter of only 2 mm. This is where it is possible for foreign objects (dust, insects, etc.) to clog the pitot tube, which can lead to inaccurate readings on the air speed indicator.

Figure 26: Pitot tube of HB-HOT. The openings for the static pressure are circled in black.

A1.6.12.4 Indicators and warnings

A1.6.12.4.1 Tachometers

Ju-Air's Ju 52 aircraft are equipped with one HRC 02 electronic tachometer per engine. This type of tachometer has an analogue and a digital display (see figure 27). The digital display for the centre engine shows the measured engine speed, while the displays for the two outer engines show the deviation in speed from the centre engine. This allows the engines to be synchronised with each other as precisely as possible. The electronic tachometers were installed in February 2002 based on the revised service bulletin no. 1025 (see section A1.6.17.2.7).

Figure 27: Type HRC 02 tachometers with analogue and digital displays. Photograph from private individual.

The electronic tachometer processes the pulses generated by a proximity switch. The number of pulses is proportional to the speed of the engine. The read-outs on the analogue display for all three engines and the digital display for the centre engine are calculated based on the above-mentioned pulses. The read-out on the digital displays for the left and right engines is based on the difference between the speed of the relevant engine and the digital display for the speed of the centre engine.

A1.6.12.4.2 Exhaust gas temperature measuring system

The aircraft is equipped with an exhaust gas temperature measuring system that measures the temperature at the exhaust pipe for cylinder no. 1 of each engine. One dial per engine is incorporated into the instrument panel. The scale of the dial is in °F (degrees Fahrenheit), the temperature indications given in the AFM are in °C.

A1.6.12.4.3 Stall warning system

A stall warning system warns the flight crew when the aircraft approaches a critical angle of attack and, thus, warns of an imminent stall. The Ju 52/3m g4e aeroplane was not equipped with such a system.

A1.6.12.5 Transponder

A1.6.12.5.1 General

The aircraft was fitted with a Garmin GTX 330D mode S transponder. This meets the requirements of level 2. The transponder transmits on 1090 MHz and receives on 1030 MHz. The transponder meets the requirements for mode S enhanced surveillance.

On request from ground radar, the transponder automatically transmits the ‘squawk’ assigned by the ATC[38] and entered by the crew, as well as the pressure altitude, the aircraft address, the ground speed (GS) and the true track (TT). The transponder also communicates with the TCAS[39] of other aircraft. The transponder therefore meets the requirements for aeroplanes licensed to fly under visual flight rules.

The transponder is equipped with an antenna, which is located on the underside of the nose of the aircraft.

A1.6.12.5.2 Altitude encoder

In Ju-Air’s Ju 52 aircraft, the transponder is connected to a type SAE 5-35 altitude encoder. This supplies the pressure altitude in feet (standard pressure 1,013.2 hPa) in 10-foot increments via a serial interface. The encoder is connected to the existing static pressure system in parallel to the altimeters. In HB-HOT, it was positioned below the left-hand instrument panel.

A1.6.12.5.3 Ground speed and true track

In Ju-Air’s Ju 52 aircraft, the transponder was connected to a Garmin GNS 430[40] navigation computer. This provides the ground speed parameter via a serial interface (A429, label 312) and the true track parameter via label 313. Both of these parameters are calculated using GPS[41].

During the flight to Locarno on 3 August 2018, the GNS 430 was in operation. The ground speed was transmitted to ATC when the aircraft was within radar coverage.

[38] ATC: Air traffic control

[39] TCAS: Traffic alert and collision avoidance system

[40] The GNS 430 is a navigation system that allows pilots to enter a flight route. Deviations from the route are indicated on the corresponding instruments.

[41] GPS (global positioning system) is a satellite system with which an exact position can be determined worldwide. GPS is integrated in the GNS 430 for this purpose.

A1.6.12.5.4 Aircraft address

The 24-bit ICAO mode S address, which is allocated individually for each aircraft by the relevant authority, is entered into the transponder by the responsible technician during installation as a hexadecimal code.

A1.6.12.5.5 Periodic inspection of the transponder system

According to FOCA technical communication TM 20.100-20, the periodic inspection of the ATC transponder system must be carried out every 24 months. For HB-HOT, this inspection was last carried out on 19 December 2017.

A1.6.12.6 On-board battery

During the Ju 52 aircraft's military service, the original on-board batteries (lead batteries) had already been replaced by nickel-cadmium batteries (NiCd batteries). A NiCd battery was installed in HB-HOT at the time of the accident. However, it was not clear from the technical files what model of battery this was. In 1983, due to a FOCA stipulation, the NiCd batteries of every aircraft were retrofitted with an overheating warning system. According to the files, the temperature sensors used for this purpose were used exclusively on the Ju-Air Ju 52 aeroplanes. There were no documents in the files relating to this warning system.

A1.6.13 Maintenance instructions supplied by the aircraft and engine manufacturer

A1.6.13.1 Airframe

A1.6.13.1.1 Operating instructions

For operation of the Ju 52 3m/g4e, the aircraft manufacturer issued operating instructions (*Betriebsanweisung*) in 1939 which serves as a reference book for operation, maintenance and inspection as well as for the training of maintenance personnel.

The table of contents for these operating instructions merely indicates the title of the individual main sections and their reference numbers. The further structure and subdivision of the instructions can be seen on the introductory tables of contents for each of these sections. Sections 1 to 9, including the reference number, correspond to the structure of the aircraft. Sections 10 and 11 contain instructions for the operation of the aircraft and section 12 contains, among other things, equipment descriptions and test sheets. The main sections are titled as follows:

0 General (gives an overview of the whole aircraft)

1 Fuselage

2 Landing gear

3 Control surfaces

4 Controls

5 Wing

6 Engine frame

7 Engine system

8 Engine containers

9 Equipment

10 Flight operations (covers practical flight operations including daily maintenance)

11	Transportation	(shows how to load and transport the aircraft)
12	Appendix	(device descriptions, test sheets, etc.)

Partial and major overhauls of the airframe are described in section 0, 'General', of the operating instructions under 'Partial and major overhauls' as follows:

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

Partial overhauls include, after removal of all covers and hatches (see cover and hatch overview), the precise examination of all operationally important joints and connections, the rivets, and – in particular – the connections of the landing-gear spring struts, the control transmission linkages, the engine system, etc. The controls must be checked for their setting dimensions (see setting diagrams in section 4, 'Controls').

Depending on the findings, it may be necessary to dismantle large structural elements such as the outer wings, empennage, landing gear, etc. in exceptional cases.

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 aeroplane is as close to factory-new as possible.

After a major overhaul, the time interval for 'partial overhauls' starts from zero as of the same date, unless the final findings indicate that a different interval would be appropriate. In addition to circumstances relating to weather and landings, the determination of the frequency primarily depends on the level of training of the persons entrusted with maintenance.

The calculation for time between inspections is therefore only connected with the calendar calculation to the extent that weathering can take place even without the aircraft being used."

Furthermore, the following relevant instructions are described in section 0, 'General', under 'Cleaning and paint care':

"*Lubricant and burnt-on exhaust residues adhering to cowlings, the wing, fuselage and empennage must be carefully removed with cleaning solvent*.

The engines as well as the inside of the cowlings are to be cleaned of any adhering lubricant using cleaning solvent.

[…]

Components that are difficult to access and yet exposed to the elements must be cleaned particularly carefully and protected against weathering.

Steel parts which are unprotected for reasons of fit must be regularly re-greased with acid-free grease after the removal of dust and dirt. Rust spots must be removed beforehand using sandpaper.

[…]

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'."

A1.6.13.1.2 Repair instructions

There is a 1939 repair instructions (*Ausbesserungsanleitung*) for Junkers metal aircraft written by the manufacturer. According to the manufacturer, these instructions are intended to provide all persons entrusted with the repair and maintenance of the aircraft with the necessary information for workshop and flight operations and to eliminate faults (which put the safety of the aircraft at risk) as a matter of principle.

In section 5, 'Surface protection', 'preliminary remarks', the manufacturer provided the following information:

"*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 a wire brush as far as possible. The cleaned surfaces must be free of paint residues, oils, greases, dirt, scale, oxides, hand perspiration, etc."

A1.6.13.2 Engines

A1.6.13.2.1 Description and operating instructions

There is a 1938 description and set of operating instructions (*Betriebsanleitung*) for the air-cooled BMW 132 A3 aircraft engine supplied by the manufacturer.

The maintenance and overhauls of the engines are described as follows:

"*V. Regular inspections*

The engine should be inspected before each flight and at regular intervals.

The following checks are to be carried out:

1. Before every flight

a) Check the fuel and oil level.

b) Check the ignition by switching on each magneto individually using the ignition switch.

c) Check that the oil and fuel pressure gauges give a reading.

d) Check that the engine is running at the correct speed at the permissible throttle opening.

e) Drain any water from the bottom of the fuel cells.

f) Check the propeller blades for play before and after the first flight, then every 10–20 operating hours.

g) Check the engine mounting bolts.

2. After every longer flight

Check the compression while the engine is still warm. […]

3. In addition, every 10 hours

a) Check the valve clearance with the feeler gauge located in the on-board tool bag.

b) Check the valve springs by depressing them by hand.

c) Check the hemispherical pintle tips in the rocker arm pintle pins (pintle tips must not be stuck or displaced).

d) Brush the valve springs clean with oil.

e) Fill the oil compression nozzles for the rocker arm shafts and pintle pins with Gargoyle Mobil Compound 3 or Stanavo 2.

f) Clean the fuel filter installed in the aircraft.

g) Check the fuel-line connections for leaks.

4. In addition to the above checks, every 20 hours

a) Change the oil.

b) Clean the oil filters.

c) Test the engine for oil leakage.

d) Clean the spark plugs, check the insulation for fractures, adjust the electrode gap if necessary.

e) Clean the magneto breaker contacts with a non-fibrous cloth.
Note: a) Do not use emery cloth!
b) Do not change breaker settings!

f) Lubricate the magnetos as described in section IX, 2. 'Ignition' and the carburettor's butterfly spindle.

g) Check the rocker arms for lateral play and the oil holes in the rocker arm bolts for blockages.

h) Check whether the propeller hub is tight.

i) Check the fuel lines for blockages.

k) Check the carburettor and nozzles for sticking if benzene-petrol mixtures are used as fuel.

l) Clean the fuel filter in the carburettor.

[…]

It is important to always have the correct valve clearance, as excessive clearance can lead to valve breakage. The correct clearance when the engine is cold is 0.25 mm for both the intake and exhaust valves. […]

VII. Overhaul in the aircraft

The usual indication that an engine may require readjustment or possibly an overhaul in the aircraft is a decrease in engine speed on the ground with the permissible throttle opening. It should be noted that unusual conditions with regard to temperature and barometric pressure sometimes influence the propeller speed by 50 to 100 rpm without there being any defects in the engine.

First check that the control levers in the cockpit correspond to the actual position of the butterfly valve and altitude control levers. The magnet interrupters must also be checked using the feeler gauge supplied for this purpose. The gap should not be more than 0.3 to 0.4 mm.

[…]

After the above check and any necessary adjustments have been made, the engine is started and operated at low speed (800 to 1,000 rpm) until the temperature of the entering oil is at least 30°C. It should then be run with the throttle fully open and a 'full rich' mixture at full early ignition. The engine speed, the oil pressure, which should be between 5.8 and 7.0 kg/cm^2 and the fuel pressure, which should be 0.21 kg/cm^2, are to be monitored. The operation of the ignition should then be checked by running the engine first using one magneto and then the other. Any drop in engine speed must not exceed 50 rpm with only one magneto switched on. After the engine has been stopped and has cooled down a little, the compression in the individual cylinders is checked, for which purpose the engine has to be turned through by two revolutions. If the ignition and fuel pressure are okay and the engine does not run at the required speed on the ground, an overhaul is necessary."

"VIII. Major overhaul

A major overhaul should rarely be necessary prior to 200 to 300 operating hours."

A1.6.13.3 Propellers

A1.6.13.3.1 Operating and maintenance instructions

For Junkers metal propellers, the manufacturer issued operating and maintenance instructions (*Betriebsanweisung und Wartungsvorschrift*) in 1939. They describe the inspection of the propellers as follows:

"*Inspection during flight operations*

After the first workshop flight with a duration of 10 minutes, the shaft nut must be retightened. Likewise, the twelve-point nuts for the propeller blades must be retightened; in both cases the nuts have right-hand threads.

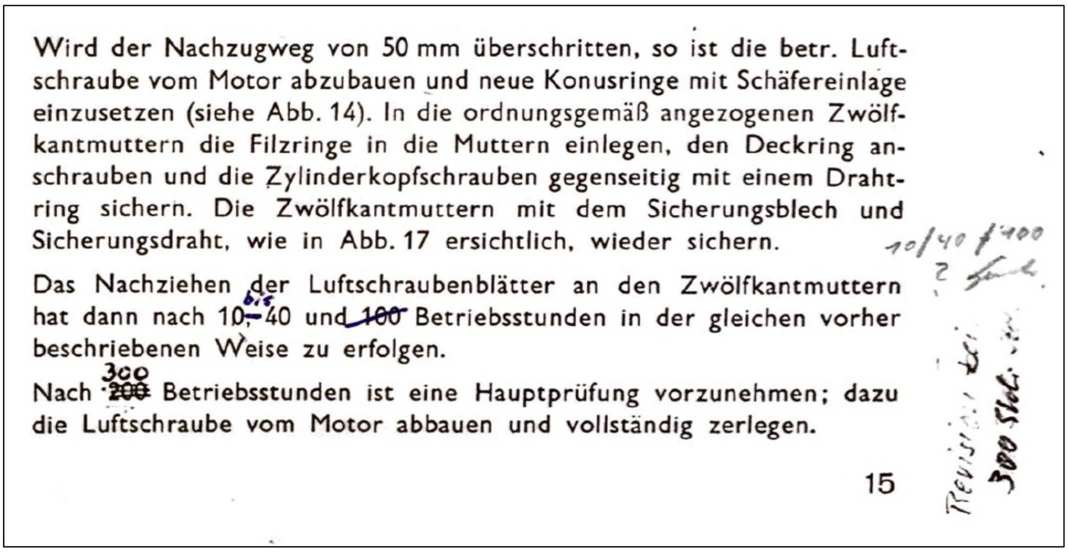
Remove the locking wire with locking plate from the twelve-point nuts. Remove the cover rings and felt rings from the twelve-point nuts. Using the W 9-20020-4 twelve-point nut wrench, tighten the twelve-point nuts with a tightening force of approx. 80 kg at a length of 1.200 m on the wrench arm. When tightening these nuts, it is advisable to support the blade in question with a wooden support in order to be able to tighten the nuts with the required force. When retightening the twelve-point nuts, make sure that the retightening distance measured on the outer circumference of the twelve-point nut after each retightening does not exceed 50 mm. To check this dimension, it is advisable to mark the nut and hub with a pencil before retightening the nuts.

If the retightening distance of 50 mm is exceeded, the propeller concerned must be removed from the engine and new conical rings with sleeves must be inserted. Insert the felt rings into the correctly tightened twelve-point nuts, screw on the cover *ring and secure the cylinder head screws with a wire clip. Re-secure the twelve-point nuts with the locking plate and locking wire.*

The propeller blades must then be retightened at the twelve-point nuts as described above after 10, 40 and 100 operating hours.

After 200 operating hours, a main inspection must be carried out; to do this, remove the propeller from the engine and disassemble it completely."

In the operating and maintenance instructions, the inspection intervals were corrected by hand and the inspection after 100 operating hours was crossed out (see figure 28). Likewise, the main inspection for the propeller was changed to 300 operating hours.



Wird der Nachzugweg von 50 mm überschritten, so ist die betr. Luftschraube vom Motor abzubauen und neue Konusringe mit Schäfereinlage einzusetzen (siehe Abb. 14). In die ordnungsgemäß angezogenen Zwölfkantmuttern die Filzringe in die Muttern einlegen, den Deckring anschrauben und die Zylinderkopfschrauben gegenseitig mit einem Drahtring sichern. Die Zwölfkantmuttern mit dem Sicherungsblech und Sicherungsdraht, wie in Abb. 17 ersichtlich, wieder sichern.

Das Nachziehen der Luftschraubenblätter an den Zwölfkantmuttern hat dann nach 10, 40 und 100 Betriebsstunden in der gleichen vorher beschriebenen Weise zu erfolgen.

Nach 200 Betriebsstunden ist eine Hauptprüfung vorzunehmen; dazu die Luftschraube vom Motor abbauen und vollständig zerlegen.

15

Figure 28: Amended values in Ju-Air's copy of the operating and maintenance instructions. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

Adjusting the blade pitch:

According to the operating and maintenance instructions, the propeller blades must be adjusted to the desired pitch by hand or by lightly hitting the blade with a wooden hammer. The pitch can be precisely adjusted either on the measuring bench or using a setting gauge.

When adjusting the blade on the measuring bench, the propeller blade is first properly aligned (see figure 29). The blade pitch is then adjusted using the inclinometer, from which the pitch can be read directly in degrees.

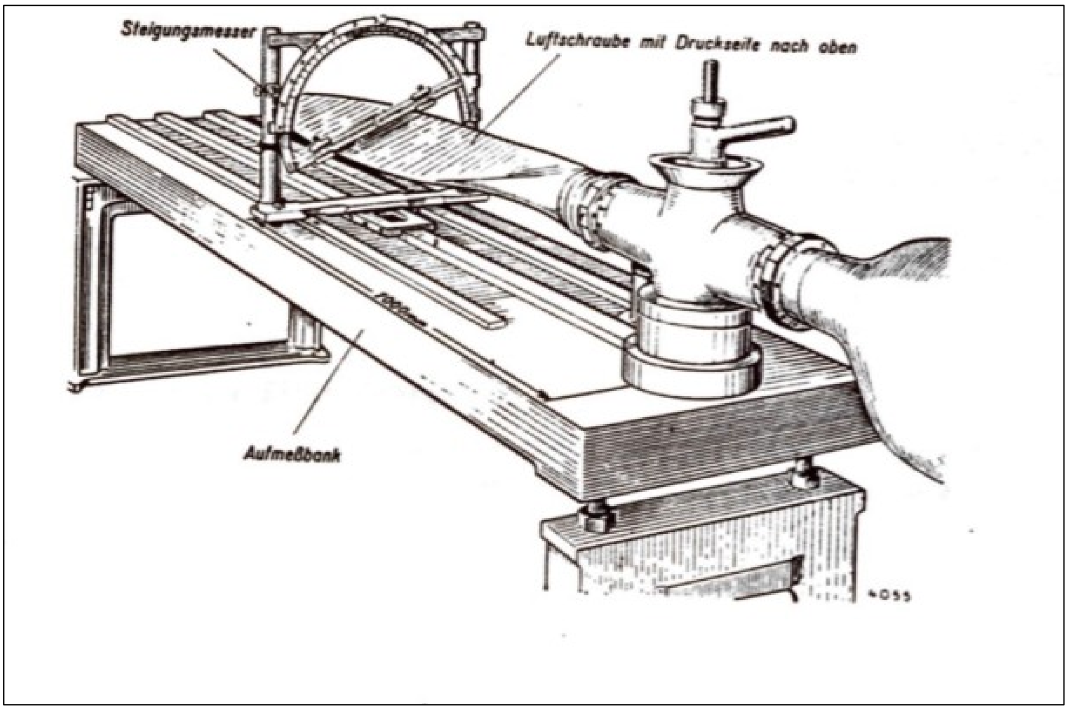


Figure 29: Adjusting the blade pitch on the measuring bench: Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

When using the setting gauge, the blade pitch is adjusted using only the setting scale on the hub and the mark on the root of the blade (see figure 30). Using this method, the propeller does not have to be removed from the engine. Ju-Air was not familiar with this method of adjustment.

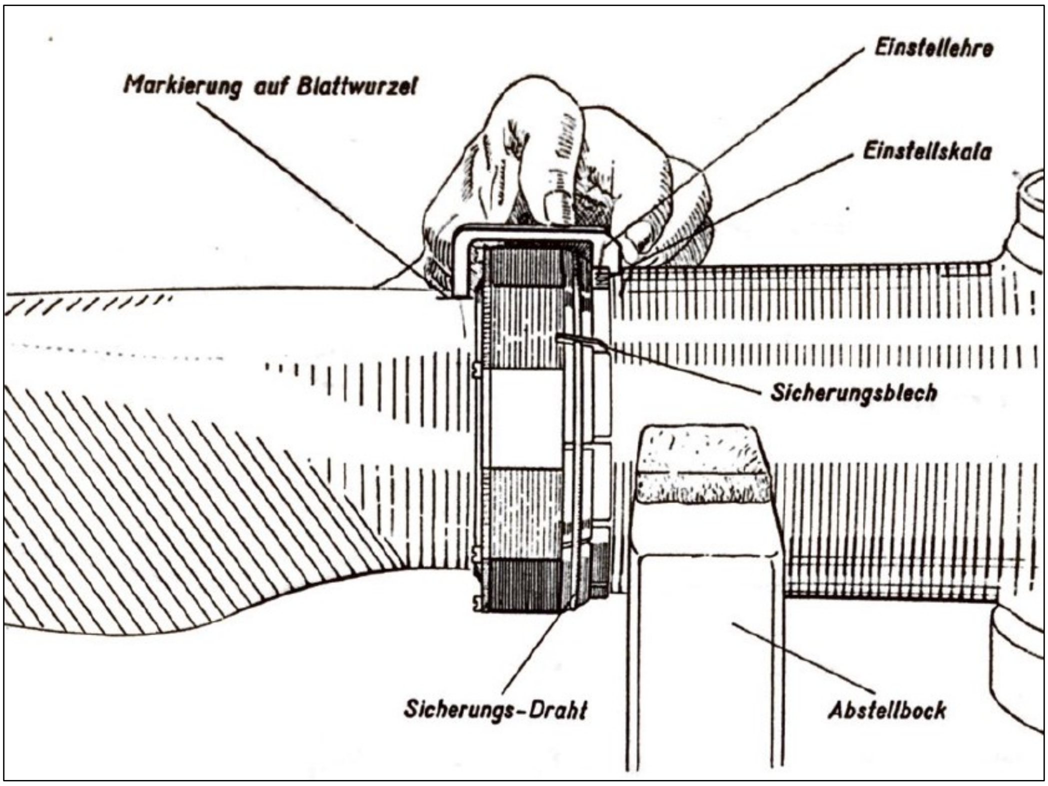


Figure 30: Inspection using the setting gauge. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

After adjusting the blade pitch, each blade is to be checked for frictional resistance as per the operating and maintenance instructions. To do so, a bracket is placed on the blade 600 mm from the centre of the propeller and a weight of 50 kg is attached to a lever arm that has a length of 1,000 mm (see figure 31). With the weight in this position, lightly tap the tip of the blade with your hand. The blade must not twist.

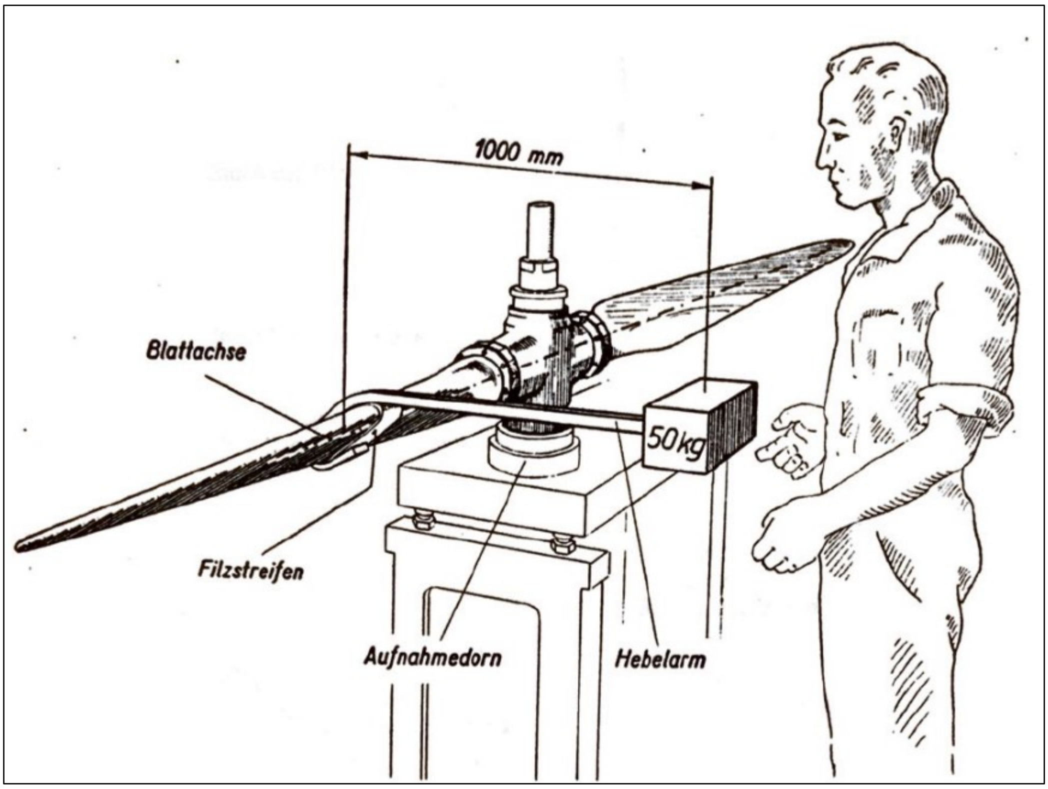


Figure 31: Checking the blade's frictional resistance. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

A1.6.14 Maintenance

A1.6.14.1 General

HB-HOT as well as its two sister aircraft have been maintained at Ju-Air's own maintenance facility since being taken over from the military. In the beginning, the engines were repaired and overhauled at Naef Flugmechanik AG in Fischenthal, just like they were during the aircraft's military service. In 1987, Naef Flugmotoren AG was founded and set up their business in the same hangar as Ju-Air. From 1988 onwards, work on the engines was carried out by this company.

A1.6.14.2 Legal basis

The following relevant paragraphs were listed in technical communication TM 02.020-35 'Handling of maintenance instructions and operating times published by the manufacturers'[42], which came into force on 1 January 2014:

"5. Maintenance programme for annex II aircraft [meaning: aircraft referred to in annex II of European Regulation 216/2008]

[42] Published in German as "*Handhabung der von den Herstellern publizierten Instandhaltungsanweisungen und Betriebszeiten*"

For annex II aircraft (aircraft which do not fall within the scope of Regulation (EC) No. 216/2008), there is no legal obligation to draw up an individual maintenance programme. As a matter of principle, all maintenance documents provided by the manufacturers / type certificate holders are binding for these aircraft (see article 25, paragraph 2 of the VLL[43]*). However, exemptions in the sense of article 25, paragraph 2 (b and c) of the VLL can still be granted for annex II aircraft, but the possible exemptions are no longer generally published in individual TM technical communications. If the operator of an annex II aircraft wishes to deviate from maintenance documents or recommended operating times, they are also obliged to draw up an individualised maintenance programme for their aircraft in accordance with article 25, paragraph 2(e) of the VLL and to have it approved by FOCA (see technical communication TM 73.700-10).* […]"

Technical communication TM 73.700-10 'Maintenance programmes for aircraft excluded from the scope of Regulation (EC) No. 216/2008'[44], which came into force on 7 March 2014, included, inter alia, the following paragraphs:

"3. *Maintenance programmes*

3.1 Aircraft with maintenance instructions from the manufacturer

In order to maintain their airworthiness, annex II aircraft are generally subject to the maintenance requirements stipulated in the Ordinance on the Airworthiness of Aircraft (VLL; SR 748.215.1). If maintenance instructions / maintenance documents from the manufacturer(s) are available, these are considered as binding maintenance requirements for the continued airworthiness of the aircraft as per article 25, paragraph 2 of the VLL:

- *The operating times specified or recommended by the type certificate holder (usually the aircraft manufacturer);*
- *The maintenance plans, maintenance instructions, work instructions, task cards and repair instructions, and airworthiness directives issued by the type certificate holder (usually the aircraft manufacturer).*

Based on article 25 of the VLL, the operator is fundamentally obliged to comply with all maintenance work and operating times recommended by the manufacturer / type certificate holder in order to maintain the airworthiness of their aircraft.

According to article 25, paragraph 2 (b and c) of the VLL, in individual cases the Federal Office of Civil Aviation (FOCA) may define exemptions from recommended operating times and recommended maintenance documentation (see TM 02.020-35) – provided it is not an 'airworthiness limitation'. If an aircraft operator wishes to make use of such an exemption or to deviate from recommended operating times or recommended maintenance work, a specific/individualised aircraft maintenance programme must be drawn up for the aircraft concerned. In this programme, they may specify deviations from recommended operating times (e.g. the operating times for engines), subject to the presentation of alternative/additional inspection or test procedures. In these cases, the design of the aircraft maintenance programme is largely based on the provisions listed under M.A.302 in annex I of Regulation (EC) No. 2042/2003. The corresponding aircraft maintenance programme must be approved by FOCA (see article 25, paragraph 2(e) of the VLL) and may

[43] VLL: *Verordnung des UVEK über die Lufttüchtigkeit von Luftfahrzeugen* (DETEC Ordinance on the Airworthiness of Aircraft)

[44] Published in German as "*Instandhaltungsprogramme für Luftfahrzeuge die vom Geltungsbereich der Verordnung (EG) Nr. 216/2008 ausgenommen sind*"

only be used as a supplement to the maintenance instructions / maintenance documentation from the time of approval.

4. Formalities/communication

Any changes to the aircraft that have an influence on the aircraft maintenance programme, or changes to the aircraft maintenance programme itself, must be submitted to FOCA for re-approval prior to implementing the respective change."

A1.6.14.3 Aircraft maintenance programme

A1.6.14.3.1 General

According to their statements, Ju-Air had written an aircraft maintenance programme (AMP) after taking over the aircraft from the military. It could not be fully clarified at what point in time the maintenance work was based on this programme, neither could its structure nor what it contained.

The first record of FOCA's AMP approval is dated 4 March 1987.

On 30 November 1995, a completely new edition of the AMP marked as revision 0 was examined and approved by the Federal Office of Civil Aviation. At the time of the accident, the AMP with revision 5 dated 8 February 2011 was valid.

The following introductory text was written in the AMP under 'Organisation':

"*This aircraft maintenance programme for the JU 52/3m g4e and CASA 352 has been prepared for regular, civilian use of the aircraft, the programme lists all requirements to be performed during scheduled maintenance*.

These are historic aircraft and the aim is to ensure the continued airworthiness and operational readiness of the aircraft over the coming years. Continued airworthiness can only be maintained as long as airworthy spare parts are in stock, can be procured or manufactured.

The requirements have been determined taking the manufacturers' specifications into account and in accordance with current maintenance procedures as well as with regard to the age of the aircraft. Based on the experience gained during maintenance, this programme can and must be adapted or changed over time.

[…]

In the event of an increase in annual flight hours, low defect frequency and increasing experience, the annual cycle may be adjusted upwards (in the opposite case downwards) without changing the programme as such."

In order to reduce aircraft downtimes, maintenance work in the AMP was arranged to be progressive and cover nine areas of the aircraft. These areas were to be maintained successively at intervals of 35 operating hours. These nine intervals formed a cycle of 315 operating hours. Each engine was to be serviced every 105 operating hours and the respective areas of the airframe every 315 hours (see figure 32). The minimum annual maintenance was to consist of a complete cycle of these nine intervals. More in-depth maintenance stages, such as partial and major overhauls, are not defined.

The individual areas are based on the main sections of the operating instructions, as is the maintenance work.

JUNKERS JU-52/3mg 4e und CASA 352 Wartungsprogramm

Intervall No	1	2	3	4	5	6	7	8	9	1	2	usw.
Arbeitsumfang	Erster Zyklus (minimum jährlich)									2 Zyklus		
Motor No 1	X			X			X			X		
Motor No 2		X			X			X			X	
Motor No 3			X			X			X			X
Cockpit	X									X		
Kabine		X									X	
Rumpf			X									X
Flügel				X								
Leitwerk					X							
Steuerung						X						
Ausrüstung							X					
Benzin- & Öl-System								X				
Fahrwerk									X			
Mängel	X	X	X	X	X	X	X	X	X	X	X	X
Flugbereitschaft	X	X	X	X	X	X	X	X	X	X	X	X
35 Std. Ergänzung	X	X	X	X	X	X	X	X	X	X	X	X

Figure 32: Maintenance intervals in Ju-Air's Ju 52 aircraft maintenance programme.

Except for one single checkpoint, the task cards for the airframe, engines and propellers as well as the checklists that were included in the AMP have not been changed since the AMP was drawn up in 1995.

Observations made when examining the AMP include:

- In four out of the five revisions to the AMP since the new edition in 1995, only the operating times (TBO[45]) for the components have been changed, or rather increased.
- For some inspection points, the task cards used by the maintenance organisation differ from those listed in the AMP.
- The manufacturers' instructions required for all maintenance and repair work were not listed.
- The generic term 'engine units' is listed, but not the individual components.
- The AMP does not contain information on the following points, despite them being published in the manufacturers' instructions (see section A1.6.13), for example:

  - Partial overhauls of the engines

[45] TBO: Time between overhaul (operating time until overhaul)

- Partial and major overhauls of the airframe
- Repair processes
- Surface protection

- Furthermore, the following points were missing from the AMP:
  - Recurring maintenance (e.g. service bulletins)
  - Deviations from the type (e.g. modifications)
  - Comprehensive list of component operating times
  - Maintenance of NiCd batteries
  - Supplemental structural inspection documents (SSID) (see section A1.6.19)

Section 2.8 of Ju-Air's maintenance organisation exposition (MOE), 'Application of and compliance with maintenance documentation' contained the following:

"*This paragraph shall apply to the following documents*:

- *Part 145 and EASA AD*
- *Maintenance and repair manuals from the manufacturers*
- *Manufacturer instructions (service bulletins, etc.)*
- *Aircraft maintenance programmes from the manufacturers*
- *Publications from the competent authorities (aviation law, technical communications, etc.)*

The operations manager is responsible for ensuring that the above-mentioned documentation is available for all maintenance work planned on-site. They shall periodically verify that the documentation is in line with the latest version and shall procure any necessary supplements."

In addition, the following was described in section 2.10 'Compliance with aircraft maintenance programmes':

"The operations manager is responsible for ensuring that the relevant documents to be used for this purpose are already specified when planning maintenance work. When carrying out this work, they shall ensure that only the manufacturer's updated maintenance programme is used and that all the tasks included therein are fully completed before release to service."

During inspections carried out by FOCA over recent years, the following complaints had been raised regarding the aircraft maintenance programme:

Date	**Complaint level 2**
13 February 2018	"*No procedure to develop the maintenance program and process of its approval in accordance with M.A.302 is available in the MOE (chapter 2.30).*"
25 November 2016	"*The checklist based on the maintenance program, used for aircraft maintenance, should be reassessed to highlight the tasks that need an independent check in order to minimize the risk of multiple errors during maintenance*."

04 July 2013	"*The procedure Maintenance Program periodical 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[46] and the JAA[47] and applicability of AD[48] shall be corrected (CAME and EASA). A procedure on how Ju Air is performing a corrosion control program shall be added.*"

The following was recorded, not as a complaint, but as a comment, during an inspection that was carried out:

Date	Comment
16 May 2017	"*To improve the readability, the AMP is under review to highlight more precisely which task(s) need a duplicate inspection. Additionally, the CASA denomination has to be removed from the AMP as this aircraft has left the managed fleet*."

A1.6.14.3.2 Operating times

Maintenance measures and operating times, which are specified to maintain the airworthiness of the respective component, are defined by the manufacturers. These are usually binding instructions or airworthiness limitations.

For airworthiness-related parts or components, the operating time between overhaul (TBO) or a life limit is specified by the manufacturer. For non-airworthiness-related components, the manufacturer may waive a limitation on operating time. Such components can be in operation as long as they are found to be good (what is known as 'on condition') by visual inspection.

The AMP for Ju-Air's Ju 52 aeroplanes only lists the maximum permissible operating time and its tolerances for a few components (see figure 33). The operating times listed have been steadily increased over time by Ju-Air (see section A1.6.14.3.3). It is not apparent in the AMP whether the maximum operating times listed are a life limit or a TBO.

Furthermore, components with calendar-based operating times are listed, however it is not clear from the AMP whether these components have a life limit or whether they are to be reconditioned.

All other components that are not listed in this table are only checked visually to assess whether they are on condition during the respective progressive inspections.

BMW engine	1,500 hours + 10 %
Ju-PAK propeller	1,200 hours + 10 % or 6 years (until next annual inspection max. 7 years)

46 MME: Maintenance management exposition. The MME has been replaced by the continuing airworthiness management exposition (CAME).

47 JAA: Joint Aviation Authorities. The JAA has been replaced by EASA (European Aviation Safety Agency).

48 AD: Airworthiness directive

Hoffmann propeller	See service bulletin 1
Engine units	Same as engine
Pallas carburettor	Bench test when reaching the engine TBO Major overhaul when reaching 2× the engine TBO
Mechanical fuel pump	Bench test when reaching the engine TBO Major overhaul when reaching 2× the engine TBO
Compressed air tank	10 years
Portable oxygen cylinder	10 years
Engine-fire extinguishers	20 years
Emergency location transmitter battery	6 years
Compass system and magnetic compass	2 years and after engine replacement
Electric fuel pump	Carbon inspection every 500 hours Overhaul, every 2,500 hours
Oil and fuel lines between engine and firewall	10 years (until next annual inspection max. 11 years)

Figure 33: The maximum operating times listed in the AMP for components in Ju 52 aircraft.

At the request of FOCA, a life limit of ten years was specified for oil and fuel lines between the engine and the firewall when the AMP was last amended in 2011. For all other fuel lines in the aircraft, no operating time limit was defined.

The electric fuel pumps, also referred to as fuel pumps or booster pumps in Ju-Air documentation, had been deactivated since 2007, but remained installed in the fuel system. The progressive inspection checklist includes the following inspection point under ‘Fuel and oil system’:

“*Check both electric fuel pumps for leaks, overall condition, mounting and operation*.”

This was amended with a handwritten note stating “*Electrically inop. see HIL*” and attested as “*n/a*”.

According to the component cards for both electric fuel pumps, the pumps were installed in HB-HOT after an overhaul on 7 July 1997. At this time HB-HOT had recorded 5,950 operating hours. Since then, the pumps had been installed for 4,239 operating hours without ever being overhauled.

Furthermore, no operating time limit had been defined in the AMP for the landing gear. According to information from Ju-Air, the landing gear as well as assemblies from the flight control system have never been completely overhauled, i.e. disassembled and crack-tested since the aeroplanes had been acquired from the military, which is backed up by the files.

The engine manufacturer did not specify any operating time limits for the magnetos; however, maintenance work had to be carried out on the magnetos every

20 and 50 hours. In the AMP, a TBO of 1,500 h (+ 10%) was specified for the magnetos and the following maintenance work had to be carried out every 105 operating hours:

- Check magnet interrupter for cleanliness, condition and distance 0.3 to 0.4 mm. If 0.5 mm, replace magnet.
- Refill magnet hinged-lid lubricator until wick is fully soaked.
- Grease magneto after TSO 650 h, grease distributor rotor arm with NBU30.

A1.6.14.3.3 Increase in operating time limit for the engines

According to the files, in 1985 the time between overhaul (TBO) for the engines was set at 1,000 operating hours. It could not be determined which value applied before.

At the request of Ju-Air, FOCA approved an increase to 1,200 operating hours in 1996, and an increase to 1,500 operating hours in 2004.

An attempt to increase the TBO to 1,800 operating hours was made between 2010 and 2014 following approval by FOCA. Two of five engines did not reach this operating time due to damage to supercharger bearings. One of these two engines, serial number 68842, was installed on HB-HOT at the time of the accident as the centre engine. After this unsuccessful attempt to increase the TBO to 1,800 operating hours, Ju-Air decided in 2014 to leave the TBO at 1,500 operating hours in order to preserve its engines.

The internal report for this attempt to increase the TBO concludes with the following remark:

“This concludes the attempt, the running time for the engines remains at 1,500 operating hours + 10 % in order to not place extreme stress on the engines.”

The following was noted from FOCA in the respective approval to increase the TBO:

“If, during the course of maintenance work, problems with the condition of the engines become apparent for any reason as a result of the increased permissible operating time, the matter would have to be re-examined. The measures that may be necessary for this purpose are set out in the MOEs of the companies involved.”

Below is an excerpt from Naef Flugmotoren AG’s MOE as mentioned by FOCA concerning the necessary measures:

“2.18.2. Internal measures

All operational faults, incidents and any trends are analysed within the scope of monitoring as per NAEF MOE sections 1.2.2 and 2.18 and are integrated into the training programme if necessary.”

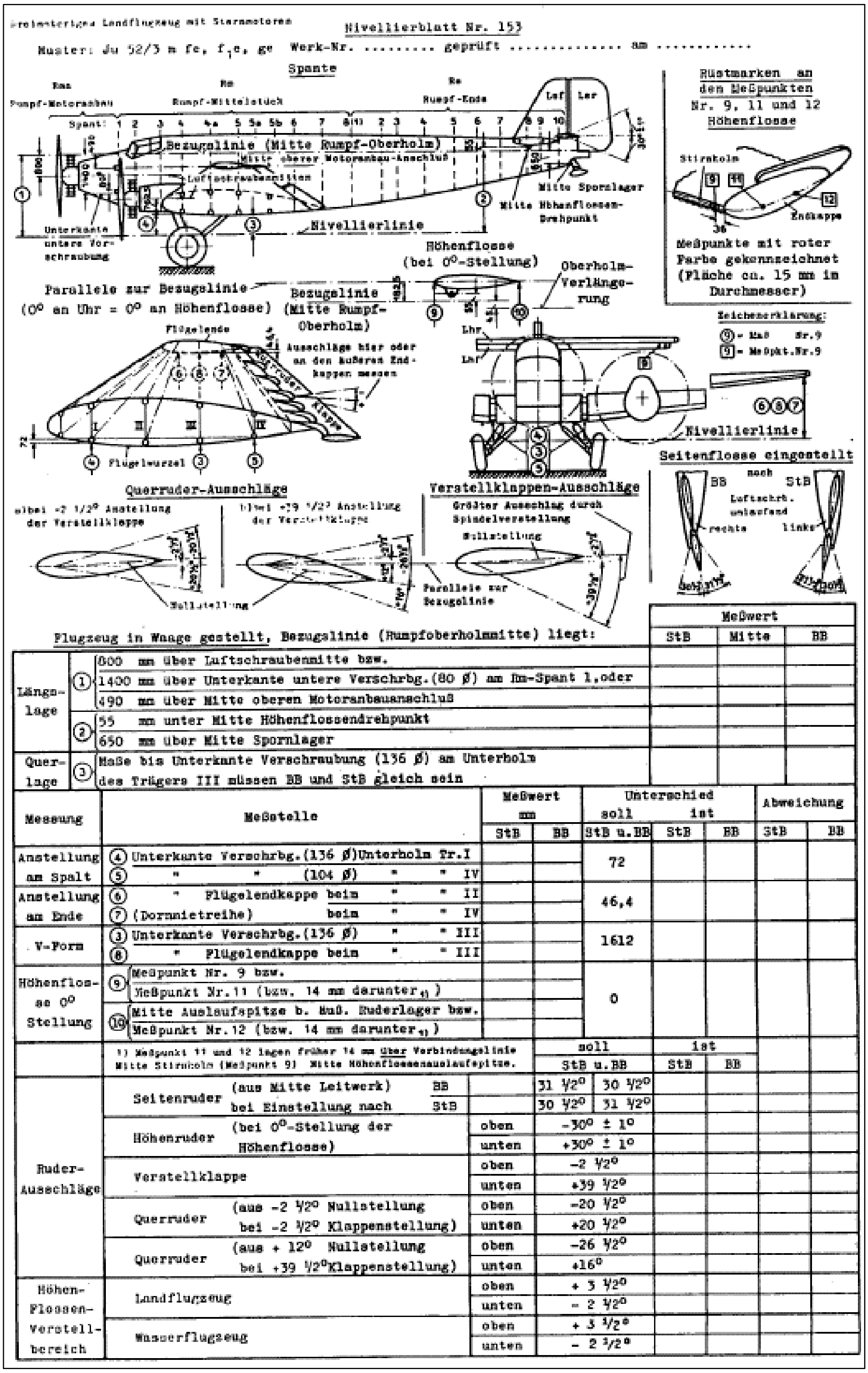
MOE section 1.2.2 describes the mandatory system for reporting faults and incidents (see annex A1.17).

This note from FOCA as a stipulation for the respective TBO increase was not followed up due to the lack of information regarding incidents and the non-systematic monitoring and safety management conducted by Ju-Air.

A1.6.14.3.4 Control settings

Section 4 of the operating instructions for the Ju 52, ‘Controls’, details the adjustment procedure, the necessary adjustment tools and the inspection intervals.

The nominal deflections for the control surfaces are listed on calibration sheet no. 153 from section 12 'Calibration and measurement sheets' of the operating instructions, (see figure 34). This sheet was intended by the manufacturer as a log for entering the measured values.



Flugzeug in Waage gestellt, Bezugslinie (Rumpfoberholmmitte) liegt:

			Meßwert StB	Meßwert Mitte	Meßwert BB
Längs-lage	①	800 mm über Luftschraubenmitte bzw.			
		1400 mm über Unterkante untere Verschrbg. (80 ø) am Rm-Spant 1, oder			
		490 mm über Mitte oberen Motoranbauanschluß			
	②	55 mm unter Mitte Höhenflossendrehpunkt			
		650 mm über Mitte Spornlager			
Quer-lage	③	Maße bis Unterkante Verschraubung (136 ø) am Unterholm des Trägers III müssen BB und StB gleich sein			

Messung	Meßstelle	Meßwert mm StB	Meßwert mm BB	Unterschied soll StB u. BB	Unterschied ist StB	Unterschied ist BB	Abweichung StB	Abweichung BB
Anstellung am Spalt	④ Unterkante Verschrbg. (136 ø) Unterholm Tr. I			72				
	⑤ " " (104 ø) " " IV							
Anstellung am Ende	⑥ " Flügelendkappe beim " " II			46,4				
	⑦ (Dornnietreihe) beim " " IV							
V-Form	③ Unterkante Verschrbg. (136 ø) " " III			1612				
	⑧ " Flügelendkappe beim " " III							
Höhenflosse 0° Stellung	⑨ Meßpunkt Nr. 9 bzw.			0				
	Meßpunkt Nr. 11 (bzw. 14 mm darunter 1))							
	⑩ Mitte Auslaufspitze b. äuß. Ruderlager bzw.							
	Meßpunkt Nr. 12 (bzw. 14 mm darunter 1))							

1) Meßpunkt 11 und 12 lagen früher 14 mm über Verbindungslinie Mitte Stirnholm (Meßpunkt 9) Mitte Höhenflossenauslaufspitze.

				soll StB u. BB	ist StB	ist BB		
Ruder-Ausschläge	Seitenruder (aus Mitte Leitwerk) bei Einstellung nach	BB		31 ½° / 30 ½°				
		StB		30 ½° / 31 ½°				
	Höhenruder (bei 0°-Stellung der Höhenflosse)		oben	-30° ± 1°				
			unten	+30° ± 1°				
	Verstellklappe		oben	-2 ½°				
			unten	+39 ½°				
	Querruder (aus -2 ½° Nullstellung bei -2 ½° Klappenstellung)		oben	-20 ½°				
			unten	+20 ½°				
	Querruder (aus + 12° Nullstellung bei +39 ½° Klappenstellung)		oben	-26 ½°				
			unten	+16°				
Höhen-Flossen-Verstell-bereich	Landflugzeug		oben	+ 3 ½°				
			unten	- 2 ½°				
	Wasserflugzeug		oben	+ 3 ½°				
			unten	- 2 ½°				

Figure 34: Calibration sheet no. 153, which was intended by the manufacturer as a test log for control surface deflections. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

The test logs in the technical files were incomprehensible (see figure 35). Practically no measured values were recorded. Moreover, the method of measurement was not apparent. Furthermore, the rudder deflections for right- and left-rotating propellers were listed, exactly as they had been written on calibration sheet no. 153 as a template. Ju-Air's Ju 52 aeroplanes had clockwise-rotating propellers. According to this, the rudder should be adjusted in line with "*Vertical stabiliser, left: 31.5°/30.5°*".

Inspection of the control surface deflections:

During the period from 30 October 2017 to 15 January 2018, progressive inspection nos. 6 to 9 were carried out. During progressive inspection no. 6, the control and control-surface settings were checked. The values of the settings for the controls recorded in the work report were incomprehensible. Of the 13 prescribed value entries, only one value was logged. The method of measurement and the time when this work was carried out were not apparent.

2	Überprüfe Ruderausschläge wie folgt (Nivellierblatt No 153) :		
	Ruder, Klappe oder Flosse	**Soll**	**Ist**
	Seitenruderpedale in 0-Lage Seitenruder (Seitenflosse links) (Seitenfl. rechts)	3° rechts 31,5°/30,5° 30,5°/31,5°	O.k.
	Höhenruder (Höhenflosse 0 Grad) auf ab	 30° + /° 30° - /°	30° + -
	Verstellklappe auf ab	2,5° 39,5°	✓ o.k
	Querruder (bei 2,5° Nullstellung und bei - 2,5° Klappenstellung) (bei 12,0° Nullstellung und bei 39,5° Klappenstellung	 auf 20,5° ab 20,5° auf 26,5° ab 16,0°	o.k.
	Höhenflosse	auf 3,5° ab 2,5°	o.k.

Figure 35: Extract from the work report for progressive inspection no. 6 with reference to calibration sheet no. 153.

Repainting:

According to the work report dated 23 October 2017, HB-HOT was repainted. For this purpose, the aircraft was flown to Altenrhein (LSZR). The elevators and rudder as well as the auxiliary wings were dismantled and reassembled after repainting. The operating instructions (see section A1.6.13.1.1) were used as the instructions when disassembling and reassembling the aircraft. According to the work report, the controls were checked "*for free movement and proper function*". Afterwards the aircraft was flown back to Dübendorf. The work report for the repainting was signed off after completion of the work on 5 December 2017. A weight sheet was prepared on 21 December 2017.

The exact process for the inspections of the controls and control surfaces as well as that of the inspection of the controls' settings could not be plausibly explained by the maintenance staff even with the help of the maintenance documents.

Based on the technical files and the information provided by the maintenance team, it is highly probable that not all control surfaces were checked or adjusted to the values specified in the operating instructions.

A1.6.14.3.5 On-board battery

A nickel-cadmium (NiCd) battery was installed in HB-HOT at the time of the accident.

According to statements made by Ju-Air, since their taking over of the Ju 52 aeroplanes in the 1980s, maintenance work on the NiCd batteries had been carried out by the Swiss Air Force's Logistics corps at Dübendorf Air Base. This was evident from the technical files for HB-HOT.

Ju-Air and Naef Flugmotoren AG were not authorised to carry out maintenance work on any batteries. They also did not possess the necessary infrastructure nor did they employ licensed personnel. No information about the NiCd battery was written in the AMP.

A1.6.14.3.6 Periodic inspections of the pitot-static system

For aircraft certified for VFR flights only, there is no requirement for periodic checks of the pitot-static system.

There is no information in the aircraft maintenance programme (AMP) regarding a periodic inspection of the accuracy of the airspeed indicator. For systems and functions that are not explicitly listed in the AMP, it is assumed that any faults are detected during operation. In the case of the air speed indicator, any obvious malfunctions can be identified by comparing two or more independent indicators. However, this is not possible in Ju-Air's Ju 52 aircraft, as the two speed indicators are connected to the same pressure source and there is no redundancy.

As ordered by Ju-Air, HB-HOT's pitot-static system was tested for leaks by an approved maintenance organisation in May 2017 but not for display accuracy. Although Ju 52 aircraft are operated by Ju-Air under visual flight rules, a full inspection, including speed indicators, would be appropriate for the reasons mentioned above, even if the regulations do not require it.

In order to be able to assess the accuracy of the indicated airspeed (IAS), HB-HOT's flight on 3 August 2018 was evaluated during the investigation. A comparison parameter, defined as IAS', was created for this purpose. The IAS' was calculated based on the true airspeed (TAS), taking into account the density altitude. The TAS was in turn calculated using the ground speed (GS) and the wind component (WK). The wind component (wind speed and wind direction) was determined along the flight path using the prevailing meteorological model.

The GS was transmitted from HB-HOT's mode S transponder to the radar system on the ground when radar coverage was possible. Due to the topography, this only occurred in certain locations. In table 14 below, these locations are designated as Rigi 1 to 5 and Lake Zurich.

Posi-tion	Altitude			IAS[1)]	TAS = GS-WK[2)]		TAS → IAS'[3)]		Δ = IAS - IAS'
	m AMSL	ft AMSL	ft AMSL	km/h	GS (kt)	TAS (kt)	km/h	km/h'	km/h
Lake Zurich	1,264[b)]	4,147[a)]	–	140	96	88	163	150.4	-10.4
Rigi 1	1,897[b)]	5,950[a)]	6,224[c)]	162.5	116	108.2	200.4	178.9	-16.4
Rigi 2	1,865[b)]	5,920[a)]	6,119[c)]	150	112	103.3	191.3	171.1	-21.1
Rigi 3	1,865[b)]	5,920[a)]	6,119[c)]	162.5	116	108.4	200.8	179.6	-17.1
Rigi 4	1,865[b)]	5,920[a)]	6,119[c)]	150	110	101.3	187.6	167.8	-17.8
Rigi 5	1,865[b)]	5,920[a)]	6,119[c)]	150	106	98	181.5	162.4	-12.4

Table 14: Comparison of the indicated airspeeds.

a) Altitude read-out on the altimeter in the cockpit, adjusted QNH 1,021 mbar

b) True altitude above mean sea level

c) Standard altitude, 1,013.2 mbar,15°C, from mode S transponder

1) Indicated air speed (IAS) read in the cockpit

2) Ground speed (GS) from the mode S transponder, wind component (WK) derived from the meteorological model

3) True air speed (TAS) converted to km/h and then indicated air speed (IAS') determined in km/h'

The above table reveals that the indicated airspeed (IAS) was 10 to 20 km/h lower than the reference IAS'. This may be due to the measuring accuracy of the indicator in the aircraft, but on the other hand, the calculated meteorological model is not completely accurate.

The evaluated radar data were mainly collected in the area around Mount Rigi. It can be assumed, however, that the indicated airspeed (IAS) in the area where the accident took place exhibited approximately the same deviation as described above.

The detected deviation is not regarded as critical because the actual airspeed is greater than the indicated airspeed.

A1.6.14.3.7 Oil change

According to the task cards for Ju-Air’s engines, the oil had to be changed every other progressive inspection for the respective engine, i.e. after 210 h (+/- 10 %). In contrast, the engine manufacturer’s operating instructions stipulate an oil change every 20 operating hours.

A1.6.14.3.8 Propeller

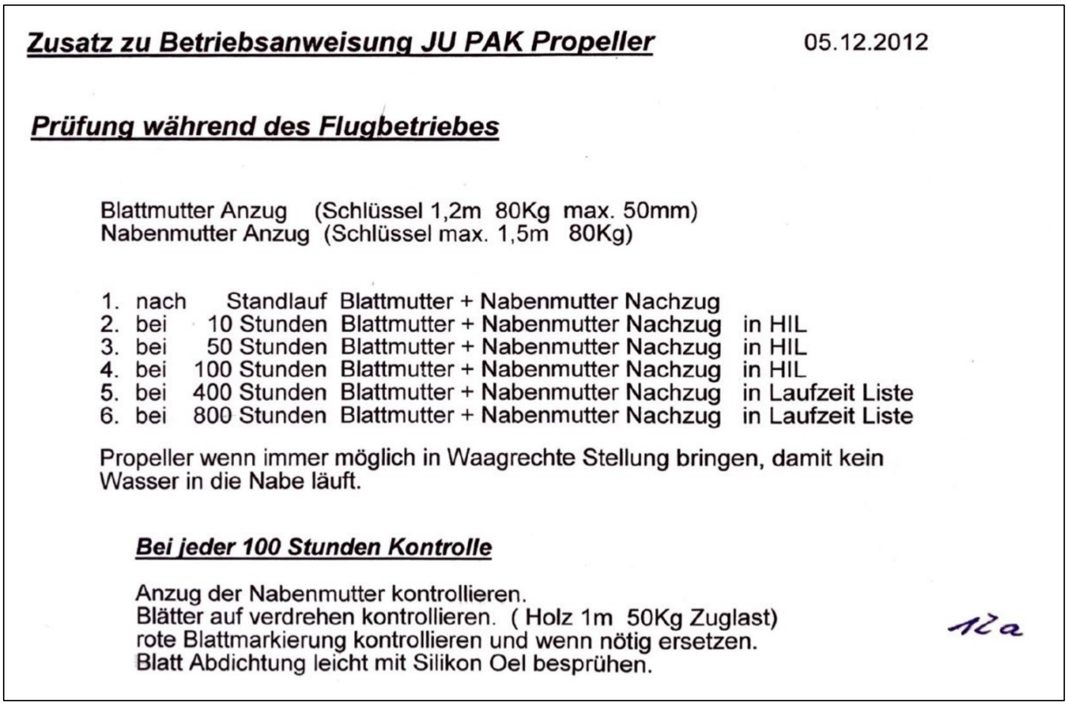
The task cards in the AMP include the following inspection points concerning the maintenance of the propellers:

35-hour inspection	*Clean propeller position 1/2/3 or polish with a suitable paste (especially the leading edge)*
105-hour inspection	*Check propeller for free play. Max. 3 mm (without spark plugs)*
	Check propeller blades for damage, hub for play. *Check that pitch is correct.* *Secure propeller nut.*

It was found that the inspection points listed on the task cards used by the maintenance team did not fully correspond with the inspection points listed in the AMP.

In Ju-Air's copy of the aircraft manufacturer's operating and maintenance instructions, an additional sheet had been inserted, which lists the intervals for blade- and hub-nut retightening (see figure 36). It also includes the tasks for a 100-hour inspection.

The torques used for tightening the nuts were in line with the manufacturer's specifications, however, the intervals were not. Also, according to the technical files, the propellers were never subjected to a main inspection after 200 operating hours.



Zusatz zu Betriebsanweisung JU PAK Propeller 05.12.2012

Prüfung während des Flugbetriebes

Blattmutter Anzug (Schlüssel 1,2m 80Kg max. 50mm)
Nabenmutter Anzug (Schlüssel max. 1,5m 80Kg)

1. nach Standlauf Blattmutter + Nabenmutter Nachzug
2. bei 10 Stunden Blattmutter + Nabenmutter Nachzug in HIL
3. bei 50 Stunden Blattmutter + Nabenmutter Nachzug in HIL
4. bei 100 Stunden Blattmutter + Nabenmutter Nachzug in HIL
5. bei 400 Stunden Blattmutter + Nabenmutter Nachzug in Laufzeit Liste
6. bei 800 Stunden Blattmutter + Nabenmutter Nachzug in Laufzeit Liste

Propeller wenn immer möglich in Waagrechte Stellung bringen, damit kein Wasser in die Nabe läuft.

Bei jeder 100 Stunden Kontrolle

Anzug der Nabenmutter kontrollieren.
Blätter auf verdrehen kontrollieren. (Holz 1m 50Kg Zuglast)
rote Blattmarkierung kontrollieren und wenn nötig ersetzen.
Blatt Abdichtung leicht mit Silikon Oel besprühen.

Figure 36: Intervals for blade- and hub-nut retightening. Signature removed by the STSB.

Propeller pitch adjustment on Ju-Air's Ju 52 aircraft was carried out by companies in Germany on their premises, in each case as part of a major overhaul.

After a major overhaul, Ju-Air applied a mark (line) on each twelve-point nut and the corresponding propeller blade using red nail polish (see figure 37). This marking was intended to aid in the detection of a loose or twisted propeller blade.

After retightening a blade nut, this marking had to be reapplied if necessary.

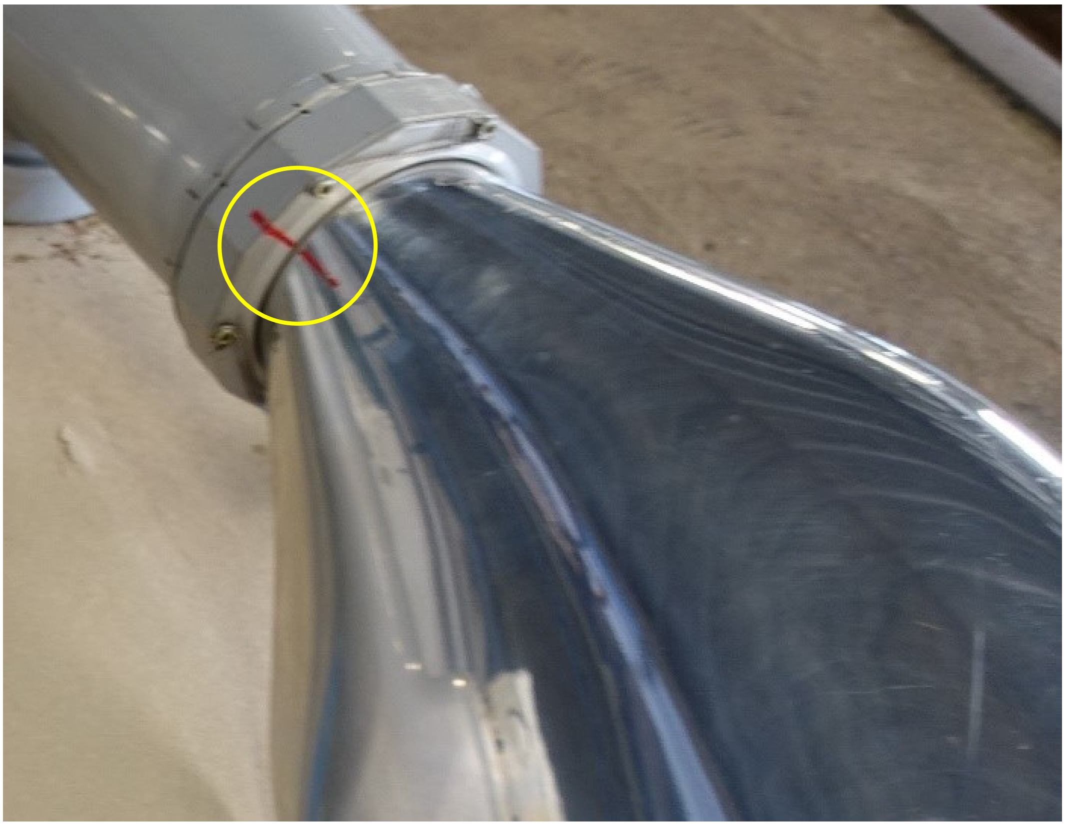


Figure 37: Red marking on the twelve-point nut and propeller blade (yellow circle).

From 2000 onwards, new propeller blades were manufactured based on pattern parts by a Czech aviation-approved company (see section A1.6.17.2.6). No release certificates[49] for the propeller blades mounted on HB-HOT were found in the files.

Due to the high degree of damage to the three propellers of HB-HOT, it was not possible to determine the pitch of the propeller blades.

There was no recorded data available for the overhaul of the propeller hubs. Nevertheless, the conical rings, which hold the propeller blades in the hubs, affected by corrosion were mechanically machined by a company not certified to provide parts for use in aviation. The propeller blades, which had either been manufactured based on pattern parts or had been reconditioned, were subsequently reassembled. Hubs were repeatedly overhauled in this way and as such, some of them exhibited the same defects again after short operating times. The responsible persons lacked the quality awareness necessary for this work. In some cases, the existing serial numbers on the hubs were removed and replaced by new numbers.

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

This is not permitted for aircraft parts. On HB-HOT, the serial numbers for the left and right hubs had been replaced.

The propeller blade's conical root is mounted into the propeller hub's corresponding conical ring; this is a frictional connection. Corrosion, wear or an inaccurate fit of the two conical surfaces can cause the frictional connection to weaken during operation and the propeller blades to become loose. This leads to changes in propeller pitch and vibrations.

Based on the poor technical condition of the connection between the propeller blades and the hub, and the resulting risk of a spontaneous change in the pitch of the propeller, it can be concluded that the propellers for the Ju 52 aircraft were no longer airworthy.

A1.6.14.3.9 Evaluation

At the time of the accident, the AMP with revision 5 dated 08 February 2011 was valid.

Ju-Air's AMP exhibited severe deficits in various areas and had not been adapted in line with the age of the aircraft and its use. For this reason, many defects in the aircraft and the engines remained undetected for long periods of time and the airworthiness of the Ju 52 fleet could not be guaranteed.

For the most part, the aircraft and engine manufacturers' maintenance instructions were not implemented in the AMP and were therefore never executed. This shows that the maintenance organisations did not follow the appropriate manufacturers' instructions.

The following important points were not defined in the AMP:

- Partial and major overhauls of the airframe according to the manufacturer
- Partial overhauls of engines according to the manufacturer
- Deviations from the manufacturers' maintenance instructions
- Corrosion protection programme
- Supplemental structural inspection document (SSID) (see section A1.6.19)
- Deviations from the type specification (STCs, modifications, etc.)
- Comprehensive list of component operating times
- Repair processes
- Recurring maintenance (e.g. service bulletins)
- Maintenance of NiCd batteries (see section A1.6.14.3.5)

Furthermore, the AMP has not been adapted to take into consideration the constant ageing of the aircraft structures, engines and systems over the last few decades. For example, no reliability programmes have been developed. Although various FOCA inspections raised complaints about this, Ju-Air's maintenance organisation did not comply with this request.

The intervals for the defined operating hours strongly deviated from the manufacturers' specifications. For these historic aircraft, which are approximately 80 years old, the intervals and cycles as defined in Ju-Air's AMP cannot meet all of the requirements for continued airworthiness. It is, for example, not appropriate to only change the engine oil at every other progressive inspection for economic reasons, i.e. after 210 operating hours, and this process should be reconsidered. Particularly in view of the BMW 132 A3 engine not being equipped with a modern oil filter system. The engine may have been equipped with a magnet with the intention of it being visually inspected for metallic abrasion debris, but was not fitted with a system that could trigger a warning in the cockpit.

Over the last 15 years, the AMP has not been adapted to reflect knowledge gained during maintenance. In four of the five revisions, only the operating times for components were changed, or rather increased. It is incomprehensible that the operating hours for components, especially engines, have been increased several times, and approved by FOCA, despite known engine faults or system malfunctions. At the time of the increase in the respective operating hours, the increase was, again, never questioned based on the age of the components and their reliability. This clearly shows a lack of understanding in terms quality as well as a lack of safety awareness among the two maintenance organisations.

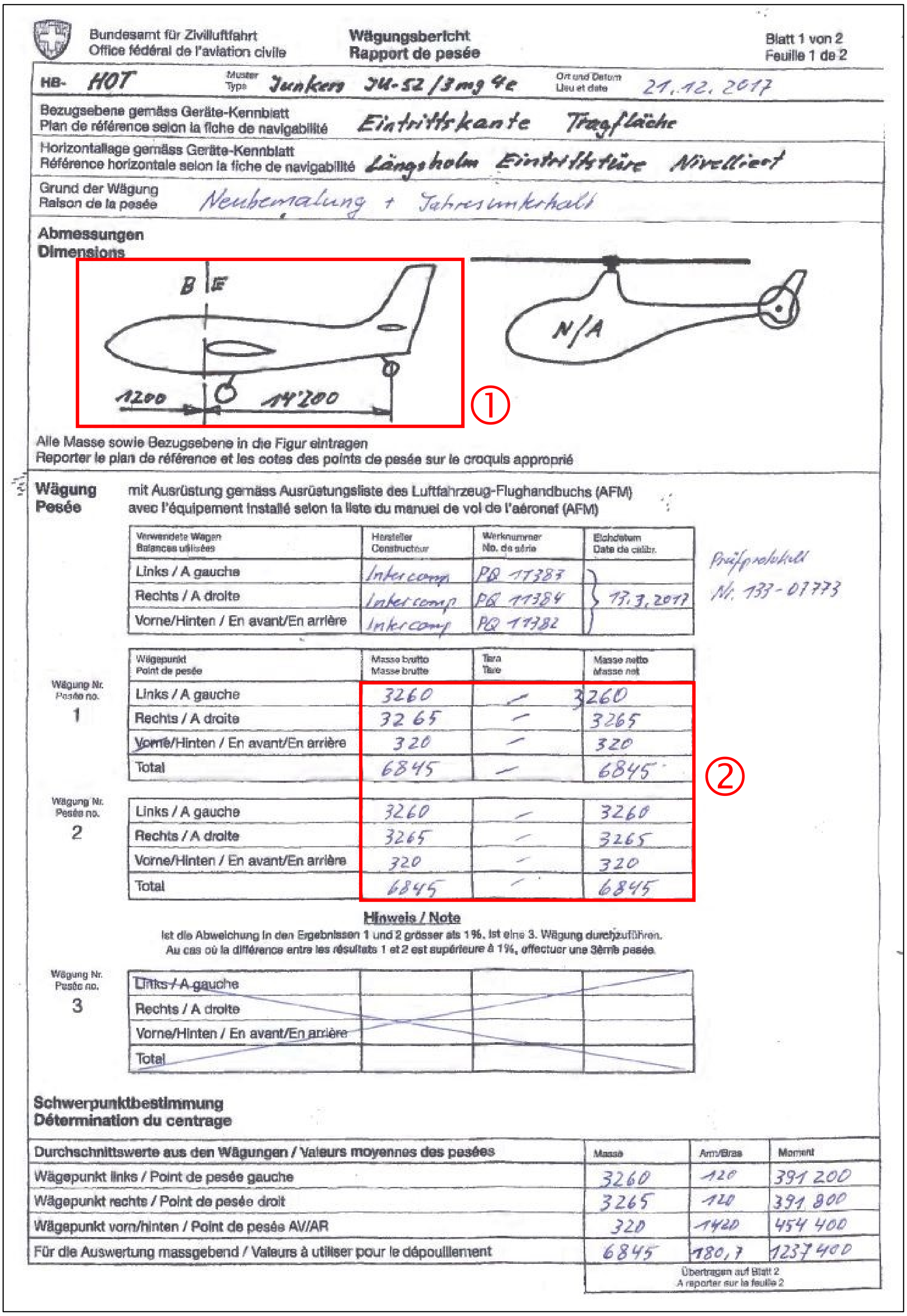
For maintenance work on the aircraft, task cards were used with inspection points that in places deviate from the task cards in the AMP audited by FOCA. This demonstrates that Ju-Air's CAMO processes were not effective.

During inspections carried out by FOCA in the years leading up to the accident, several complaints had been raised regarding the aircraft maintenance programme (see section A1.6.14.3). For the most part, these were not remedied and FOCA did not take any measures in response.

A1.6.14.4 Aircraft weighing

HB-HOT was last weighed on 21 December 2017 after the entire aircraft had been repainted. FOCA's weight sheet was used for this purpose. Observations made when examining the weight sheet include:

- The arm 'reference datum – main landing gear' was drawn incorrectly, the measured values (in mm) were correct (see figure 38, (1)).
- All measured values were given without units.
- It is mandatory and makes metrological sense to weigh the aircraft at least twice in succession. If the deviation in the measured values from the first and second weighing is greater than 1 %, a third weighing must be carried out. In HB-HOT's weight sheet, the measured values entered for the first and second weighing were exactly the same (2).



Bundesamt für Zivilluftfahrt
Office fédéral de l'aviation civile

Wägungsbericht
Rapport de pesée

Blatt 1 von 2
Feuille 1 de 2

HB- HOT	Muster / Type: Junkers JU-52/3mg4e	Ort und Datum / Lieu et date	21.12.2017
Bezugsebene gemäss Geräte-Kennblatt / Plan de référence selon la fiche de navigabilité	Eintrittskante Tragfläche		
Horizontallage gemäss Geräte-Kennblatt / Référence horizontale selon la fiche de navigabilité	Längsholm Eintrittstüre Nivelliert		
Grund der Wägung / Raison de la pesée	Neubemalung + Jahresunterhalt		

Abmessungen
Dimensions

Alle Masse sowie Bezugsebene in die Figur eintragen
Reporter le plan de référence et les cotes des points de pesée sur le croquis approprié

Wägung / **Pesée** — mit Ausrüstung gemäss Ausrüstungsliste des Luftfahrzeug-Flughandbuchs (AFM) / avec l'équipement installé selon la liste du manuel de vol de l'aéronef (AFM)

Verwendete Wagen / Balances utilisées	Hersteller / Constructeur	Werknummer / No. de série	Eichdatum / Date de calibr.
Links / A gauche	Intercomp	PQ 11383	13.3.2017
Rechts / A droite	Intercomp	PQ 11384	
Vorne/Hinten / En avant/En arrière	Intercomp	PQ 11382	

Prüfprotokoll Nr. 133-01773

Wägung Nr. / Pesée no.	Wägepunkt / Point de pesée	Masse brutto / Masse brute	Tara / Tare	Masse netto / Masse net
1	Links / A gauche	3260	–	3260
	Rechts / A droite	3265	–	3265
	Vorne/Hinten / En avant/En arrière	320	–	320
	Total	6845	–	6845
2	Links / A gauche	3260	–	3260
	Rechts / A droite	3265	–	3265
	Vorne/Hinten / En avant/En arrière	320	–	320
	Total	6845	–	6845

②

Hinweis / Note
Ist die Abweichung in den Ergebnissen 1 und 2 grösser als 1%, ist eine 3. Wägung durchzuführen.
Au cas où la différence entre les résultats 1 et 2 est supérieure à 1%, effectuer une 3ème pesée.

Wägung Nr. / Pesée no.	Wägepunkt / Point de pesée			
3	Links / A gauche			
	Rechts / A droite			
	Vorne/Hinten / En avant/En arrière			
	Total			

Schwerpunktbestimmung
Détermination du centrage

Durchschnittswerte aus den Wägungen / Valeurs moyennes des pesées	Masse	Arm/Bras	Moment
Wägepunkt links / Point de pesée gauche	3260	120	391 200
Wägepunkt rechts / Point de pesée droit	3265	120	391 800
Wägepunkt vorn/hinten / Point de pesée AV/AR	320	1420	454 400
Für die Auswertung massgebend / Valeurs à utiliser pour le dépouillement	6845	180,7	1237 400

Übertragen auf Blatt 2
A reporter sur la feuille 2

Figure 38: Weight sheet, page 1. Source: Technical records HB-HOT.

At the end of the weighing, the mass, the centre of gravity and the aircraft's moment when empty were calculated and entered on the weight sheet (see figure 39, (3)). These values have been verified by the STSB and were found to be correct.

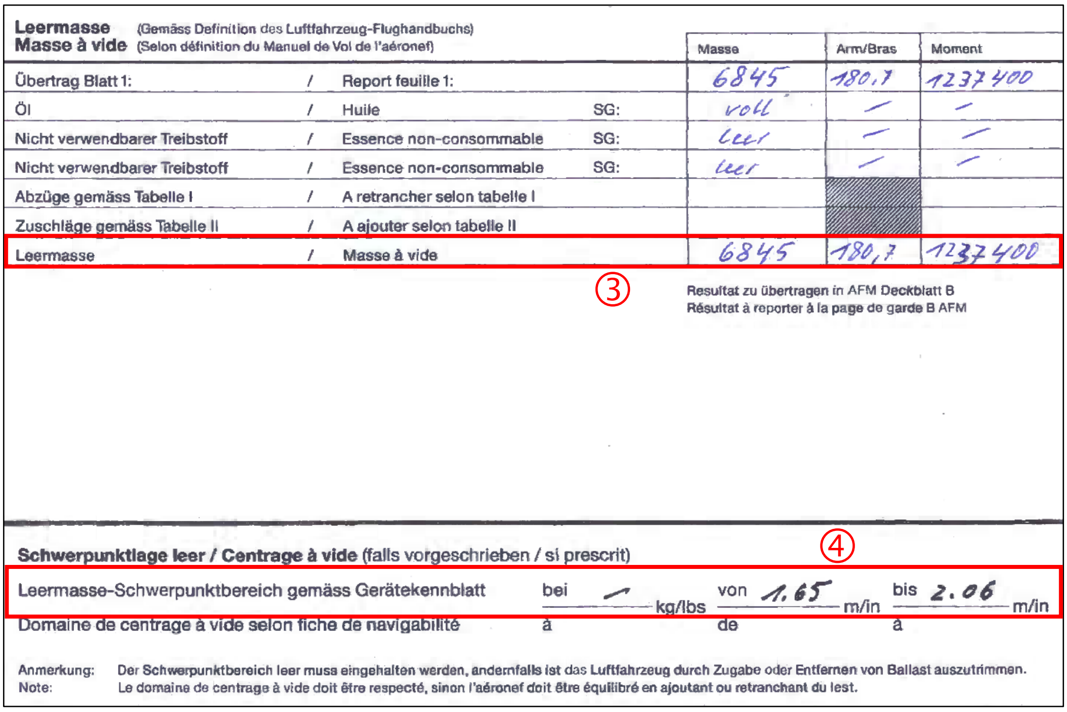
Furthermore, Ju-Air entered the values 1.65 (m) and 2.06 (m) under 'Centre of gravity range when empty according to the equipment data sheet'. No value was entered for the empty mass (4).

The values stated apply for the aircraft's centre of gravity range when laden.

In the operating instructions for the Ju 52/3m g4e, in the loading plans, the centre of gravity range was defined as follows:

"*Maximum permissible forward:* *1,650 mm*

Maximum permissible aft: *2,060 mm*"



Leermasse (Gemäss Definition des Luftfahrzeug-Flughandbuchs) / **Masse à vide** (Selon définition du Manuel de Vol de l'aéronef)			Masse	Arm/Bras	Moment
Übertrag Blatt 1:	/ Report feuille 1:		6845	180,7	1237400
Öl	/ Huile	SG:	voll	–	–
Nicht verwendbarer Treibstoff	/ Essence non-consommable	SG:	leer	–	–
Nicht verwendbarer Treibstoff	/ Essence non-consommable	SG:	leer	–	–
Abzüge gemäss Tabelle I	/ A retrancher selon tabelle I				
Zuschläge gemäss Tabelle II	/ A ajouter selon tabelle II				
Leermasse	/ Masse à vide		6845	180,7	1237400

③

Resultat zu übertragen in AFM Deckblatt B
Résultat à reporter à la page de garde B AFM

Schwerpunktlage leer / Centrage à vide (falls vorgeschrieben / si prescrit)

④

Leermasse-Schwerpunktbereich gemäss Gerätekennblatt bei – kg/lbs von 1.65 m/in bis 2.06 m/in
Domaine de centrage à vide selon fiche de navigabilité à de à

Anmerkung: Der Schwerpunktbereich leer muss eingehalten werden, andernfalls ist das Luftfahrzeug durch Zugabe oder Entfernen von Ballast auszutrimmen.
Note: Le domaine de centrage à vide doit être respecté, sinon l'aéronef doit être équilibré en ajoutant ou retranchant du lest.

Figure 39: Extract from the weight sheet, page 2. Source: Technical records HB-HOT.

A1.6.15 Borescope inspection of the wing spars

On 9 January 2006, the inside of spars I and II of the two outer wings was inspected using a borescope[50]. According to the work report, neither cracks nor corrosion were detected and the condition of the spar tubes was judged to be visually faultless. Subsequently, spars I to IV were treated with the corrosion inhibitor ACF 50. According to the files, the centre wing's spars were not inspected. No other information was recorded in the files.

In 2015, a fracture was discovered on lower spar II from the centre wing of the Ju 52/3m operated by Deutsche Lufthansa Berlin-Stiftung (DLBS). On the basis of this information, an inspection of the wing spars was carried out on HB-HOT on 24 February 2017 shortly before reaching 10,000 operating hours. During this inspection, the outer wings remained mounted on the fuselage. For this work, a drainage maintenance company was commissioned to carry out an inspection of the eight spar tubes over the aircraft's entire wingspan, together with Ju-Air's responsible aircraft mechanic. However, neither the person from the drainage maintenance company nor the aircraft mechanic had the necessary experience and level of expertise in performing borescope inspections and damage assessments on aircraft. The inspection of the spar tubes began at the left- and right-hand wingtips respectively. Due to the length of the borescope, the spars in one outer

[50] A borescope is an optical device used to illuminate and inspect the inside of a structure that cannot otherwise be seen.

wing, the centre wing and up to approximately one metre of the opposite outer wing could be seen.

This inspection ultimately revealed a crack in lower spar I of the centre wing (see section A1.6.16.2.3).

When reviewing these recordings, the STSB detected large quantities of drilled-out rivets, swarf and rivets that had fallen out by themselves in the spar tubes (see figures 40 to 42). Dirt deposits and flaking anti-corrosion paint were present in places. In some places, small quantities of the ACF 50 corrosion inhibitor applied during the borescope inspection on 9 January 2006 were still visible in the tubing (see figure 40). The condition of the tubing under this layer could not be assessed. The borescope's camera lens was moved at relatively high speed through the spar tubes during the inspection on 24 February 2017. This led to insufficient image and video quality, meaning that it was not possible to assess the condition of the spar tubes more precisely.

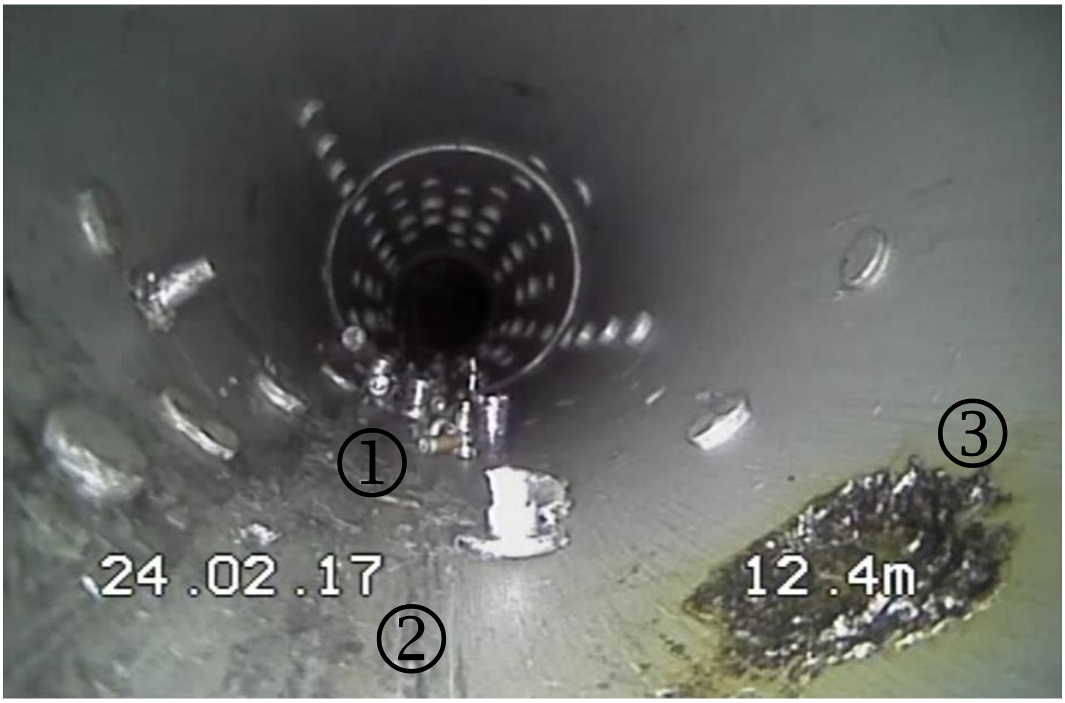


Figure 40: Left-hand outer wing, lower spar I – various rivets lying around (1), partly flaked off anti-corrosion paint (2) and dried ACF 50 corrosion inhibitor (3). Photograph provided by Ju-Air.

Figure 41: Left-hand outer wing, lower spar II – large quantity of rivets. Photograph provided by Ju-Air.

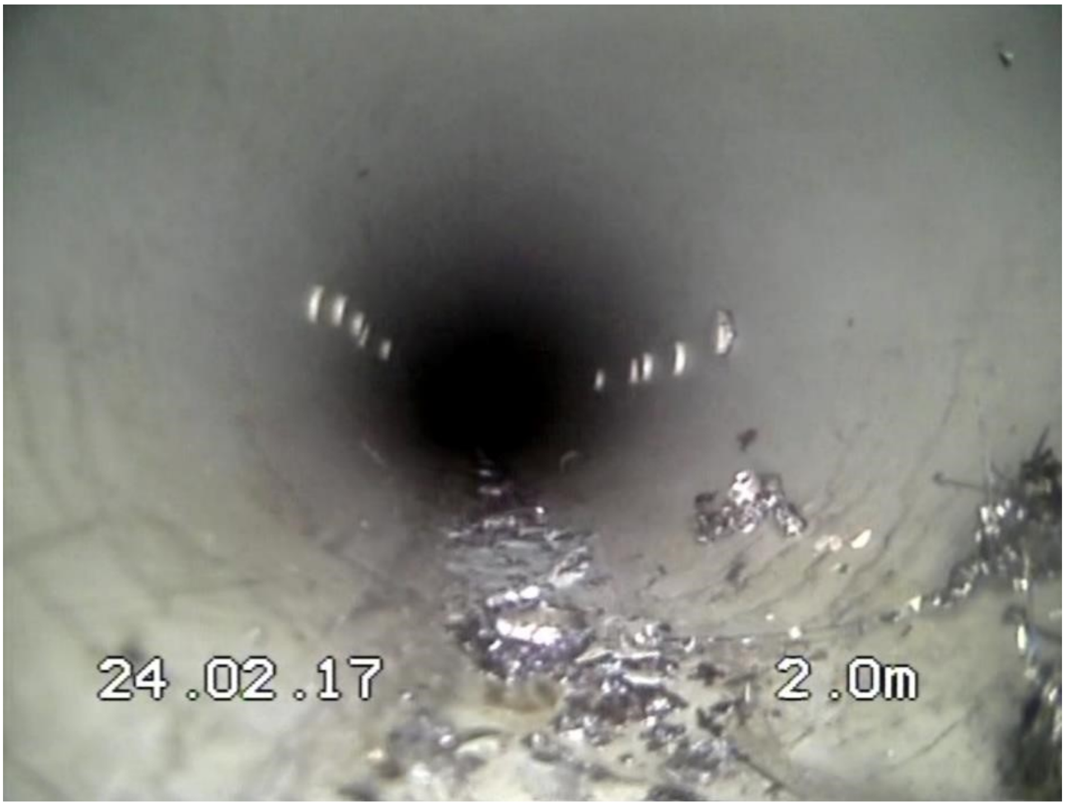


Figure 42: Right-hand outer wing, lower spar IV with swarf. Photograph provided by Ju-Air.

On 18 October 2017, another borescope inspection was carried out by Ju-Air. The following summary was written on the work report:

"*The spar tubes exhibit no signs of cracks, corrosion or other damage. However, some faulty rivets as well as several drilled-out rivets can be seen. In addition, the condition of the paint in some spar tubes is poor.*"

The review of these recordings by the STSB revealed that the situation in the spars on 18 October 2017 was the same as had been detected during the borescope inspection on 24 February 2017 (see figure 43). This shows that these deficiencies had not been remedied in the meantime.

Figure 43: Left-hand outer wing, lower spar II. Photograph provided by Ju-Air.

In the area where the spar had been repaired in May 2017, there were many loose rivets and large quantities of swarf in the spar tube (see figure 44). This is further indication of the poor quality of the repair work.

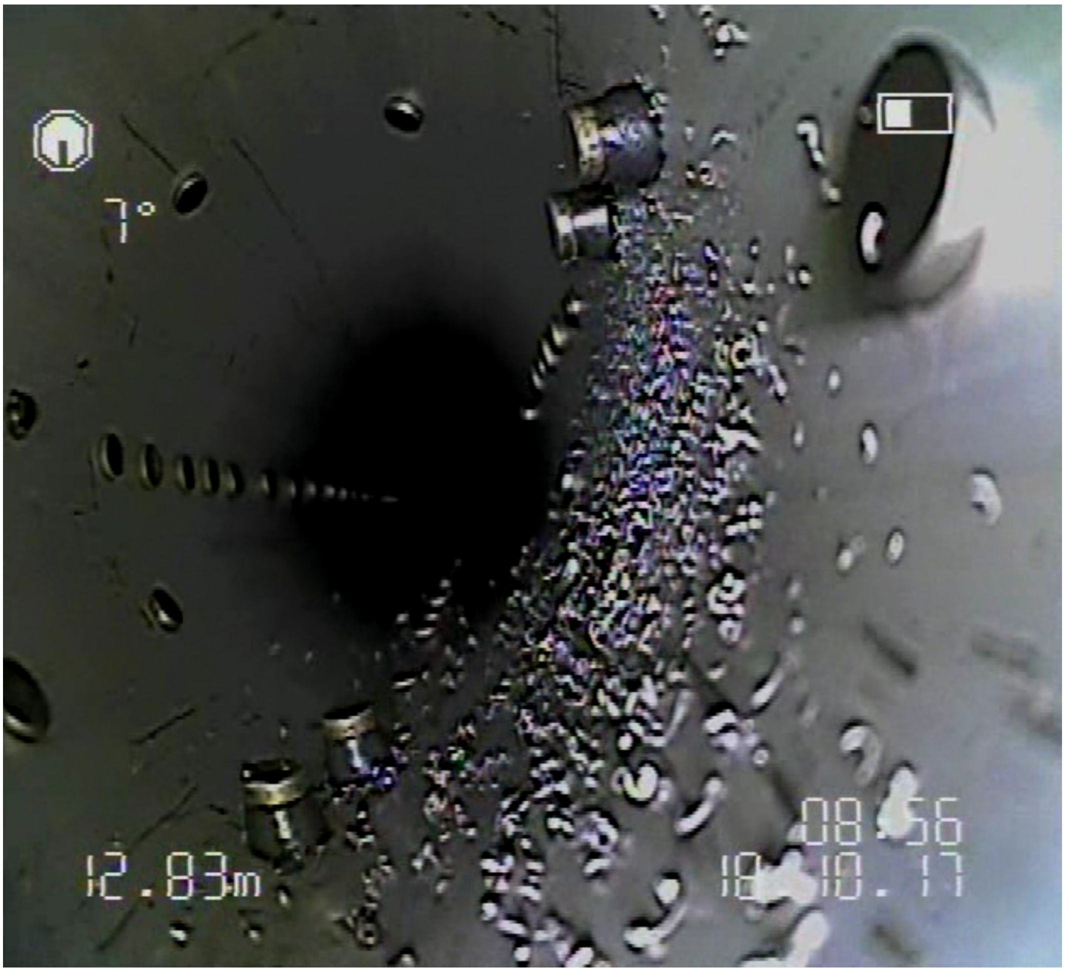


Figure 44: Centre wing, lower spar I, after repair. Photograph provided by Ju-Air.

The pre-existing crack in the spar (see annexes A1.12 and A1.16) identified as part of this safety investigation was not detected during the borescope inspections. This shows that borescope inspection on its own was an inappropriate and unreliable method in this particular case.

A1.6.16 Repairs and modifications

A1.6.16.1 Legal basis

Maintenance on Ju-Air's Ju 52 aircraft was required to be performed according to annex II (part 145) including annex I (part M) of European Regulation 2042/2003 (see section A1.6.5.3). However, according to FOCA, repairs and modifications were subject to the national DETEC Ordinance on the Airworthiness of Aircraft (VLL). Based on this ordinance, FOCA published Technical Communication TM 02.020-60, which specifies modifications to aircraft and aircraft parts in greater detail.

The VLL contains the following information regarding repairs and modifications:

"Art. 42 Obligation to obtain a permit

1 Modifications to aircraft as well as to engines, propellers, aircraft parts and equipment must be approved by FOCA.

2 Relevant documents must be submitted to FOCA before any modification work may commence.

3 Repairs that are not carried out within the scope of ordinary maintenance and require development work shall be considered modifications."

"Art. 44 Permit and approval of modifications

1 FOCA differentiates between major and minor aircraft-type modifications.

2 What type documents are required to be submitted is determined on a case-by-case basis.

3 In the event of major aircraft-type modification, FOCA shall confirm that airworthiness requirements are met by issuing:

a. An extended type certificate, provided the applicant is the type-certificate holder;

b. A supplemental type certificate, provided the applicant is not the type-certificate holder.

4 Minor modifications are approved by FOCA if the airworthiness requirements are met.

5 FOCA may accept extended or supplemental type certificates issued or minor modifications approved by a foreign aviation authority.

6 FOCA shall issue guidelines in the form of Technical Communications (art. 50) on the following:

a. Distinction between major and minor modifications;

b. Relevant procedures;

c. Type documentation required."

The Ju-Air and Naef Flugmotoren AG maintenance organisation expositions (MOEs) contain the following provisions regarding repair work:

"*2.9 Procedure for repair work*

[…]

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 themselves, 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'."

A1.6.16.2 Performed repairs or modifications to the aircraft structure

A1.6.16.2.1 General

Various repairs or modifications to the aircraft structure were carried out on HB-HOT. This work was carried out by various companies, including Ju-Air itself. The period considered as part of this investigation dates from 2000 onwards.

Since 2000, FOCA received the following notices of modification across Ju-Air's entire Ju 52 fleet. These notices were all approved by FOCA.

Registration	Description	Classifi-cation	Activity	Approval by FOCA
All Ju 52 aircraft	Auxiliary fuel tank for ferry flights	Major	Change	05/09/2013
HB-HOP	Avionics upgrade	Minor	Change	28/02/2013
HB-HOT	Avionics upgrade	Minor	Change	08/05/2012
HB-HOT	New transponder	Minor	Change	08/05/2008
HB-HOP	New transponder	Minor	Change	04/04/2008

Table 15: List of notices of modification approved by FOCA.

For the avionics upgrades, the notices of modification were processed by the appropriate avionics company.

However, according to the files, various repairs and modifications were carried out during the same period which had not previously been approved by FOCA. The majority of the work carried out was noted in the form of a handwritten note on what is known as the 'complaint sheet'. Working processes and specifications of the material used were not listed. Tracing the repair and modification work performed proved difficult, and in parts even impossible. For some of the deficiencies that resulted in repair or modification work, no OCRs[51] were produced.

The following table lists repair and modification work carried out that had not been reported to FOCA as regards to their execution or process and consequently had not been approved by FOCA.

Date	Description	Work report
24/05/2018	Repair on the engine frame (centre)	Yes
23/10/2017	Repair on the airframe and the LHS aileron	No
24/08/2017	Repair on the RHS aileron	Yes
17/05/2017	Repair on spar I	Yes
10/05/2017	Repair on the engine frame (left, centre)	Yes
07/12/2015	Repair on the engine frame (left)	No
26/10/2009	Repair on the LHS aileron	No
13/06/2005	Repair on the tip of the left-hand outer wing	No
06/02/2004	Overhaul of the engine frame (left)	No

51 OCR: Occurrence report, an incident report to be sent to FOCA or EASA.

11/03/2003	Repair on the elevators and ailerons	No
11/03/2003	Misc. work on the adjustment spindle	No
04/11/2002	Fitting a lubrication groove on the right-hand shock-absorbing strut	No
06/03/2002	Misc. substantial metal work on the cabin	No
27/02/2001	Repair on the tip of the left-hand outer wing	No

Table 16: List of repairs and modifications not reported to and consequently not approved by FOCA.

Due to incomplete record keeping, it must be assumed that this list is not exhaustive.

Since 2017, any more substantial metal work has been carried out by Kaelin Aero Technologies GmbH. There are work reports for the respective work.

The following sections provide illustrated descriptions for a few examples of the repairs and modifications that were carried out and for which no FOCA approval was available.

A1.6.16.2.2 Engine frame

During a progressive inspection of HB-HOT's centre engine at the end of May 2018, approximately two months before the accident, a crack was detected on the engine frame in the lower-right mounting frame attachment (gusset plates) (see figure 45). To allow the repair to be carried out with the engine frame in place, the corner tube between the engine mount and the firewall was cut through (see figure 46). The cracked gusset plate was replaced by a remanufactured part, welded aluminium sheets with subsequent heat treatment (see figure 47). The severed corner tube was reattached using a doubler consisting of two manufactured U-shaped wraps. Corrosion protection was not applied (see figure 48). The repair was carried out by Kaelin Aero Technologies GmbH. According to the work report, the repair was carried out based on the "*Reparaturanweisung Ju 52/3m*" (Ju 52/3m repair instructions)'.

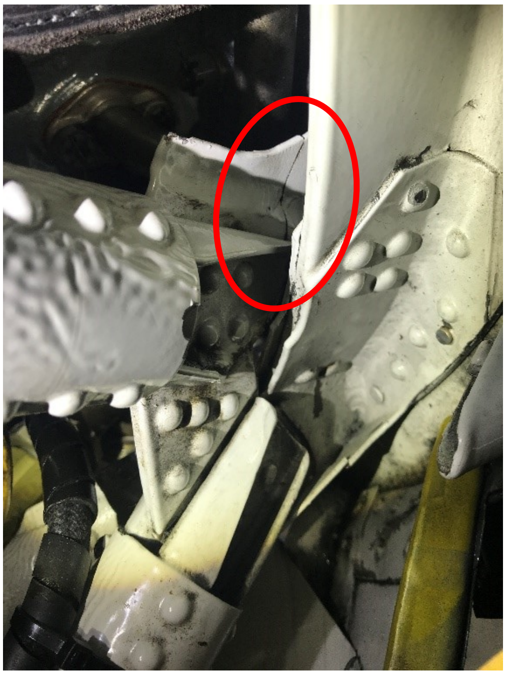


Figure 45: Crack in the mounting frame gusset plate (red circle). Photograph provided by Ju-Air.

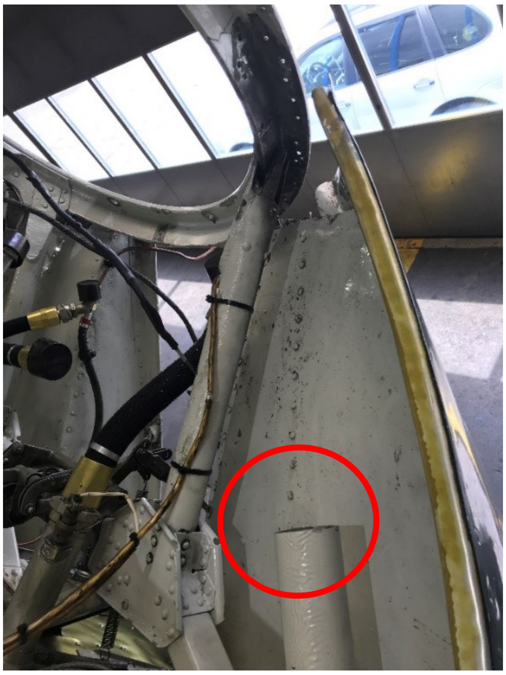


Figure 46: Cut strut tubing (red circle). Photograph provided by Ju-Air.

Figure 47: Remanufactured and assembled plate. Photograph provided by Ju-Air.

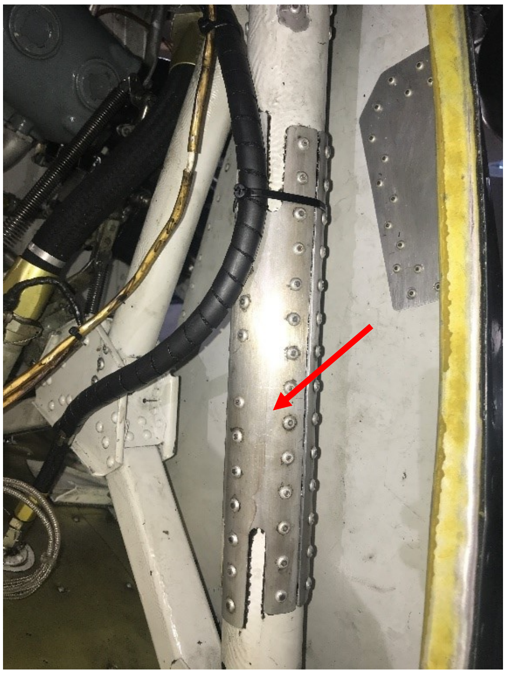


Figure 48: Tubular strut repaired with a doubler. Photograph provided by Ju-Air.

A1.6.16.2.3 Wing spar

In 2015, a fracture was discovered on lower spar II from the centre wing of the Ju 52/3m operated by Deutsche Lufthansa Berlin-Stiftung (DLBS). The extensive repair work was carried out by Lufthansa Technik in cooperation with the German company Kaelin Aero Technologies GmbH. The necessary processes and supporting documents were prepared by Lufthansa's own design organisation using an engineering bulletin to this effect. As there had been a constant exchange of information between Ju-Air and the DLBS for many years, Ju-Air was also informed about the crack detected in the spar.

During a progressive inspection on HB-HOT in February 2017 at 9,858:04 operating hours, the inside of the tubing for each spar was inspected for the first time using a borescope supplied by a drainage maintenance company (see section A1.6.15). A crack was found in lower spar I of the centre wing, immediately next to the left-hand joint and threaded piece to which the left-hand outer wing is attached (see figures 49 and 50). The crack originated from a borehole. The crack had an approximate length of half the circumference of the spar tube.

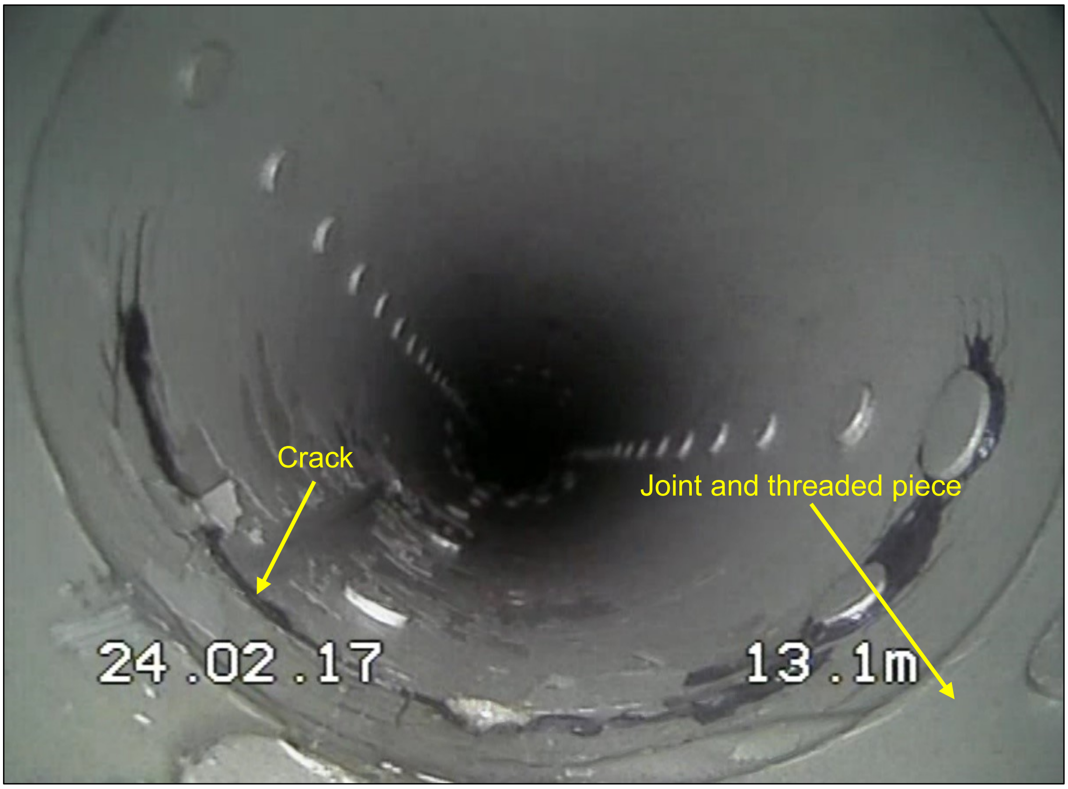


Figure 49: Interior view – crack in lower spar I of the centre wing, immediately next to the left-hand joint and threaded piece (borescope image). Photograph provided by Ju-Air.

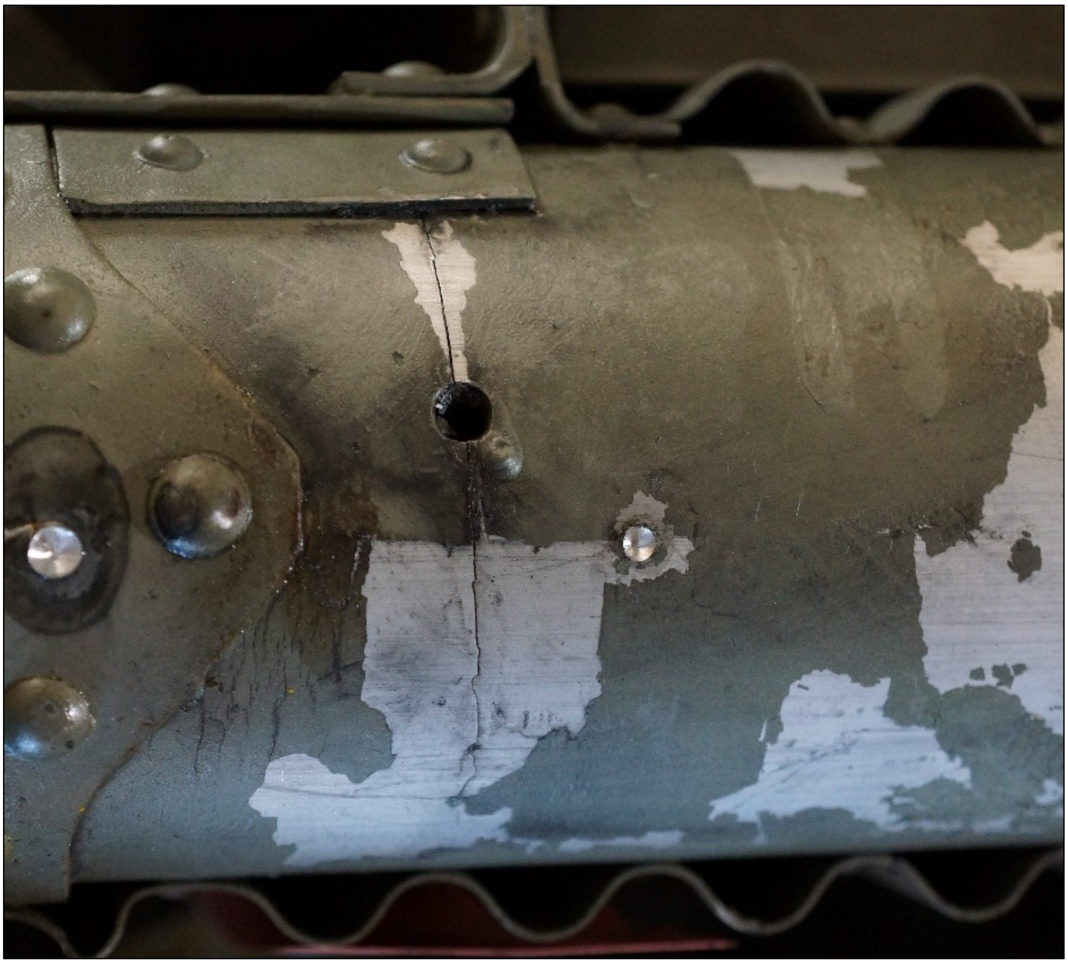


Figure 50: Exterior view – crack in lower spar I of the centre wing. Photograph provided by Ju-Air.

This finding was reported by Ju-Air to FOCA using the intended form. Under 'Analysis and follow-up' the following was noted by Ju-Air with respect to this:

"*The crack was discovered during scheduled comprehensive maintenance. The maintenance programme has therefore proven to be effective. As FOCA has been conducting investigations into the service life of the Ju 52 for some time, the events are being discussed in this context. Apart from the replacement of the spar tube and other regular inspections, no further measures are necessary.*"

In Ju-Air's 'Hazard and occurrence report', the possibility of the present problem recurring was assessed as very unlikely (see figure 51).

Your personal opinion:

Probabilty: can it happen again?	*extremely improbable*	1☐	2☒	3☐	4☐	5☐	*may / has occurr(ed) frequently*
Severity: or potential consequences?	no damage, injury or adverse consequences	1☐	2☒	3☐	4☐	5☐	**live threatening**

Figure 51: Extract from Ju-Air's hazard and occurrence report.

Ultimately this major repair work was carried out by Ju-Air together with the metal worker from Kaelin Aircraftstructure GmbH. No FOCA approval was available for the repair of HB-HOT (see section A1.6.16.1).

Ju-Air was able to use the existing devices (jigs) and repair documents from the DLBS used in the earlier repair of the German Ju 52/3m. However, the jigs had to be modified for use in the repair work on HB-HOT, as the repair was not the same. In Ju-Air's work report, the following was written with regard to this:

"*For the spar repair, we're benefiting from engineering work performed by the DLBS, which had a similar repair on middle spar II. This repair was also performed by Kaelin Technologies.*

Elements from the DLH type certification report and the Lufthansa Technik design organisation's engineering bulletin 'Simplified aircraft repair' [...] were consulted for the repair [...].

Adaptation of the centre box jigs provided by the DLBS (Deutsche Lufthansa Berlin-Stiftung) to suit the centre box of HB-HOT."

According to the work report from Kaelin Aircraftstructure GmbH, the repair work on HB-HOT took place between 27 February and 3 May 2017. The individual tasks were all initialled to have been carried out on 7 September 2017. The entire order was also certified with this date.

At the end of the work report, the following was written:

"*All of the above-mentioned works have been completed according to SRM[52] instructions and drawings and were checked by*". No such SRM existed for the Ju 52/3m g4e at the time. The repair instructions of the aircraft manufacturer for type Ju 52/3m aeroplanes did not support this repair.

In the technical files for HB-HOT, the repair and maintenance work was certified by Ju-Air on 10 May 2017 and the aircraft was released to service. Due to incomplete record keeping, tracing this repair was difficult, and in parts even impossible. The following task was listed in the work report: "*Provisionally install new connection pieces LH + RH (manufactured according to DLBS drawing)*". No files were available with respect to this.

A1.6.16.2.4 Horizontal stabiliser

Between 4 November 2002 and 11 March 2003, a variety of repair and maintenance work was carried out on HB-HOT. Among other things, corrosion was found on the joints and the bearing bracket for the horizontal stabiliser's adjustment spindle. Thereupon the horizontal stabiliser and elevator were removed from the aircraft (see figure 52).

52 SRM: Structural repair manual

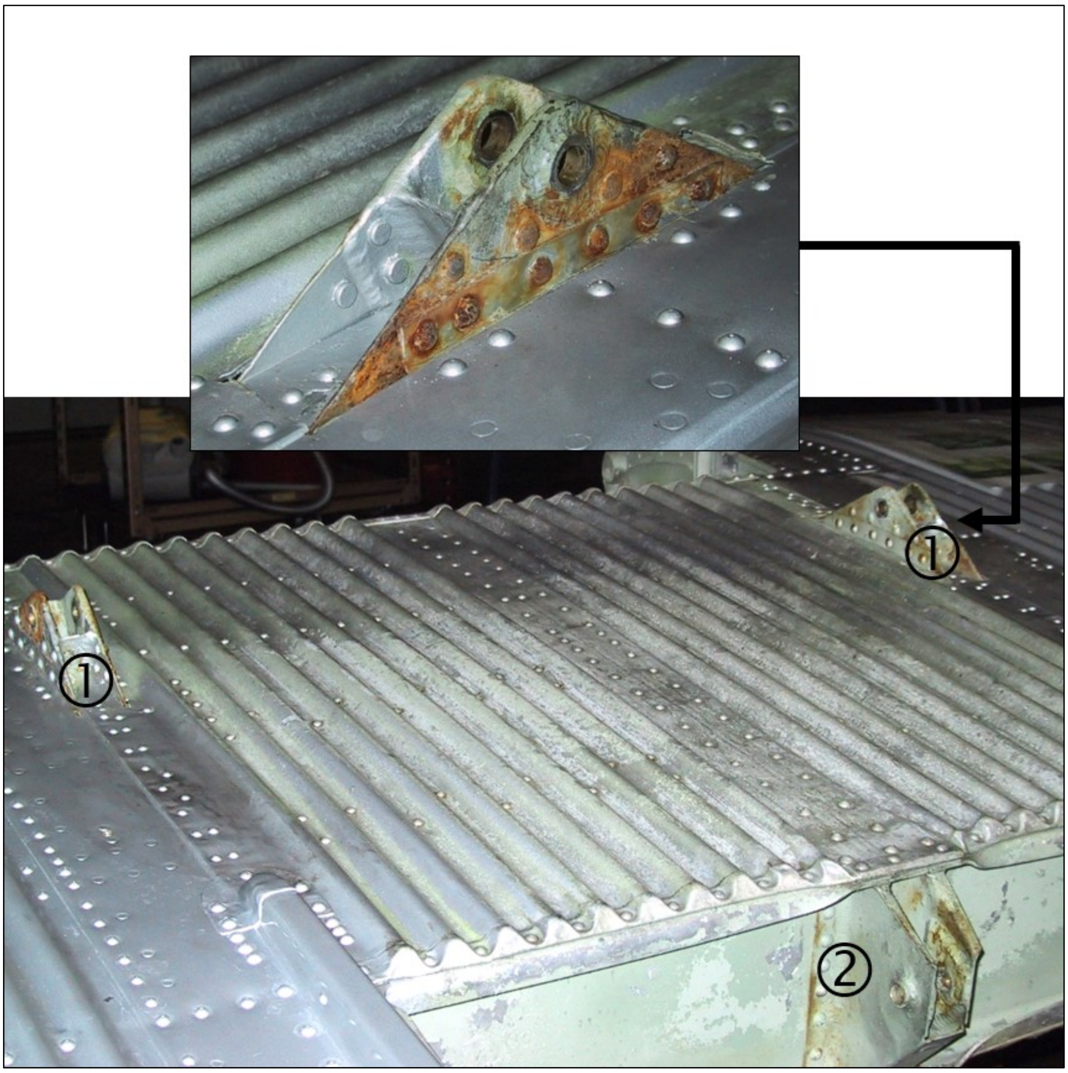


Figure 52: Horizontal stabiliser with severely corroded joints (1), bearing bracket (2) and panelling. Photograph provided by Ju-Air.

The panelling on the top of the horizontal stabiliser was then removed to expose the fittings. Afterwards the joints and the bearing bracket were removed by drilling out the rivets (see figure 53).

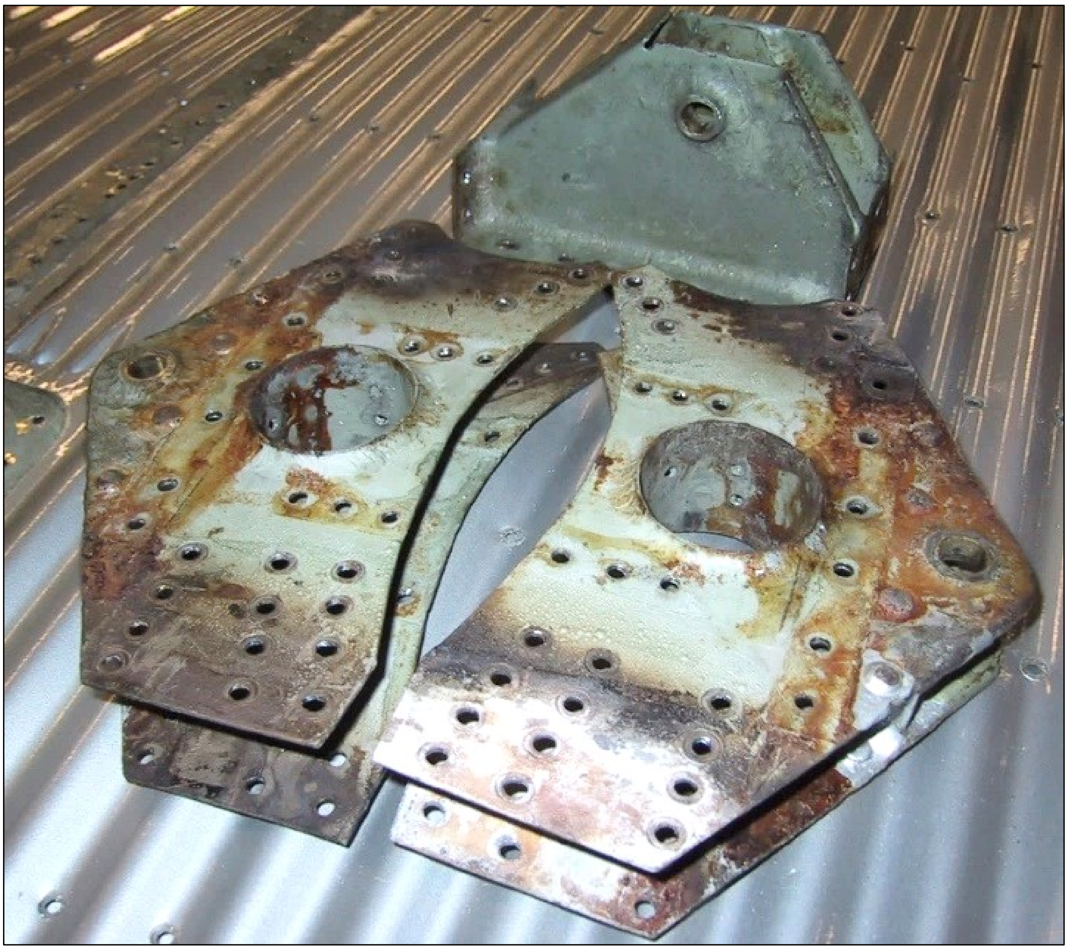


Figure 53: Removed, severely corroded components from the horizontal stabiliser. Photograph provided by Ju-Air.

According to the files, the joints and the bearing bracket were cleaned, inspected and the surface treated (cadmium-plated). As the spar tubing also exhibited corrosion in the area of the two joints, it was replaced with a new section of tubing. Afterwards the horizontal stabiliser's components were riveted back together again. As can be seen in figure 54, there were other severely corroded components in the area where the repairs were conducted which had not been treated or replaced.

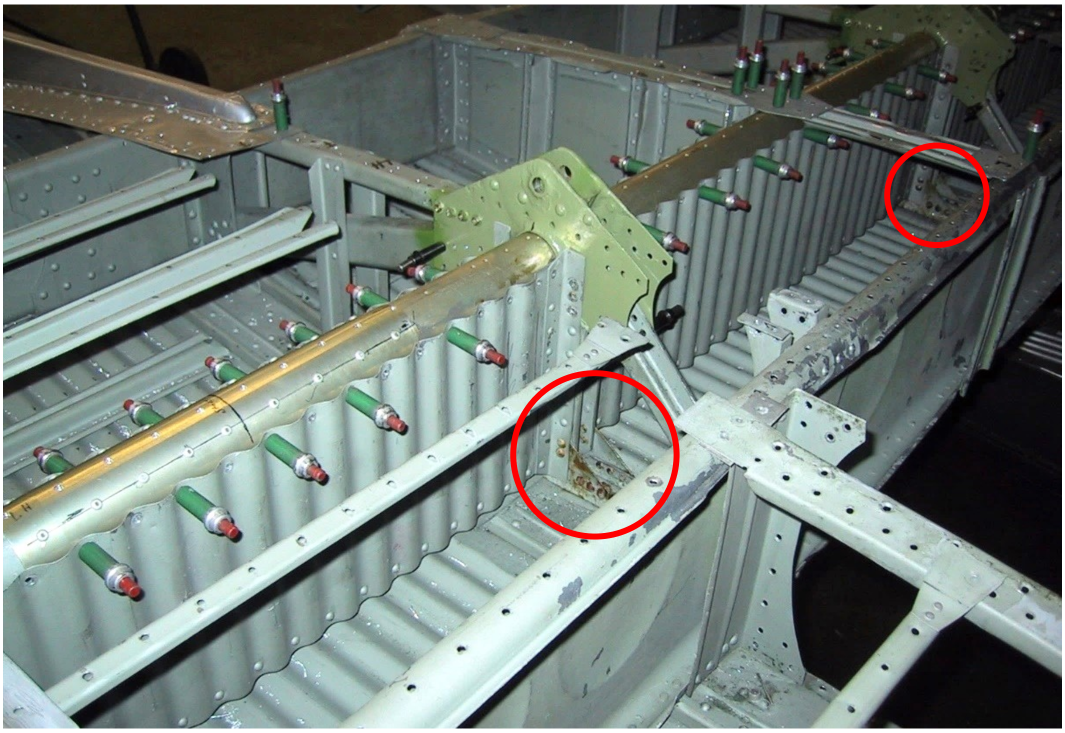


Figure 54: Reworked components in the horizontal stabiliser with new spar tubing. Circled in red are other severely corroded components that have not been treated or replaced. Photograph provided by Ju-Air.

This repair was carried out using a hand-drawn sketch only (see figure 55) and no work report could be found in the technical files, only a complaint sheet with minimal description of the work carried out (see figure 56).

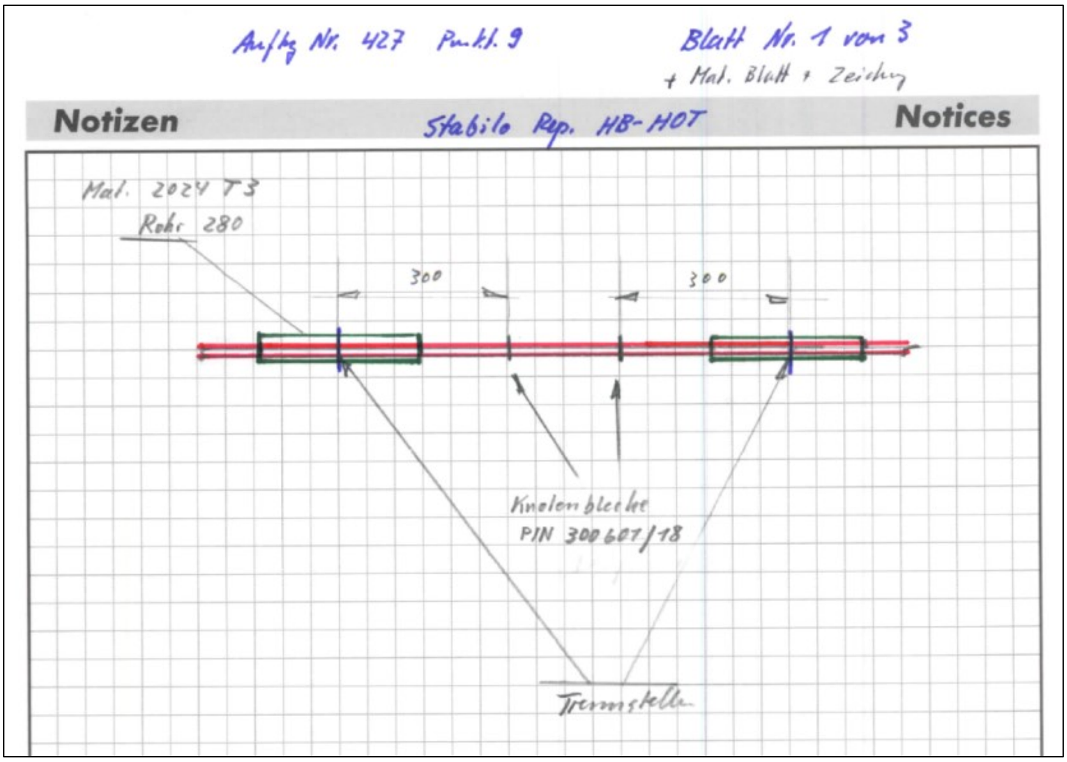


Figure 55: Repair work based on this hand-drawn sketch. Source: Technical records HB-HOT.

5.1.5 Auftragsformular JU-AIR, Interner Gebrauch

BEANSTANDUNGSBLATT Nr.: 3

Flugzeug: HOT Datum: 4.11.02 Auftrg. ~~oder LOG~~ Nr.: 424
Zellen Std.: 6957:33

Betrifft: Kontrolle, Reparatur, Unterhalt, Änderung

Pt.	Beanstandung und Behebung	Mech	T.K.
9.	Am Höhenstabilo Knotenstück am Unterholm (Lagerung) LH + RH stark rostig		
	- Seiten Steuer demontieren.		
	- Seiten steuer montieren		
	- Höhensteuer LH demont.		
	- Höhensteuer LH montieren		
	- Höhensteuer RH demont.		
	- Höhensteuer RH montieren		
	- Seitenstabilo demont.		
	- Seitenstabilo mont.		
	- Höhenstabilo Streben LH+RH demont.		
	- Höhenstabilo demont.		
	- Höhenstabilo montier		
	- Streben LH + RH montieren		
	- Elektr. Anlage siehe Pt. 8		
	- Alle Lager abschmieren		
	- Einstellungen nach BAW + Kontr. Blatt Intervall Nr. 6		
	- Am Höhenstabi. die Lagerpunkte Knotenbleche LH+RH P/N 3006.01/.18 ausbauen, reinigen, cadmieren, Kontr. und Grundieren		
	- Knotenbleche einbauen + vernieten nach Junkers Ausbesserungsanleitung (Spengler)		

Alle Arbeiten vor dem Einschalen der Kontrolle melden.
Komponentenwechsel notieren.

Figure 56: Complaint sheet with minimal description of the work carried out. Names of persons and initials removed by the STSB. Source: Technical records HB-HOT.

There were no basic conceptual explanations documenting the professional execution of the repair, and the required approval for the work had not been obtained from FOCA. There was also no adequate description of the findings nor an analysis of the damage that led to the repair. The actual repair of the corroded part could not be reproduced using the documents available. Nor is it apparent which methods were used to carry out the repair. Furthermore, the setting for the horizontal stabiliser after this repair could not be determined due to missing documentation.

A1.6.16.3 Performed repairs or modifications to the engines and propellers

A1.6.16.3.1 General

Since Ju-Air took over the three Ju 52/3m g4e aircraft from the Swiss air defence corps, the engines have had to be continuously repaired and modified. This work was carried out by Naef Flugmotoren AG and commissioned subcontractors. Some of the repairs and modifications were carried out on the basis of a service bulletin (SB) provided by Ju-Air (see section A1.6.17.2). No SBs existed for other repairs and modifications, nor were any notices of modification submitted to FOCA. Consequently, this work had not been approved by FOCA.

The following sections describe some examples of repairs and modifications to the respective engines.

A1.6.16.3.2 Left engine

HB-HOT's left engine last underwent a complete overhaul on 12 October 2010, performed by Naef Flugmotoren AG. After 180 operating hours, a cylinder had to be repaired for the first time. In the time between the major overhaul and the accident, the engine recorded 946 operating hours. During this time, a total of 13 cylinders had to be dismantled and repaired.

Cylinder nos. 1 and 9, which were sourced from an aircraft that had crashed on a glacier, were installed on 24 September 2015 (see section A1.6.17.4). On 28 January 2016, after 13 operating hours, Naef Flugmotoren AG subsequently issued a release certificate for each of these two cylinders. Cylinder no. 1 was repaired on 18 January 2017 at 108 operating hours, and on 30 July 2018 at 214 operating hours, a leak in the tappet tube was repaired. Neither of these pieces of repair were entered on the component card.

Before the 2018 Locarno adventure tour, three cylinders were repaired during the last progressive inspection on 31 July 2018.

A1.6.16.3.3 Centre engine

The centre engine last underwent a complete overhaul on 17 April 2013. At the time of the accident, the engine had recorded 1,153 operating hours. In addition to eight cylinders and the oil pump, the cam disc had to be replaced after 821 operating hours. The engine frame had to be repaired twice too.

The operating hours for cylinder no. 2 could not be traced because the entries were missing from the component card. Entries regarding a repair on 5 February 2016 could also not be found. As the cylinder had been used on various engines during its service life and these changes had not always been documented, it was not possible for the maintenance team to monitor the operating hours using their record keeping system.

In the time between this engine recording 556 and 1,079 operating hours, a total of eight cylinders had to be removed and repaired.

At 1,060 operating hours, the oil pump had to be replaced. The installed replacement had been in stock since the engine's last major overhaul (6 years).

A1.6.16.3.4 Right engine

Cylinder nos. 1 and 9 installed in the right engine were sourced from an aircraft that had crashed on a glacier (see section A1.6.17.4).

The right engine last underwent a complete overhaul on 1 June 2016. At the time of the accident, this engine had recorded 457 operating hours. 105 operating hours after the engine's major overhaul, the cam disc was found to be defective and was replaced.

During the 457 operating hours, four cylinders had to be repaired. Cylinder no. 2 was repaired at 299 and 416 operating hours (41 operating hours before the accident). Cylinder nos. 4 and 5 were also repaired after 416 operating hours, i.e. 41 operating hours before the accident.

A1.6.16.3.5 Propeller

According to the technical files, between February 2008 and September 2018, there were 23 occasions of a propeller undergoing a major overhaul at a company in Germany.

Following complaints about strong vibrations or insufficient performance being observed during flight operations, eight of these major overhauls were requested because the maximum permissible rotation was exceeded when retightening the propeller blade nut or because of loose propeller blades. In some cases, this was only a few operating hours after a general overhaul. FOCA was never informed about this recurrent problem (see annex A1.17).

This problem of loose propeller blades had not been solved by the time of the accident.

Among other things, Ju-Air repeatedly commissioned a company not certified to provide parts for use in aviation to repair conical rings and hub threads that had been damaged by corrosion. According to the description of the work processes, the following work was carried out:

- Removal of the damaged surfaces, layer thickness approx. 0.3 mm;
- Nickel-plating, layer thickness 0.3 to 0.5 mm; this work was carried out by a company certified to provide parts for use in aviation;
- Machining of the conical ring and thread to correspond to the original dimensions.

No records, such as technical drawings or process descriptions, were available for this work.

Afterwards the propellers with the reworked hubs were assembled at a company in Germany. The majority of the propeller blades had been manufactured based on pattern parts; some had been reconditioned (see section A1.6.17.2.6).

The hubs for HB-HOT's left and centre propellers were mechanically reworked in the same way.

The propeller blade's conical root is mounted into the propeller hub's corresponding conical ring; this is a frictional connection. Corrosion, wear or an inaccurate fit of the two conical surfaces can cause the frictional connection to weaken during operation and the propeller blades to become loose. This leads to changes in propeller pitch and vibrations.

On some hubs the serial numbers have been removed and replaced by new numbers (see table 17). This is not permitted for aircraft parts.

Original serial number	Newly applied serial number	Date of change	Remarks
31851	32026	December 1993	Hub for HB-HOT's right propeller
32015	3201	February 2000	Hub for HB-HOT's left propeller
32050	32018	November 1994	–
31865	31861	August 1995	–
32018	31851	January 2000	–

Table 17: Changed serial numbers on propeller hubs.

In summary, this type of repair work on propellers is not permitted.

Based on the poor technical condition of the connection between the propeller blades and the hub, and the resulting risk of a spontaneous change in the pitch of the propeller, it can be concluded that the propellers for Ju-Air's Ju 52 aircraft were no longer airworthy.

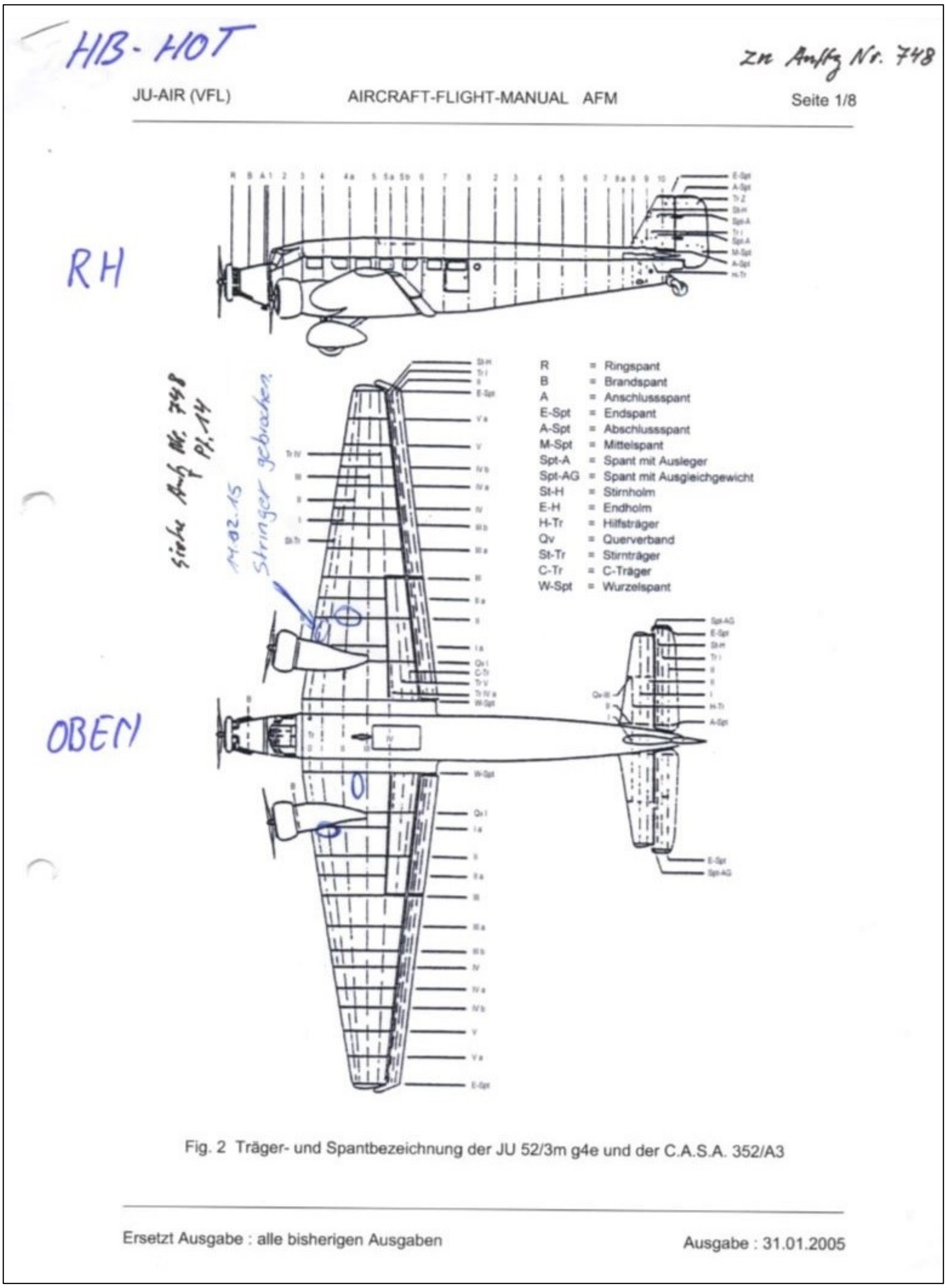
A1.6.16.4 Evaluation

During the last few decades, various repairs and modifications have been carried out on Ju-Air Ju 52 aircraft and their engines. For some modifications, service bulletins were drawn up concerning the procurement of spare parts and the reconditioning of components and were approved by FOCA. Furthermore, dozens of repairs and modifications were carried out, largely without approved technical bases and without approval from FOCA. For example, only five notices of modification were submitted to FOCA for approval between 2000 and the time of the accident. Four of these were submitted by an avionics company because of a modification to the avionics. In addition, non-aviation-compliant components were procured and installed. The procedures were defined, among other places, in Ju-Air's maintenance organisation exposition and in a European Regulation, but for the most part they were not applied.

During the examination of the maintenance work, various shortcomings were found, in particular in the documentation for carrying out major changes and in the management of spare parts. Such deficits represent a risk.

A1.6.16.5 Known, but not repaired damage to the aircraft

In December 2015, a broken stringer was found on the right-hand outer wing during maintenance work (see figure 57). The findings were recorded, but no repair was ever carried out.


HB-HOT

zu Auftg Nr. 748

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Fig. 2 Träger- und Spantbezeichnung der JU 52/3m g4e und der C.A.S.A. 352/A3

Ersetzt Ausgabe : alle bisherigen Ausgaben Ausgabe : 31.01.2005

Figure 57: Ju-Air document where the broken stringer is noted. Names of persons and signatures removed by the STSB. Source: Technical records HB-HOT.

The files also contained a photograph from 2003 showing a section of damaged strut tubing (diagonal tube) that was part of an engine frame (see figure 58). Here too, there were no files regarding repair work or necessary clarifications.

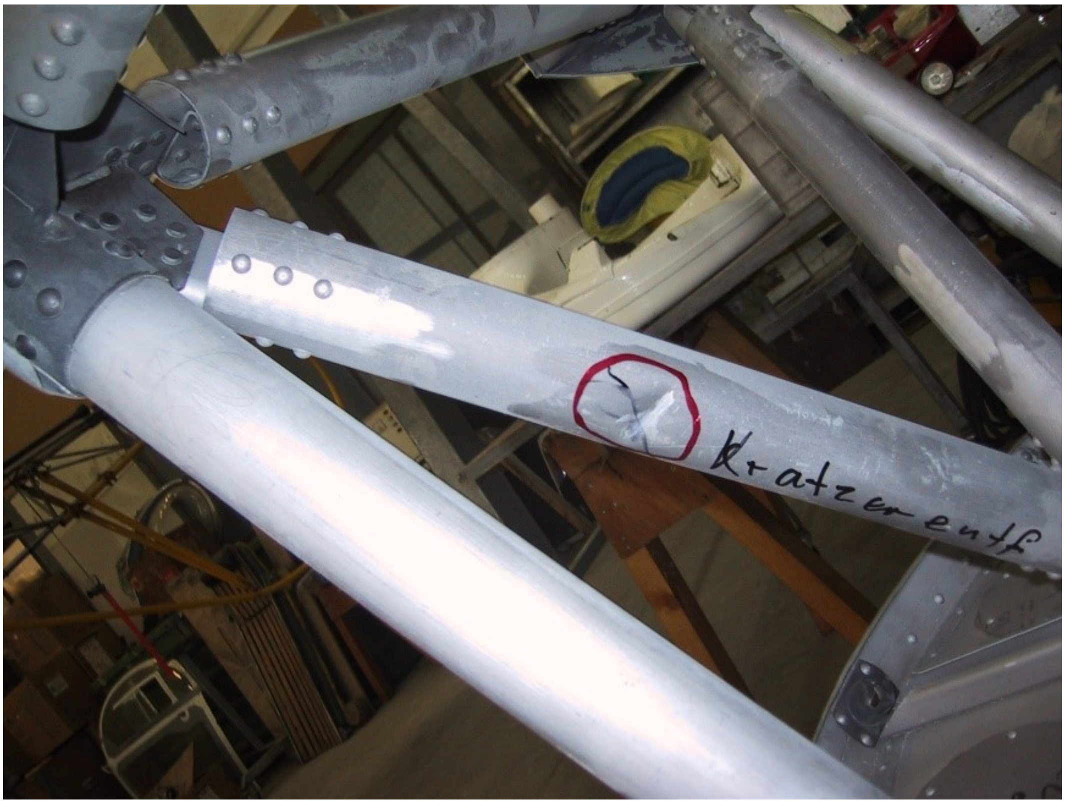


Figure 58: Damaged strut tubing (diagonal tube). Photograph provided by Ju-Air.

A1.6.17 Spare-part procurement

A1.6.17.1 General

As by the end of the Second World War the aircraft manufacturer Junkers had ceased to exist and BMW had ceased operating as an aircraft engine manufacturer, the flight operation and maintenance companies were dependent on the procurement of spare parts from other sources. Parts were remanufactured, reconditioned and non-certified standard components were also installed. Since the 1980s, service bulletins have been issued by Ju-Air for certain remanufactured components and manufacturing processes, and approved by FOCA. A release certificate was issued by Naef Flugmotoren AG for the remanufactured and reconditioned engine components.

A1.6.17.2 Service bulletins

A1.6.17.2.1 General

A service bulletin (SB) is a document that is published by an aircraft or engine manufacturer and contains changes, improvements or inspections that are recommended to be performed on an aircraft or engine. The decision to implement a service bulletin rests with the aircraft operator.

The aircraft manufacturer Junkers has not existed since the end of the Second World War, neither has BMW operated as an aircraft engine manufacturer since that time. Consequently, original spare parts could no longer be obtained from these two companies.

When Ju-Air took over the three Ju 52 aircraft in the 1980s, the company had to source spare parts for the engines so that it could continue to operate its aircraft.

A1.6.17.2.2 Service bulletins issued by Ju-Air

Ju-Air wrote a service bulletin (SB) for some of the remanufactured components, original parts to be reconditioned and the installation of components not certified for use in aviation. These SBs were subsequently examined and approved by FOCA. The majority of these SBs regarded engine components. Between 1984 and 2001, a total of 41 SBs were drawn up and approved by FOCA (see table 18). During this time, some SBs were replaced by a new version, and some SBs were repealed.

The last newly created SB no. 1047 was approved by FOCA in 2005.

The majority of the service bulletins lacked necessary information or supporting documents such as:

- Certification proof for components or materials with new manufacturer;
- Tool numbers when using special tools;
- Information on the set of drawings for design modifications or adaptations to the aircraft or engine;
- Information on drawings regarding their approval and official release as well as the respective revision status with date.

Most of the individual service bulletins were not accompanied by any technical files or documentation.

During its review of the records, the STSB identified that SB no. 1005 (engine piston), which was produced in 1989, was modified in 2018 and approved by FOCA. This SB was not included in the current version of the SB overview list dated 15 March 2013.

From 2002 onwards, apart for SB no. 1005, the SBs were no longer maintained, meaning that processes and subcontractors were no longer updated and thus no longer approved by FOCA.

The following sections present some service bulletins as examples.

For many other remanufactured components, an SB was not written or submitted to FOCA for approval (see section A1.6.17.3). As a result, these SBs did not undergo the review and approval processes with FOCA.

SB no.	Description	Up-to-date version	Replaced version
1001	Exhaust valves	21/11/1995	15/11/1986
1002	Oversize steel cylinder	Repealed	–
1003	Oversize chrome cylinder	02/05/2001	07/04/1987
1004	Cam rings	Repealed	–
1005	Oversize pistons and piston rings	10/04/2018	25/01/1989
1006	Lubricant indicator	12/01/1984	–
1007	Propeller shaft bearings	05/03/1984	–
1008	Solenoid actuator	13/03/1984	–
1009	Inlet valve guides	21/11/1995	23/11/1988
1010	Galley	10/09/1984	10/07/1984
1011	Exhaust valve guides	21/11/1995	24/11/1988
1012	Cylinder and valve data	Repealed	–
1013	Spark plugs	25/02/1985	–
1014	Starter	26/02/1985	–

1015	Ball bearings for BMW 132 A3 engines	17/08/1992	25/06/1985
1016	Blank	–	–
1017	Blank	–	–
1018	Oil temperature gauge	14/02/1985	–
1019	Oil pressure indicator	10/08/1985	–
1020	EGT indicator	10/08/1985	–
1021	Extension of the NAV system and renovation of the instrument panel	27/09/1985	–
1022	Air brake instruments	10/09/1985	–
1023	Valve seats for BMW 132 A3 engines	01/02/1992	07/11/1988
1024	Intake valves for BMW 132 A3 engines	21/11/1995	26/01/1989
1025	Electronic tachometer	26/02/2002	10/01/1986
1026	Modification to the brake valves	15/03/1986	–
1027	Compressor system for the Ju 52's air brake system	26/01/1987	02/07/1986
1028	Cam disc for BMW 132 A3 engines	29/11/2001	31/08/1995
1029	Fuel pressure gauge	01/09/1986	–
1030	Oil pressure indicator	28/01/1991	01/10/1986
1031	Valve control for BMW 132 A3 engines	20/01/1989	21/04/1988
1032	PA system	15/03/1988	–
1033	On-board power supply monitoring	06/10/1989	–
1034	Blank	–	–
1035	Countershaft for BMW 132 A3 engines	31/08/1995	27/06/1989
1036	Threaded spark-plug bushing for BMW 132 A3 engines	27/01/1996	20/08/1989
1037	Blank	–	–
1038	Propeller bearings for BMW 132 A3 engines	Repealed	–
1039	GPS device	08/05/1991	–
1040	Generator voltage regulator	30/10/1991	–
1041	Starting ignition system	07/07/1992	–
1042	Upper loading hatch	25/10/1996	–
1043	Installation of electric fuel pumps	07/01/1998	22/05/1997
1044	Blank	–	–
1045	Replacement blade for Ju-PAK propellers	28/06/2000	–
1046	Replacement of the emergency location transmitter	10/11/1999	–
1047	Engine drain system	20/01/2005	–

Table 18: Service bulletin overview list, version dated 15 March 2013 valid at the time of the accident. The SB marked in yellow was not included in Ju-Air's list.

A1.6.17.2.3 Oversize chrome cylinder – SB no. 1003

The diameter of the bore when new is 155.56 to 155.60 mm, the wear limit is 155.80 to 155.90 mm. According to the 1939 operating instructions written by the manufacturer of the BMW 132 A3 aircraft engine, a cylinder must be replaced with a new component when the wear limit is reached. The manufacturer also states that it is not permitted to re-bore the cylinder.

As in 1984 most of the cylinders in the BMW 132 A3 aircraft engines had started to reach their wear limit, Ju-Air was looking for a solution. A company specialising in engine parts in Germany suggested honing the cylinder bore beyond the limit and then chrome-plating it to the wear measurement specified by BMW (see figure 59). Honing is a fine-machining process and chrome plating is a galvanic process.

In 1984, an initial batch of 15 cylinders were reconditioned at this company using this method. In 1988 and 1989 a further 18 cylinders were reconditioned by the same company. In 1994, this company informed Ju-Air that they were no longer chrome-plating cylinders.

Between 1998 and 2005, Ju-Air then commissioned two companies in the United States of America to chrome-plate another 33 cylinders.

In 2015 and 2017, a company in Switzerland plated a further 20 cylinders for Ju-Air. This company's method of plating cylinders is a process in which the powder is injected into a hot plasma, where it melts and is accelerated before then being applied to the surface to be coated. There was neither a SB for this procedure nor was it approved by FOCA. Naef Flugmotoren AG issued a release certificate for each of the cylinders reconditioned using this method. Cylinders with chrome-plated and plasma-coated bores were installed in HB-HOT's engines.

Figure 59: Example of a chrome-plated cylinder bore. The crack network typical for this method is clearly visible.

A1.6.17.2.4 Cam discs for BMW 132 A2 engines – SB no. 1028

As spare parts for BMW engines were no longer available from 1983, Ju-Air repaired and reconditioned worn cam discs.

1985 was the first time a larger number of cam discs were remanufactured. Various companies manufactured the individual components based on pattern parts, some of these companies were not certified to provide parts for use in aviation.

From 1985 onwards, manufacturing drawings and specifications for production were also created based on existing cam discs. These have been amended on several occasions over time.

A total of 38 cam discs were ordered and delivered between 1996 and 2013. The cam discs were manufactured based on pattern parts and drawings or sketches produced by Ju-Air. Individual parts were manufactured by companies not certified to provide parts for use in aviation.

A1.6.17.2.5 Ball bearings, roller bearings and rollers for BMW 132 A2 engines – SB no. 1015

From 1984 onwards, there were no original roller bearings, ball bearings and rollers for the BMW engine. They were therefore replaced by readily available, standard bearings. In some cases, the design was adapted with a spacer to accommodate the new bearing.

Service bulletin no. 1015, published in 1986, was last revised in 1992 and approved by FOCA. During engine overhauls from 1986 onwards, bearings were installed in accordance with this service bulletin. The supercharger shaft for the BMW 132 A3 engine rotates at up to 20,500 rpm. According to the bearing manufacturer, the maximum permissible speeds for the cylindrical roller bearings and deep-groove ball bearings newly installed on the supercharger shaft were considerably below this. The manufacturer of these bearings did not guarantee their use.

A1.6.17.2.6 Replacement blade for Ju-PAK propellers – SB no. 1045

Because the original propeller blades had to be replaced for operation due to corrosion, wear or damage, and because original propeller blades were no longer available, reproduction propeller blades had to be manufactured.

In order to continue using the original hubs, it was decided to produce new propeller blades that were identical to the originals and to issue a declaration of conformity (report no. E-657). In this, it was stated that the replacement blades were manufactured within defined tolerances of the original dimensions and original material specifications. The manufacturer was of the opinion that no type testing was necessary for the propeller or the aircraft. As no original drawings were available, new construction drawings were created from the average measurements of various used blades. The material composition of the original blades was determined via metallurgical analysis and then a suitable material was determined for the construction of the replacement blades. The data for the vibration tests during the static test and in flight were verified in the E-690 and E-654 reports.

There is no evidence to support a subsequent performance evaluation based on flight tests using the new blades was conducted. Consequently, there is no corresponding pool of data on which to base the data on flight performance in the AFM.

In July 2000, SB no. 1045, which regulates and permits the replacement of the old original propeller blades with a remanufactured part, was approved by FOCA.

In a letter dated October 1999, FOCA informed Ju-Air of the following information concerning a remanufactured propeller blade:

"[…]

- *The above application was reviewed internally by FOCA and approved in principle. The undersigned has been appointed for the detail work and as a point of contact.*

- *We have already stated on the phone that the present case only concerns the production of new metal blades, which are fundamentally the same as the original propellers. Consequently, neither a new type-certificate nor an STC is required, but only proof of conformity for the replacement blades.*
- *The processing can therefore take place in the context of a Ju-Air service bulletin, as has already been done on several occasions for the production of spare parts no longer available. Ju-Air is responsible for the preparation of the SB, naturally in collaboration with MT, and approval is to be granted by FOCA.*"

The propellers were manufactured based on pattern parts by a company in the Czech Republic. A company in Germany was responsible for construction management, supervision and quality control. Not every propeller installed in HB-HOT was issued with a certificate of release to service.

Due to the lack of an equipment data sheet, SB no. 1045 was entered in the certificate of release to service as the basis for approval. This was approved by FOCA.

In 2003, Ju-Air submitted an application to FOCA to increase the operating time for these propellers from 1,000 to 1,200 operating hours. This request was approved by FOCA.

A1.6.17.2.7 Electronic tachometer – SB no. 1025

Service bulletin no. 1025 was first written in 1986. This concerned the replacement of the mechanical tachometers for the two outer engines with electric tachometers. On 26 February 2002, the SB was revised and approved by FOCA. As per this revised SB, the mechanical tachometer for the centre engine and the electric tachometers for the two outer engines were replaced with electronic devices with analogue and digital displays.

According to the SB, the old indicators were showing different read-outs for the same engine speed. Furthermore, the mechanical and electrical systems were susceptible to faults.

When converting to the new system, four steel cams were soldered onto each of the coupling sleeves in the magneto drive system, whereupon this component received a new part number. The display instruments were developed and manufactured especially for Ju-Air. According to the SB, the built-in proximity switches, cabling and plugs corresponded to the industry standard and were commercially available. There was no indication that the parts used were aviation-certified material.

A1.6.17.3 New production of engine components without approval

A1.6.17.3.1 General

Until 2002, the service bulletins were maintained and mostly concerned the new production of components and reconditioning of original components. After 2002, dozens of components, mostly using an old and worn part as a template, were remanufactured or modified by subcontractors by order of Ju-Air (see table 19). Many of the components that were not certified for use in aviation were general, commercially available products.

Release certificates were issued by Naef Flugmotoren AG for each of the remanufactured engine components. No supporting documentation of any kind (strength, material, test runs, etc.) was available for these components.

The following sections describe some illustrative examples of remanufactured components.

Component	Component
Supercharger cover gasket	Discs for rocker-arm bearing
Aluminium seal, sump gasket	Rocker arm axle
Cylinder head screws for bearing cover	Dust caps, grease nozzles
Sealing groove supercharger housing	Rollers for rocker arm
Cover with bushing for mixture control	Valve control rollers
Gear for control drive	Set screws
Crankshaft bolts	Modification to the tappet housing
Washers	Modification to the valve tappet
Propeller bearings	Rocker arm, cover gasket
Locking screws	New production of a test cylinder
Roller bearings	Tappet springs
Crankshaft-bolt locking pin	Deep-groove ball bearings
Crankshaft	Bevel gears for tachometers
Pistons	Starter shaft
R-piston ring	Bearing
Gudgeon pin mushroom for gudgeon pin	Magnetic drive seal
Articulated-rod bushing	Starter pawls
Master-rod bearing bushing	Sealing ring for threaded connectors
M-piston ring, nos. 2 and 3	Cylinder head bolts
Gudgeon pin bushings	Magnetos
F-piston ring	Spark plug set
Master and articulated rods	Pallas carburettor
Outlet-flange gasket	Angle piece for atomizer nozzle
Stud bolts	Inlet flange gasket
Seals for tappet tubes	Gasket for supercharger tube
Union nut for fairing tube	Supercharger tube
Tappet tubes	Feather key insert
Rocker-arm cover gaskets	Oil pumps
Cylinder head screws for rocker-arm cover	Sealing ring
Screws for rocker-arm cover	Sealing rings for oil distributor
Inlet valves	Oil sump gasket
Inner and outer valve springs	Cylinder head screw for distributor sleeve
Bosch generator interference protection	Lower oil riser pipe
Inlet, outlet flanges	Oil filter seal
Cylinder locking pin	Lock nozzle for lubricant sump
Rocker-arm bearing shells	Elbow for oil return
Bendix starter	Oil return pipe
O-rings for cylinder base	Transverse bearing for dynamo drive
Leaf springs	Pump drive
Valve seats	Supercharger shaft
Countershaft with spur gear	Gear shaft with countershaft gear
Tappet guides	-

Table 19: Procured, commercially available components or those that have been remanufactured or modified. This list is most likely not exhaustive.

A1.6.17.3.2 Crankshaft bolts

In 1983, a sketch was made for the production of crankshaft bolts which were to be remanufactured. Subsequently, two bolts were manufactured by Naef Flugmotoren AG based on a pattern part and the sketch. It is not clear from the documents what material was used.

In 1985, material analysis of an existing bolt was commissioned. At the end of 1997, two more bolts were ordered from Naef Flugmotoren AG, manufactured according to sketches and templates. The material used was specified as 34CrNiMo6.

A1.6.17.3.3 Valve springs

In 1985, Ju-Air commissioned a company in Germany to provide 200 sets of valve springs to be manufactured based on pattern parts.

In 1989, a company in Switzerland invoiced Ju-Air for 560 inner springs and 530 outer springs.

Neither sketches or drawings for the production nor material specifications were found in the files.

A1.6.17.3.4 Supercharger shaft

On 8 March 2001, Ju-Air ordered five shafts and seven turbine wheels from a company in Switzerland for the superchargers of the Ju 52 engines. The order included the preparation of the manufacturing plans according to pattern parts and the preparation of operation plans. The choice of material was left to the manufacturer.

In 2012, this company delivered another six supercharger shafts.

A1.6.17.4 Cylinders from a wreck

On 4 January 1941, a Ju 52/3m had to make an emergency landing on the glacier on the Grossvenediger mountain in Austria. This wreckage was salvaged in 2002 and 2003, after the glacier released it from the glacier ice. The left and right engines were removed by Ju-Air and 16 cylinders were reconditioned from these engines for reuse. Release certificates were subsequently issued by Naef Flugmotoren AG for each of these cylinders. At the time of the accident, some of these cylinders were installed in the HB-HOT engines.

A1.6.17.5 Procurement of a flap

Following damage to the right-hand (inner) flap in May 1997, a replacement flap from a CASA 352[53] was purchased from a museum in Germany. A company in Switzerland, certified to perform aircraft repairs, was commissioned by Ju-Air to repair this flap. After the repair work was completed that same month, the flap was installed on HB-HOT; this flap was still installed at the time of the accident. It differs from the left-hand original Junkers flap mainly in the panelling on the underside of the flap, which was made of smooth and not corrugated sheet metal for a length of 2.33 m from the fuselage.

It could not be clarified whether the flap profile differs from the original flap, if for no other reason than because of the lack of drawings from the two aircraft manufacturers.

[53] CASA 352: The first series of the Ju 52 built under licence by CASA (Spain) from the end of the Second World War onwards.

The two flaps may exhibit different aerodynamic characteristics due to their design. However, no complaints from flight crews have been documented that would indicate an impact on flight operations.

A1.6.17.6 Evaluation

From 2002 onwards, SBs were no longer written for the new production and new procurement of spare parts and the reconditioning of original components.

Dozens of components were remanufactured or modified by a large number of subcontractors by order of Ju-Air, mostly using an old and worn part as a template. As a rule, the files did not contain any sketches, drawings or supporting documents (strength, material, test runs, etc.) for the remanufactured or reconditioned components. The technical records for the production of such components were missing. In many instances, the subcontractors contracted by Ju-Air were not certified to provide parts for use in aviation. In the majority of cases, no certification of airworthiness was available for these remanufactured components. Ju-Air also installed many commercially available, non-certified standard components.

A release certificate was issued by Naef Flugmotoren AG for each of the remanufactured and reconditioned engine components. With regard to the remanufactured or reconditioned aircraft components, there was no indication in the files that a certificate of release to service was available when these parts were installed.

The identified deficits in spare parts management led to many of the newly procured, reproduced or reconditioned components lacking a certificate of airworthiness.

The installation of such components in an aircraft is not permitted and, if the components are used, will result in an aircraft's formal and material loss of airworthiness.

A1.6.18 Record keeping

A1.6.18.1 Guidelines issued by the Federal Office of Civil Aviation

A1.6.18.1.1 General

Matters relating to airworthiness are published by the Federal Office of Civil Aviation (FOCA) in the form of technical communications (TMs). These include the development, certification, production and maintenance of aircraft and aircraft components, as well as maintenance organisations and maintenance personnel.

The TMs are usually explanations or information from FOCA. They are not legally binding regulations. They represent the official interpretation of the underlying directives or laws.

A1.6.18.1.2 Keeping a record of technical files

Technical communication TM 02.010-50, 'Keeping a record of technical files for aircraft and aircraft components'[54], includes the following information:

"*1. General and purpose*

Technical files (TAs) should be issued for each aircraft and for certain aircraft components (in particular engines, propellers and on-board equipment) to provide chronological evidence of all maintenance work carried out on an aircraft. In particular, the AMCs (acceptable means of compliance) for part M.A.305 should also contain information about keeping a comprehensible and complete record of technical files for an aircraft within the scope of the European Aviation Safety Agency

[54] Published in German as "*Führung der technischen Akten der Luftfahrzeuge und Luftfahrzeugteile*"

(EASA). In the interests of clarity and to ensure that records of these documents are kept as consistently as possible for all Swiss aircraft, the Federal Office of Civil Aviation (FOCA) issues the following notes, explanations and detailed definitions. The AMCs relating to part M.A.305 are complied with or are continued and their implementation is facilitated by providing templates.

2. Scope of application

This technical communication (TM) is applicable to aircraft falling within the scope of Regulation (EC) No. 216/2008 as well as to aircraft excluded from its scope as per annex II of said regulation (known as annex II aircraft).

3. Issuing and form of the technical files

The technical files are usually prepared by FOCA when the aircraft and its components (in particular the engines, propellers and on-board equipment) are registered in Switzerland. As a general rule, one corresponding folder is issued per aircraft.

Component cards represent a short form of technical files that briefly summarise the data relevant for the monitoring of airworthiness for individual aircraft components. It is important that the component card applies to a specific part with a defined serial number and accompanies this part from when it is issued until it is taken out of service.

[…]

4. Records in the technical files

In line with M.A.305(a), all maintenance work carried out shall be recorded and certified in the tech log or flight log immediately after completion by appropriately authorised maintenance personnel (the technical files shall be updated within no later than 30 days).

The records shall be legible and signed. Erroneous records shall not be erased or deleted but shall be crossed out in a way that the incorrect text can still be seen (as per M.A.305(g)).

5. Scope of records

The records shall be clear and complete, and document the type and scope of the work carried out in a transparent manner.

[…]

7.1 Maintenance record (form 52.02)

All maintenance work carried out shall be recorded chronologically in a logbook. Each log shall be accompanied by an attestation issued by the appropriately authorised maintenance personnel or organisation.

[…]

7.4 Component cards (forms 52.09 and 52.091)

The completion of component cards is not mandatory, but recommended. Component cards can be used to considerably simplify the overview, e.g. for aircraft components with their own airworthiness directives. Component cards are usually not issued by FOCA, but by the operator or the person/organisation tasked with the maintenance of the aircraft (completion of component cards as per M.A.305(e) 1 – 4).

There should be a directory of the currently applicable component cards, which shall be updated by the person/organisation tasked with the maintenance of the aircraft. From this, it should be apparent which parts of the aircraft are monitored using component cards.

As an attachment to the directory, the individual component cards should be kept in the technical files.

7.5 Work reports, test reports and certification documents

The test reports for the initial and final inspections of aircraft shall be filed and stored in the 'airframe' technical files.

TM 02.010-30 provides information on the preparation, structure and content of work reports accordingly.

Work reports shall be stored in the technical files or attached to the component cards. At the very least, these shall be kept as follows:

A) Until existing work reports and their annexes are replaced by equivalent ones.

B) For as long as the aircraft or aircraft component is in service/use and for at least 12 months after the aircraft or aircraft component has been permanently taken out of service."

A1.6.18.1.3 Work reports

Technical communication TM 02.010-30 'Work reports' includes the following information:

"*1. General and purpose*

Work reports provide supplementary information to the maintenance records of an aircraft. This communication/directive specifies when a work report is required, what it should contain, to whom it should be addressed and how it should be stored.

2. Scope of application

This directive applies to all aircraft on the Swiss aircraft register. For aircraft falling within the scope of Regulation (EC) 216/2008 (EASA aircraft), M.A.305 of annex I of Regulation (EC) No. 2042/2003 also applies.

3. Preparation of a work report

3.1 When is a work report required?

- *If a brief description in the maintenance record is not sufficient to describe the work carried out.*
- *For maintenance work that is not included in existing aircraft maintenance programmes (AMPs), such as engine and propeller replacements which must be reported to FOCA as per article 28, paragraph 2 of the VLL.*
- *For repairs, overhauls and modifications.*
- *If, for particular reasons, information is to be recorded in the technical files or at the request of the Federal Office of Civil Aviation (FOCA).*

3.2 Scope of a work report

A sample work report is provided in the annex to this technical communication. This contains all of the desired information that a report should contain at the very least. Separate reports for the engine and propeller shall only be prepared if the work was carried out on uninstalled units. Separate reports shall be prepared for *work carried out on the on-board equipment (electrical equipment, instruments, and avionics). Where necessary, the reports must also include the required information regarding the change in empty mass and centre of gravity.*"

A1.6.18.2 Maintenance organisation exposition (MOE)

Section 2 of Ju-Air's MOE, revision 9 dated 5 June 2018, 'Maintenance procedures' includes the following information:

"2.13 Maintenance records and their preparation

Aircraft or component cards for the individual parts recorded. Work on the entire aircraft (such as inspections) is only recorded in the aircraft files.

For work on components that are not intended to be installed immediately into an aircraft operated by the organisation or are to be supplied to third parties, [a release certificate] *must be issued in addition to the records on the component card.*

If components are removed from, repaired and then reinstalled in the same aircraft, [no release certificate] *shall be issued. The corresponding records on the component card will be sufficient.*

Over the course of the maintenance work, staff log the individual steps in the worksheets, based on which the work report is later prepared if such a report is required by the competent authority (i.e. FOCA).

If specific inspections or measurements are required within the work documents, the operations manager is responsible for ensuring that the results of these are provided in clear language in the work documents."

"2.16 Procedure for maintenance work certification

The purpose of the release certificate for parts/components is:

1) *To identify a part, a component or entire units, hereinafter referred to as 'part', after manufacturing or assembly.*
2) *To release the parts following maintenance work carried out on them within the framework of part 145.*
3) *To confirm that the required maintenance has been carried out professionally in line with procedures as per our MOE."*

In the corresponding section of Naef Flugmotoren AG's MOE, revision 10 dated 4 July 2018, stated the following:

"*All documentation concerning maintenance work is to be recorded in the aircraft files or on the component cards for the individual components. Work on the entire aircraft (such as inspections) is only recorded in the aircraft files.*

For work on components, a [release certificate] *is issued in addition to the records on the component card, provided that the part in question is not intended to be immediately installed in a component within the organisation or is to be supplied to third parties.*

Over the course of the maintenance work, the staff record the individual steps in the worksheets, based on which the work report is later prepared if such a report is required by the competent authority. If special inspections or measurements are required within the work documents, the technical manager is responsible for ensuring that the results of these are provided in clear language in the work documents.

Maintenance documentation for aircraft maintenance in line with the VLL annex must make reference to the current revision of the AMP in at least the relevant *work report. Before the relevant component or aircraft can be released, a final check must be carried out to ensure that no tools or parts have been left in the aircraft or component.*"

"2.16 Procedure for maintenance work certification

The purpose of the release certificate for parts, components and aircraft is:

1) *To identify a part, a component or entire units, hereinafter referred to as 'part', after manufacturing or assembly.*
2) *To release the parts following maintenance work carried out on them within the framework of part 145.*
3) *To confirm that the required maintenance has been carried out professionally in line with the procedures as per our MOE.*
4) *To release the parts in line with VLL annex, section 11.6, for maintenance of annex II aircraft."*

A1.6.18.3 Record keeping by maintenance organisations

A1.6.18.3.1 General

Ju-Air was responsible for the maintenance of its Ju 52 aircraft through its own maintenance organisation, which was approved according to annex II (part 145) of European Regulation 1321/2014, and kept a record of all of the aircraft's maintenance files (see annex A1.17).

Naef Flugmotoren AG, which was also certified as a maintenance organisation in line with part 145, carried out repair work and major overhauls on the engines and their components. Naef Flugmotoren AG kept a record of the files for this work.

The record keeping by these two maintenance organisations showed severe deficits. The sections that follow illustrate some of the shortcomings in their record keeping.

A1.6.18.3.2 Ju-Air technical files

The cover pages of the maintenance records were not prepared by FOCA, but initially by the VFMF[55] and later by Ju-Air, and were signed by a Ju-Air mechanic.

All maintenance work carried out on the airframe, engine, propeller or on-board equipment must be logged in the maintenance record upon completion, including the date and the relevant operating hours, and certified by an authorised person (certification of release to service). It must also be recorded which maintenance documents were used as the basis for the relevant work carried out.

The handwritten records in the technical files were at times difficult to read. Until 2012, the work carried out was certified only by the mechanic's initials and licence number. It was only possible to identify the person authorised to certify the work using their licence number. In the release certificates, there was never any reference to the maintenance documents that formed the basis for the work carried out. On numerous occasions, the documents in the technical files on work carried out were incomplete and tracing the work was difficult, in parts even impossible.

The task cards for the progressive inspections of the flight controls' settings listed the desired values. The inspection of these figures or settings was certified in the

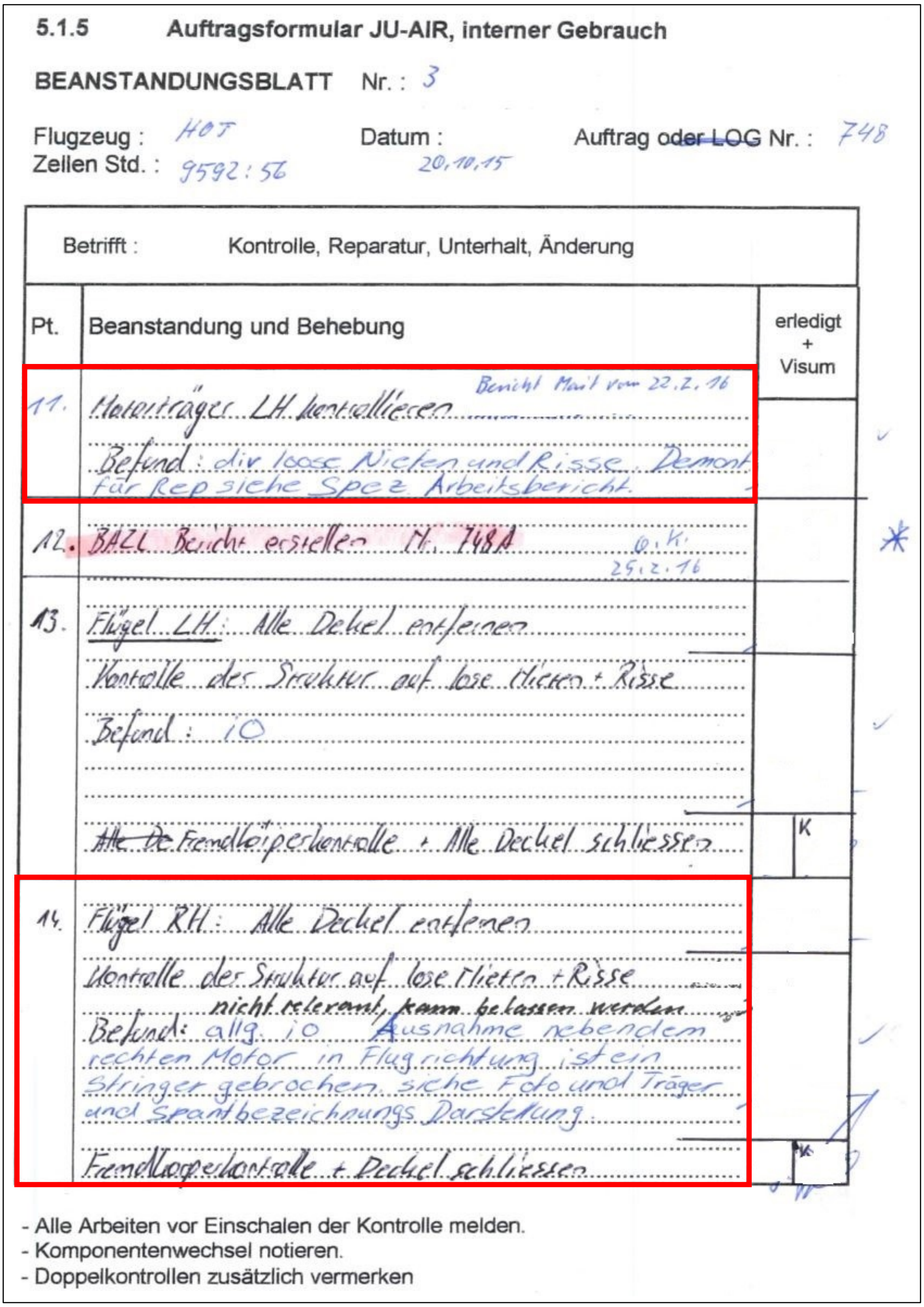
[55] *Verein der Freunde des Museums der Schweizerischen Fliegertruppen* (association of the friends of the Swiss air corps museum)

relevant work report using initials, whilst in most instances the actual values had not been noted (see section A1.6.14.3.4).

In addition to the task cards for the progressive inspections, there was also a ‘complaint sheet’. Additional work, such as repair work or modifications to the airframe or engines, was also recorded in shorthand notes on this sheet (see section A1.6.16.2.4). A rectified complaint was certified using initials. It was not clear whether this was someone who was authorised to certify the work carried out. The work carried out was largely documented in an incomplete and incomprehensible manner (see figures 60 and 61). Where work carried out was also logged in the maintenance record or other lists, it was described differently (see section A1.6.18.3.3). Categorically, no work reports were prepared in compliance with TM 02.010-30.

Since new propeller blades were produced, the cover pages of the propeller maintenance records were no longer correct in terms of part and serial numbers. Only the operating time of the hub was listed, not that of the blades. As the hub and the blades of a propeller did not have the same operating times, it was difficult, or even impossible, to trace the operating hours of the blades.

The information in section 2 of Ju-Air’s MOE and FOCA’s guidelines were not implemented.



5.1.5 Auftragsformular JU-AIR, interner Gebrauch

BEANSTANDUNGSBLATT Nr.: 3

Flugzeug: HOT | Datum: 20.10.15 | Auftrag ~~oder LOG~~ Nr.: 748

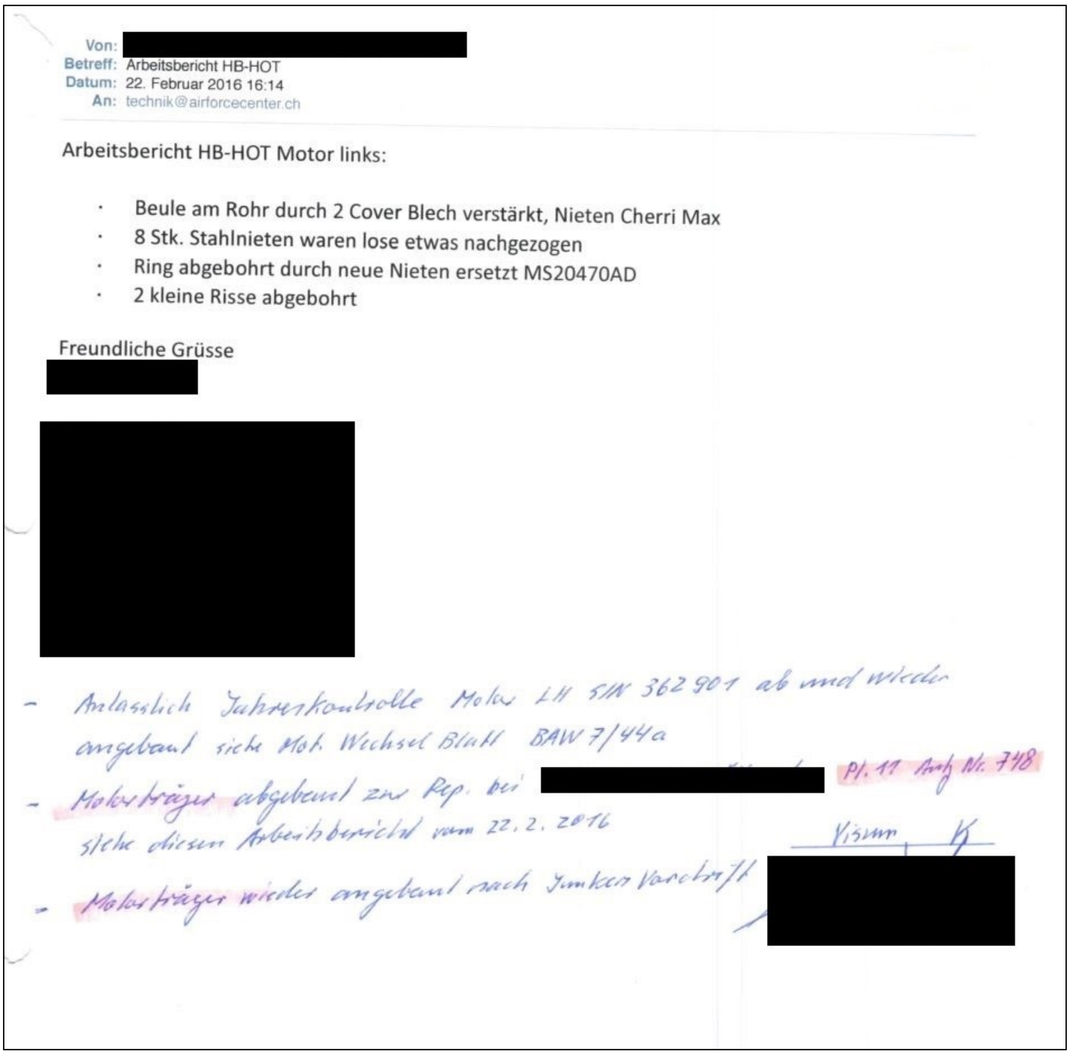
Zellen Std.: 9592:56

Betrifft: Kontrolle, Reparatur, Unterhalt, Änderung

Pt.	Beanstandung und Behebung	erledigt + Visum
11.	Motorträger LH kontrollieren (Bericht Mail vom 22.2.16) Befund: div. lose Nieten und Risse. Demont. für Rep siehe Spez. Arbeitsbericht.	✓
12.	BAZL Bericht erstellen Nr. 748A (o.K. 25.2.16)	*
13.	Flügel LH: Alle Deckel entfernen Kontrolle der Struktur auf lose Nieten + Risse Befund: i.O.	✓
	~~Alle De~~ Fremdkörperkontrolle + Alle Deckel schliessen	K
14.	Flügel RH: Alle Deckel entfernen Kontrolle der Struktur auf lose Nieten + Risse nicht relevant, kann belassen werden Befund: allg. i.O. Ausnahme neben dem rechten Motor in Flugrichtung ist ein Stringer gebrochen, siehe Foto und Träger und Spantbezeichnungs Darstellung.	✓
	Fremdkörperkontrolle + Deckel schliessen	K

- Alle Arbeiten vor Einschalen der Kontrolle melden.
- Komponentenwechsel notieren.
- Doppelkontrollen zusätzlich vermerken

Figure 60: Complaint sheet no. 3 dated 20 October 2015. Initials and subcontractor removed by the STSB. Relevant work items are framed in red. Source: Technical records HB-HOT.



Von: [redacted]
Betreff: Arbeitsbericht HB-HOT
Datum: 22. Februar 2016 16:14
An: technik@airforcecenter.ch

Arbeitsbericht HB-HOT Motor links:

- Beule am Rohr durch 2 Cover Blech verstärkt, Nieten Cherri Max
- 8 Stk. Stahlnieten waren lose etwas nachgezogen
- Ring abgebohrt durch neue Nieten ersetzt MS20470AD
- 2 kleine Risse abgebohrt

Freundliche Grüsse
[redacted]

- Anlässlich Jahreskontrolle Motor LH S/N 362 901 ab und wieder angebaut siehe Mot. Wechsel Blatt BAW 7/44a
- Motorträger abgebaut zur Rep. bei [redacted] Pl. 11 Anf. Nr. 748
siehe diesen Arbeitsbericht vom 22. 2. 2016 Visum K
- Motorträger wieder angebaut nach Junkers Vorschrift [redacted]

Figure 61: Work report by the Ju-Air subcontractor for item 11, complaint sheet no. 3 dated 20 October 2015. Names, signatures and subcontractors have been redacted by the STSB.

A1.6.18.3.3 Horizontal-stabiliser adjustment spindle

According to the technical files, work on the horizontal-stabiliser adjustment spindle was certified on 11 March 2003. Due to records being incomplete, it is not possible to provide precise details about the work carried out and ultimately about the final condition of the horizontal-stabiliser adjustment spindle. The following table lists the different descriptions for the work from the relevant files. A complete work report was not available.

Complaint sheet no. 5, item 18 (job no. 424)	"*Chronological record of replaced components*", sheet no. 13	Maintenance record
• "*Höhenstabilo*[56] *adjustment mechanism P/N 460502/21*" • "*Remove from aircraft*" • "*Remove, clean, inspect, re-grease*" • "*Install in the aircraft and secure*" • "*Check setting and function*"	• "*Components: Höhenstabilo gears and Stabi*[57]" • "*Reason: overhaul*"	• "*Höhenstabilo repaired*"

Table 20: Different descriptions for the same piece of work carried out on the same part.

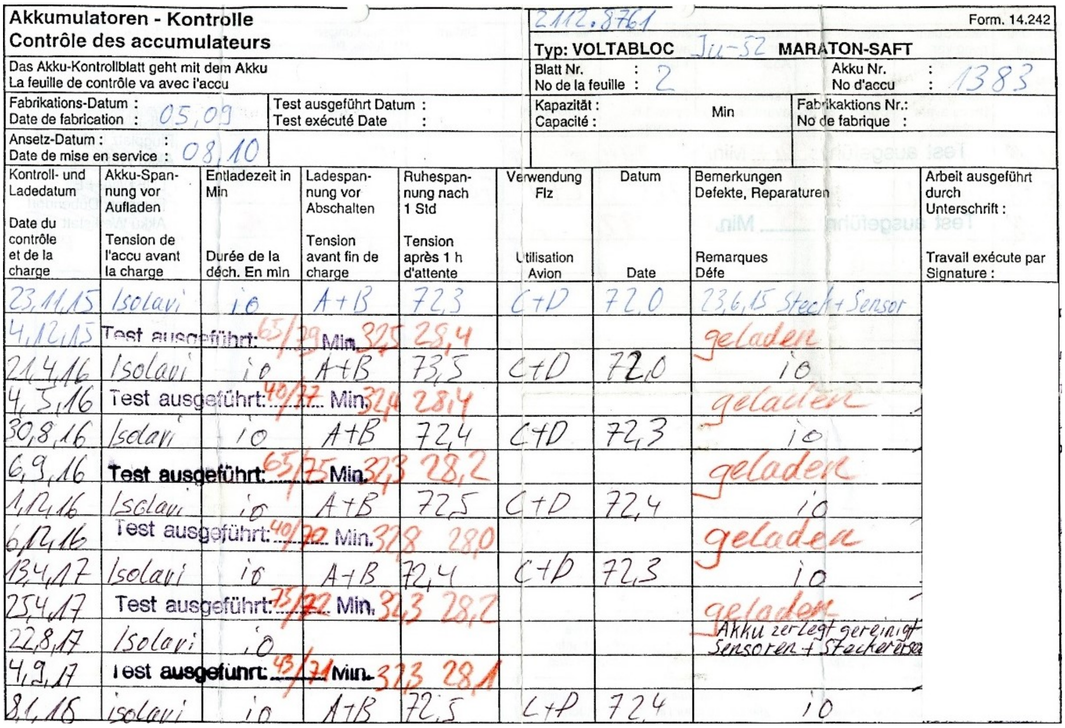
A1.6.18.3.4 On-board battery

An NiCd battery was mentioned in HB-HOT's equipment list, but neither the model of battery (part number) nor the serial number were recorded. The files did not contain a release certificate for the battery.

The Air Force continued to carry out the maintenance of the NiCd batteries at Dübendorf Air Base, even after Ju-Air had acquired the Ju 52 aircraft in the 1980s. For certification of the work, the 'Battery inspection' military form was used, in which the inspection results were noted. The form was filled out incorrectly in parts (see figure 62). In addition, the technical files included an on-board battery log, in which inspection findings were also written. The information in the form and the on-board battery log for the same period of time did not match, even though the two documents were marked with the same serial number.

[56] Record keeper's shorthand note meaning 'horizontal stabiliser'

[57] Another shorthand note meaning 'horizontal stabiliser'



Akkumulatoren - Kontrolle
Contrôle des accumulateurs

2112.8761 — Form. 14.242

Typ: VOLTABLOC Ju-52 MARATON-SAFT

Das Akku-Kontrollblatt geht mit dem Akku
La feuille de contrôle va avec l'accu

Blatt Nr. / No de la feuille : 2 — Akku Nr. / No d'accu : 1383

Fabrikations-Datum / Date de fabrication : 05,09 — Test ausgeführt Datum / Test exécuté Date : — Kapazität / Capacité : Min — Fabrikaktions Nr. / No de fabrique :

Ansetz-Datum / Date de mise en service : 08,10

Kontroll- und Ladedatum / Date du contrôle et de la charge	Akku-Spannung vor Aufladen / Tension de l'accu avant la charge	Entladezeit in Min / Durée de la déch. En min	Ladespannung vor Abschalten / Tension avant fin de charge	Ruhespannung nach 1 Std / Tension après 1 h d'attente	Verwendung Flz / Utilisation Avion	Datum / Date	Bemerkungen Defekte, Reparaturen / Remarques Défe	Arbeit ausgeführt durch Unterschrift : / Travail exécute par Signature :
23,11,15	Isolavi	io	A+B	72,3	C+D	72,0	23,6,15 Steck+Sensor	
4,12,15	Test ausgeführt: 65/39	Min.	32,5	28,4			geladen	
21,4,16	Isolavi	io	A+B	73,5	C+D	72,0	io	
4,5,16	Test ausgeführt: 40/37	Min.	32,4	28,4			geladen	
30,8,16	Isolavi	io	A+B	72,4	C+D	72,3	io	
6,9,16	Test ausgeführt: 65/75	Min.	32,3	28,2			geladen	
1,12,16	Isolavi	io	A+B	72,5	C+D	72,4	io	
6,12,16	Test ausgeführt: 40/70	Min.	32,8	28,0			geladen	
13,4,17	Isolavi	io	A+B	72,4	C+D	72,3	io	
25,4,17	Test ausgeführt: 75/72	Min.	32,3	28,2			geladen	
22,8,17	Isolavi	io					Akku zerlegt gereinigt Sensoren + Steckerersa	
4,9,17	Test ausgeführt: 43/71	Min.	32,3	28,1				
8,1,18	isolavi	io	A+B	72,5	C+D	72,4	io	

Figure 62: Air Force form including inspection results for the NiCd battery. Signatures removed by the STSB. Source: Technical records HB-HOT.

In HB-HOT's 'on-board equipment' maintenance record and on the relevant complaint sheet, the maintenance work carried out on the NiCd battery was certified by Ju-Air mechanics E and G, who did not hold the required licence for this (see annex A1.17).

A1.6.18.3.5 Naef Flugmotoren AG technical records

Naef Flugmotoren AG carried out repair work and major overhauls on engines and their components. Upon conclusion of this work, a work report had to be written, the component cards had to be updated and, if necessary, a release certificate had to be issued. The handwritten records in the technical files were at times difficult to read. The component cards were not completely updated and were not transparent, meaning there was often no precise information available regarding operating hours or work carried out. There was no directory of the currently valid component cards.

The work reports were handwritten in shorthand, were incomplete and in some places barely or not comprehensible. Furthermore, the release certificates contained no reference to the documents that formed the basis for the repairs or major overhauls carried out. As of 2018, work reports were typed and their content and structure were slightly modified. On various occasions, however, the work reports were certified by a person who was not authorised to do so.

The overhaul reports for the engines are not transparent. According to the report, virtually every dismantled component was reworked. Other information was missing (see figure 63). There were also no test reports available for bench-tested components.

The specifications in Naef Flugmotoren AG's MOE and FOCA's guidelines were not implemented into the company's working processes.

NAEF FLUGMOTOREN AG CH – 8600 Dübendorf	Baumuster BMW 132 .3 Werk Nr. 67438 NAEF Auftrag Nr. 7/2003	Befundbericht : Triebwerk Baugruppe : 03 Kolben und Pleuel Ersatzteil-Best.	TSN: 4740:41 TSO: 0.00	Blatt : 4 von : 11

Stck.	Teilebezeichnung	Teil-Nr.	*	LTA/TM SI/SB	Stck	Neuteil bzw. Austauschteil	**	Bemerkungen	*** M	*** Z
3	Kolben Zyl.1,2,9	43M-1600-U3	N	SB 1005				Reinigen Kolbenring nuten		
6	Kolben	43M-1601-U3	N	SB1005				Reinigen Kolbenring-Nuten		
9	Kolbenbolzen	43M-1610	N							
18	Pilz	43M-1611	N							
8	Nebenpleuelbüchsen	43M-1619	N							
8	Schlammbüchsen	43M-1620	N							
1	Hauptlagerbüchse	43M-1621	N							
9	Kolbenbolzenbüchse	43M-1627-1	N	TM-134						
1	Hauptpleuel	43M-1645	N							
8	Nebenpleuel	43M-1646	N							
8	Anlenkbolzen	43M-1640	N							
	-Lösedruck: 1.0									
9	Kolbenringe	43M-1626-U3	A	SB 1005	9	43M-1626		Stoss-Spiel Kontrolle		
18	Kolbenringe	43M-1605-U3	A	SB 1005	18	43M-1605		Stoss-Spiel Kontrolle		
9	Oelabstreifringe	43M-1628-U3	A	SB 1005	9	43M-1628		Stoss-Spiel Kontrolle		

Code :

*
J = auswärts
A = Ausschuss
F = Fehlteil
K = Kreislauf
N = Nacharbeit
U = Wiederverwendung

**
1 = Grundüberholung
2 = i.O.
3 = lt. Aenderung aussondern
4 = Aenderung durchführen
5 = Laufbuchse riefig (honen)
6 = Ventilführung ausgeschlagen
7 = Sitzfläche eingeschlagen
8 = Buchse/Führung wechseln
9 = nachschleifen Korngrösse...
10 = Masse ausser Toleranz
11 = Gewinde beschädigt
12 = Oberflächenbehandlung
13 = Risse / gerissen
14 = allg. Korrosion
15 = allg. Verschleiss
16 = Riefen/Kratzer/Kerben
17 = Galling / Fretting
18 = eingewalzte Fremdkörper
19 = Materialausbruch
20 = Materialüberhitzung/Abbrand
21 = reinigen/Funktionsprüfung
22 = Federdruck zu schwach
23 = ...

***
Z = Rissgepr. ZYGLO
M = Rissgepr. MAGNETISCH
2 = i.O.
13 = gerissen/Risse

Figure 63: Overhaul report from July 2009, sheet 4, pistons and connecting rods. Source: Technical records HB-HOT.

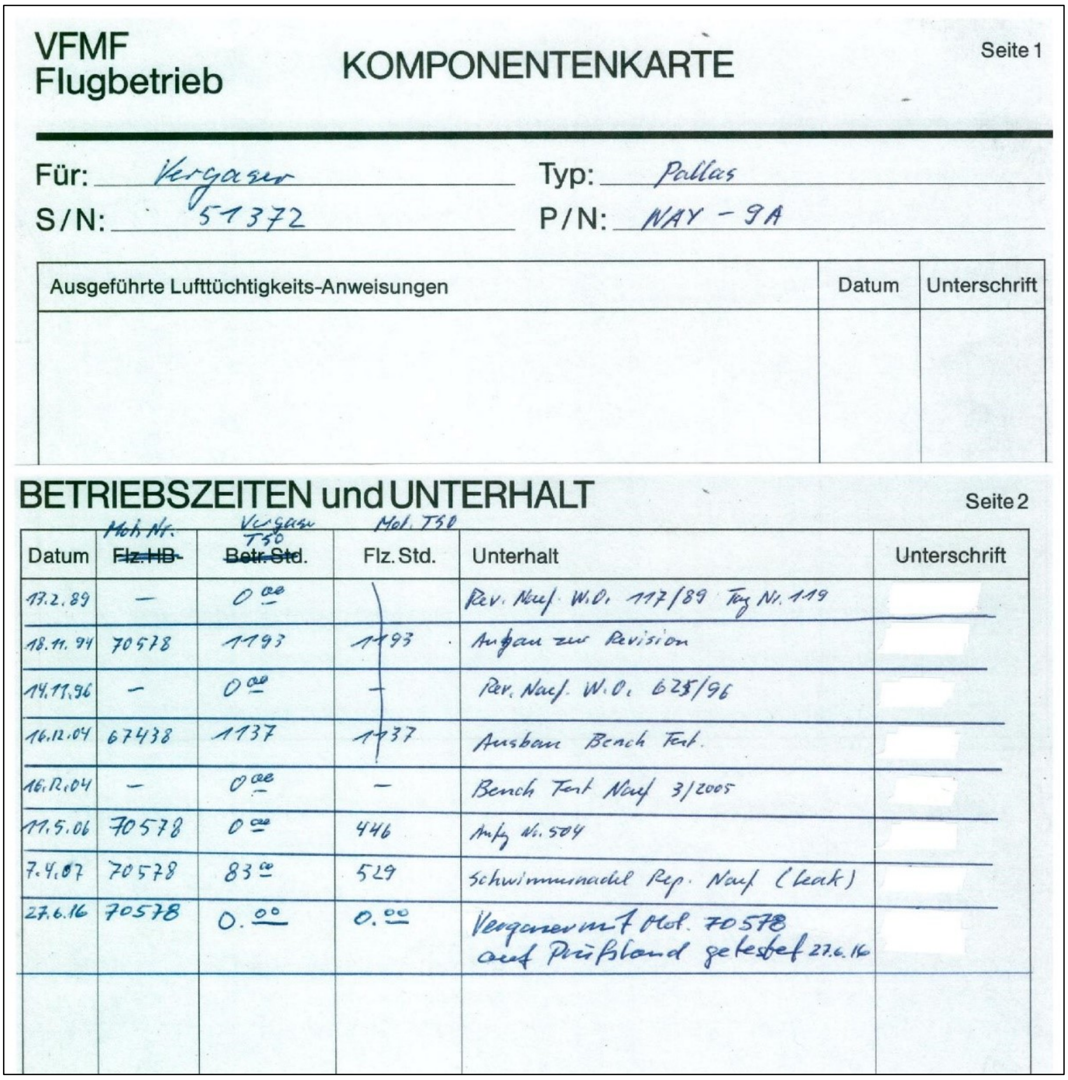
A1.6.18.3.6 Carburettors

The previous operating time was not apparent in the maintenance organisation's records.

Maintenance work carried out on the carburettor was not consistently recorded on the component card and could sometimes only be found in the engine logbook. During this investigation, it was difficult to trace updates to the operating hours following work or inspections.

The carburettor with serial number 60930, installed on the centre engine, was overhauled in June 2003. The test run performed in April 2013, after 1,772 operating hours, is listed as the next inspection. The aircraft maintenance programme stipulated the maximum operating time between test runs or overhauls as 1,500 hours. This limit was thus exceeded by 272 operating hours.

For the carburettor with serial number 51372, installed on the right engine, the first entry on the component card was dated February 1989 (see figure 64). An overhaul was carried out in November 1996. In December 2004, after 1,137 operating hours, the maintenance team carried out a test run. Thus, based on the Ju 52's maintenance programme, an overhaul would have been due no later than after another 1,500 hours. In June 2016, after a total of 1,611 operating hours instead of 1,500 hours since the last test run, another test run was carried out instead of an overhaul. According to the records, the carburettor had exceeded the limit for the next overhaul by 569 operating hours at the time of the accident.



VFMF
Flugbetrieb

KOMPONENTENKARTE

Seite 1

Für: Vergaser
Typ: Pallas
S/N: 51372
P/N: NAY - 9A

Ausgeführte Lufttüchtigkeits-Anweisungen	Datum	Unterschrift

BETRIEBSZEITEN und UNTERHALT

Seite 2

Datum	Mot. Nr. ~~Flz. HB~~	Vergaser TSO ~~Betr. Std.~~	Mot. TSO Flz. Std.	Unterhalt	Unterschrift
17.2.89	—	0.00		Rev. Naef W.O. 117/89 Tag Nr. 119	
18.11.94	70578	1193	1193	Aufbau zur Revision	
14.11.96	—	0.00	—	Rev. Naef. W.O. 625/96	
16.12.04	67438	1137	1137	Ausbau Bench Test.	
16.12.04	—	0.00	—	Bench Test Naef 3/2005	
11.5.06	70578	0.00	446	Aufb. Nr. 504	
7.4.07	70578	83.00	529	Schwimmernadel Rep. Naef (leak)	
27.6.16	70578	0.00	0.00	Vergaser mit Mot. 70578 auf Prüfstand getestet 27.6.16	

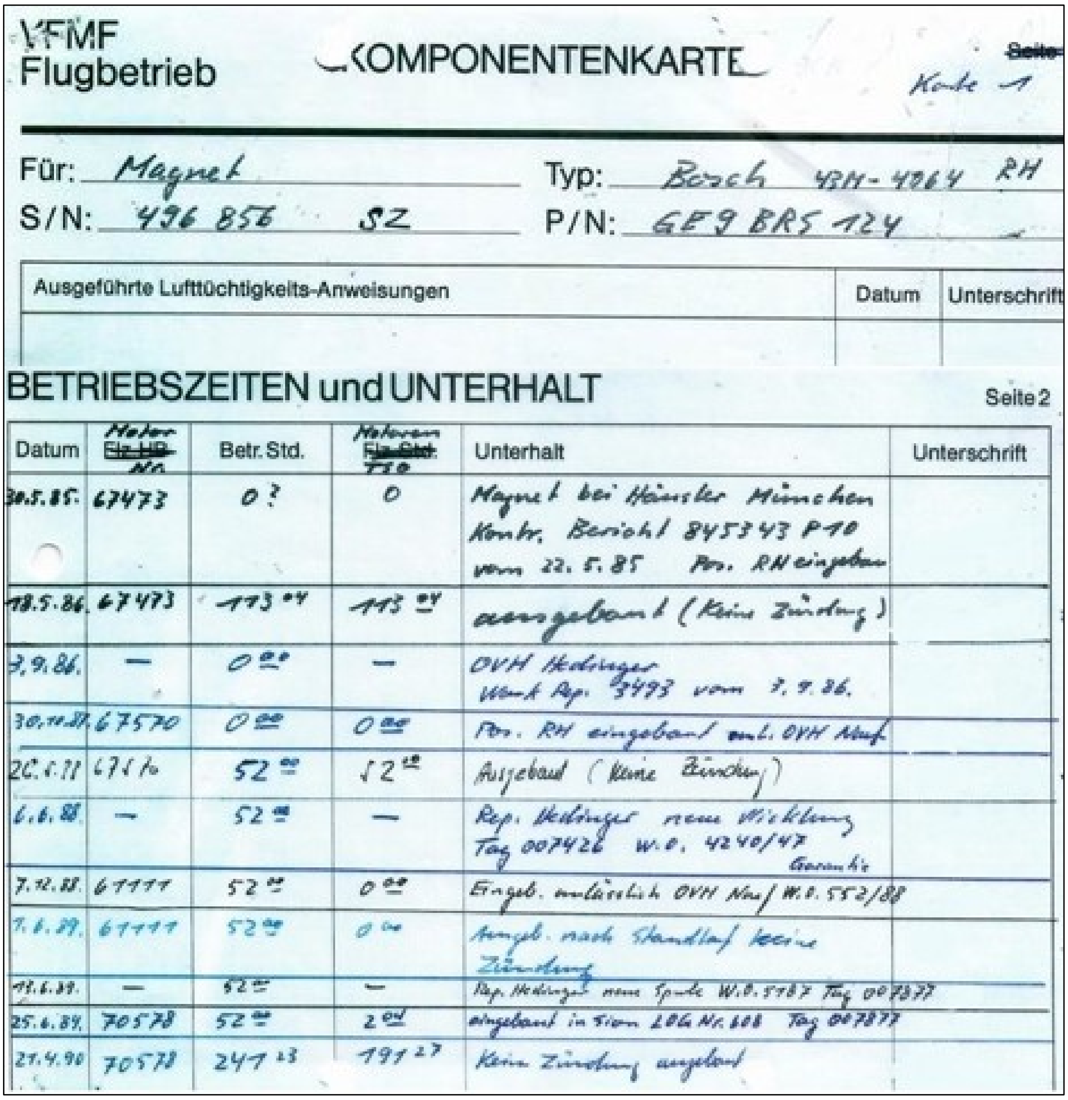
Figure 64: Component card for the carburettor with serial number 51372. Signatures of mechanics removed by the STSB. Source: Technical records HB-HOT.

According to Naef Flugmotoren AG, the carburettors were bench-tested following repair work or overhauls. During this process the carburettor was only checked for fuel flow and leaks. There were no records of test logs or work reports.

A1.6.18.3.7 Magnetos

The magnetos' previous operating times were not apparent from the technical files. Maintenance work carried out on the magnetos was not consistently recorded on the component card and could sometimes only be found in the engine files.
The magnetos were used in both positions, in various engines and in various aircraft. During this investigation, it was difficult to trace updates to the operating hours following repairs, inspections or overhauls. For example, the position of the magneto (serial number 496856) on the right engine could not be determined using the component card.

The first log on the component card is dated 30 May 1985 and shows 0 operating hours following an inspection (see figure 65). By the time of the accident, a total operating time of 3,644 hours had been recorded. During this period of operation, the magneto had been overhauled three times and repaired five times without achieving the expected operational life. The 650-hour inspection was never recorded on the component card. This magneto had been used in seven different engines.


VFMF
Flugbetrieb

KOMPONENTENKARTE

~~Seite~~ Karte 1

Für: Magnet
Typ: Bosch 4BM-4064 RH
S/N: 496 856 SZ
P/N: GE9 BRS 124

Ausgeführte Lufttüchtigkeits-Anweisungen	Datum	Unterschrift

BETRIEBSZEITEN und UNTERHALT

Seite 2

Datum	Motor ~~Flz.HB~~ Nr.	Betr. Std.	Motoren ~~Flz.Std.~~ TSO	Unterhalt	Unterschrift
30.5.85.	67473	0 ?	0	Magnet bei Häusler München Kontr. Bericht 845343 P10 vom 22.5.85 Pos. RH eingebaut	
18.5.86.	67473	113 04	113 04	ausgebaut (Keine Zündung)	
3.9.86.	—	0 00	—	OVH Hedinger Werk Rep. 3493 vom 3.9.86.	
30.11.87.	67570	0 00	0 00	Pos. RH eingebaut auf. OVH Mot.	
26.5.88	67570	52 00	52 00	Ausgebaut (Keine Zündung)	
6.6.88.	—	52 00	—	Rep. Hedinger neue Wicklung Tag 007426 W.O. 4240/47 Garantie	
7.12.88.	67777	52 00	0 00	Eingeb. anlässlich OVH Mot./ W.O. 552/88	
7.6.89.	67777	52 00	0 00	Ausgeb. nach Standlauf keine Zündung	
19.6.89.	—	52 00	—	Rep. Hedinger neue Spule W.O. 5787 Tag 007877	
25.6.89.	70578	52 00	2 00	eingebaut in Sion LOG Nr. 608 Tag 007877	
27.4.90	70578	247 23	197 23	Keine Zündung ausgebaut	

Figure 65: Component card for the magneto with serial number 496856. Signatures removed by the STSB. Source: Technical records HB-HOT.

A1.6.18.3.8 Cylinders

A cylinder's serial number, its relative position on the engine and operating hours since the last service were not consistently recorded on its component card. Information regarding the cylinder's installed position was not consistently updated. After a cylinder had been replaced or repaired, the serial number of the relevant cylinder was not declared in the technical files and work report. This approach meant that the documentation on engine maintenance was incomplete and not transparent.

A1.6.18.3.9 Evaluation

The vast majority of the technical files of both maintenance organisations were handwritten. In places these were barely legible, sometimes even illegible. For the most part, the work carried out was not transparent and it was extremely difficult, in most cases even impossible, to trace the work carried out on components. Records were not kept as specified in FOCA's technical communications and the companies' MOEs.

Work reports for the repairs carried out by Naef Flugmotoren AG were certified by an unauthorised person in 2018.

A1.6.19 Ageing aircraft programme

FOCA recognised the need to gain an overview of the operation of ageing aircraft. In many instances, these were aircraft that had previously been operated by the military and now required maintenance in accordance with civil regulations. In particular, aspects of material fatigue or ageing, and the maximum permissible operating time of aircraft needed to be assessed with the aim of continuing to ensure their airworthiness. Often, the manufacturers' maintenance programmes had not been designed to check critical areas of the structure. As can be seen from the example of Ju-Air's Ju 52 aircraft, such areas can barely or not at all be seen or inspected without extensively dismantling the aircraft. Furthermore, data on the maximum permissible operating time was missing.

To this end, in 2010 FOCA launched the ageing aircraft programme for models of aircraft on the Swiss register that were referred to in annex II of European Regulation 216/2008. In October 2011, the respective operators were contacted in writing and informed about this project.

The project was divided into three phases:

Phase I: - Situation analysis and collecting data

Phase II: - Evaluating existing reports

- Conducting a special inspection of the fleet-leader aircraft
- Performing or studying various analyses

Phase III: - Creating supplemental structural inspection documents (SSID)

In phase I, the following operating data was requested in order to carry out a risk assessment:

- Year of manufacture
- Total flight hours and landings
- Total flight hours and landings of the oldest aircraft (fleet leader)
- Executed repairs and/or changes, such as weight increases, etc.
- Service life tests carried out
- Problems arising (AD, SB)
- Load on and/or stress level in the critical components

Ju-Air's Ju 52/3m g4e aircraft were also part of this programme. In the beginning, FOCA had to ask Ju-Air several times to submit the operating data for phase I. In a statement dated 30 September 2015, Ju-Air informed FOCA of the status of the investigation and further action. Ju-Air stated that an extended special assessment programme, tailored to the aircraft's operating conditions, was to be developed. The statement did not include a concrete action plan and timeline. FOCA subsequently asked Ju-Air several times to develop an action plan for phase II, complete with deadlines. Ju-Air had not complied with this request at the time of the accident.

In early 2017, Zurich University of Applied Sciences (ZHAW), who had been commissioned for the project, suggested to FOCA that the forces acting on the horizontal-stabiliser adjustment spindle during flight be measured using strain gauges. At the time of the accident, this project had not yet been completed.

A supplemental structural inspection document (SSID) had not been developed by the time of the accident.

A1.6.20 Condition of HB-HOT's sister aircraft

HB-HOT's two sister aircraft, HB-HOS and HB-HOP, exhibited the same poor condition as HB-HOT. In particular, the anti-corrosion paint prescribed by the manufacturer had severely flaked off (see figures 66 to 70). This surface protection is necessary for Duralumin, as otherwise intergranular corrosion can occur (see annex A1.16). The aircraft also featured overaged fuel lines (see figure 68).

Figure 66: Surface flaking and a lack of anti-corrosion paint on the inside of HB-HOS's left-hand horizontal stabiliser.

Figure 67: Surface flaking and a lack of anti-corrosion paint on the inside of HB-HOS's right-hand outer wing.

Figure 68: Flaking anti-corrosion paint and severe contamination on the inside of HB-HOP's left-hand outer wing, and fuel line from 1989.

Figure 69: Lack of anti-corrosion paint on a spar tube in HB-HOP's left-hand outer wing.

Figure 70: Corroded components and a lack of anti-corrosion paint on the inside of HB-HOP's left-hand outer wing.

Contents

A1. Factual information

A1.7 Meteorological information

This annex to the final report discusses the meteorological aspects of the accident in more detail. The key points are referenced in the main report. Some discussions and figures might need specific knowledge for a full understanding. However, where possible, the descriptions are aimed at interested, but not necessarily specialised readers. The references in the footnotes will help readers find further useful information.

For technical terms and abbreviations, please refer to the glossary.

Swiss geographical names can be found via swisstopo[1].

All of the times mentioned in this report, unless otherwise indicated, are given in Central European Summer Time (CEST), i.e. local time (LT) in Switzerland. The relationship between LT, CEST and UTC (Coordinated Universal Time) is: LT = CEST = UTC + 2 h. Even when the primary information was given in UTC, the times in the text and in captions are given in LT.

A1.7.1 General weather conditions

The Alps were within an extension of the Azores anticyclone (high-pressure system). The flat pressure distribution and the vertical temperature profile were supporting the formation of cumulus clouds including isolated TCUs and CBs. The wind at the altitude of the main ridges and above was from the northern sector. The freezing level was between about 4,400 m AMSL in the south of the Alps, and 4,600 m AMSL in the north.

A1.7.2 Weather at the time and location of the accident

The following information about the weather conditions at the time and location of the accident is based on data sources described in sections A1.7.11, A1.7.12, and A1.7.14.3.

In the Alpine region of the accident (cantons of Glarus and Grisons), warm and sunny weather prevailed. The base of the cumulus clouds was around 10,000 ft AMSL (2,800 to 3,400 m AMSL). Above the Segnes pass between the Vorab mountain and Piz Segnas, the wind at the altitude of the flight was blowing from north to north-west. In combination with the thermal activity above the sunny slopes, this created turbulent conditions within the steep side valley (see sections A1.7.7 as well as A1.7.12 to A1.7.15). At the altitude of the flight in this region, the atmosphere was 13 °C warmer than ISA[2], which corresponded to a density altitude of 10,100 ft AMSL (3,080 m AMSL).

Please note that the temperature enhancement against ISA is not a universal constant for all altitudes. For a typical summertime temperature profile with 10 °C/km temperature decrease with altitude, the positive difference to ISA (cooling with only 6.5 °C/km) decreases with altitude. At the time of the departure from Locarno, the temperature was ISA+17 °C in contrast to the ISA+13 °C at about 2,750 m AMSL.

[1] https://map.geo.admin.ch/?topic=swisstopo&lang=en&bgLayer=ch.swisstopo.pixelkarte-farbe

[2] ISA: International Standard Atmosphere according to ICAO, the International Civil Aviation Organization

The archived images from the weather radar network of MeteoSwiss[3] (see section A1.7.10) were showing weak showers about 7 km west of the accident, and 15 to 20 km west of it. The cumulus clouds above Piz Segnas can be seen on the webcam images shown in section A1.7.8.

Weather/clouds	3 to 4 oktas cumulus clouds Base at about 10,000 ft AMSL (3,000 m AMSL)
Visibility	More than 10 km
Wind	Crap Masegn station[4], 009° / 16 kt, 26 kt in gusts COSMO analysis[5] at the altitude of flight 340° / 18 kt (± gusts) Station 4 km south[6], 10 kt from north, with gusts in the vicinity of the accident[7] 060-070° / 17 kt
Temperature / dew point	Crap Masegn station, 14.9 °C / 6.7 °C COSMO analysis at the flight's altitude, 10.5 °C / 7.4 °C
Atmospheric pressure	Crap Masegn station, 762.3 hPa (QNH 1,030.8 hPa) COSMO analysis at 2,750 m AMSL, 738.3 hPa QNH south of the Alps (LSZL), 1,014 hPa QNH north of the Alps (LSMD), 1,017 hPa (QNH: pressure reduced to sea level, as calculated according to ICAO[8])
Hazards[9]	*"Isolated showers and thunderstorms, especially over the mountains. Temperature exceeding 30-degree centigrade (consider the density altitude)."*

A1.7.3 Astronomical information

Position of the sun[10]	Azimuth: 252°	Elevation: 39°
Light conditions	Daytime	

[3] MeteoSwiss is the short name for the Federal Office of Meteorology and Climatology: https://www.meteoswiss.admin.ch/home.html?tab=overview

[4] Meteorological station of MeteoSwiss at 2,480 m AMSL next to the site of the accident (wind at 2,495 m AMSL; temperature and pressure at 2,482 m AMSL; see sections A1.7.11.2 and A1.7.14.3)

[5] Fine-mesh meteorological model of MeteoSwiss (see section A1.7.12)

[6] Meteorological station of Flims Electric AG (see section A1.7.14.3)

[7] Derived from the moving dust cloud after the impact, documented in a video

[8] ICAO, the International Civil Aviation Organization, defining the ISA, the International Standard Atmosphere

[9] Translated from the aviation weather forecast of MeteoSwiss from 13:00 LT (see section A1.7.5.1)

[10] https://www.esrl.noaa.gov/gmd/grad/solcalc/

A1.7.4 Airport weather reports

The following sections contain many abbreviations and codes, which are explained in the glossary. For French or Italian explanations, see the brochure[11].

These reports (Meteorological Aviation Routine Weather Report – METAR) have no direct relevance to the accident. However, the reports that were valid well before departure until the planned landing are listed here. They are referenced in section A1.7.16.1).

Between 14:20 LT and 18:50 LT, the following reports were issued (the times in the messages are in UTC, i.e. 041220Z is denoting the fourth day of the month at 14:20 LT):

[11] https://www.meteosuisse.admin.ch/content/dam/meteoswiss/fr/service-und-publikationen/publikationen/doc/MCH_Flugwetter_2020_F_Web.pdf and https://www.meteosvizzera.admin.ch/content/dam/meteoswiss/it/service-und-publikationen/doc/MCH_Flugwetter_2020_I_Web.pdf

METAR from Locarno Aerodrome (LSZL)

041220Z AUTO 27006KT 9999NDV NCD 30/21 Q1015 RMK=
041250Z AUTO 25006KT 230V290 9999NDV NCD 30/21 Q1015 RMK=
041320Z AUTO 26006KT 220V300 9999NDV NCD 31/22 Q1015 RMK=
041350Z AUTO 26005KT 9999NDV NCD 31/22 Q1014 RMK=
041420Z AUTO 26005KT 9999NDV NCD 31/22 Q1014 RMK=
041450Z AUTO 27004KT 230V300 9999NDV NCD 32/21 Q1014 RMK=
041520Z AUTO 27005KT 230V290 9999NDV NCD 32/21 Q1014 RMK=
041550Z AUTO 28005KT 230V330 9999NDV FEW160 32/21 Q1013 RMK=
041650Z AUTO 28003KT 230V340 9999NDV NCD 31/21 Q1014 RMK=

METAR from Lugano Airport (LSZA):

041220Z 20008KT 9999 FEW060 32/20 Q1016 NOSIG=
041250Z 19007KT 9999 FEW060 32/20 Q1016 NOSIG=
041320Z 20007KT 9999 FEW060 33/20 Q1016 NOSIG=
041350Z 20007KT 9999 FEW060 33/19 Q1015 NOSIG=
041420Z 20007KT 9999 FEW060 33/19 Q1015 NOSIG=
041450Z 19006KT 9999 FEW060 33/19 Q1015 NOSIG=
041520Z AUTO 19007KT 9999 //////TCU 33/20 Q1014=
041550Z 19008KT 9999 SCT060 32/20 Q1014 NOSIG=
041620Z 19008KT 9999 FEW060 32/20 Q1015 NOSIG=
041650Z 19006KT 150V220 9999 FEW060 32/20 Q1015 NOSIG=

METAR from Dübendorf Air Base (LSMD):

041220Z AUTO VRB03KT 9999NDV NCD 33/14 Q1018 RMK=
041250Z AUTO VRB05KT 9999NDV FEW083 33/14 Q1018 RMK=
041320Z AUTO 16004KT 120V240 9999NDV SCT082 33/14 Q1018 RMK=
041350Z AUTO 35006G18KT 290V060 9999NDV BKN081 BKN100 32/15 Q1018 RMK=
041420Z AUTO VRB05KT 9999NDV FEW078 SCT098 33/15 Q1017 RMK=
041450Z AUTO 03005KT 300V080 9999NDV FEW079 33/17 Q1017 RMK=
041520Z AUTO 03005KT 330V100 9999NDV NCD 33/15 Q1017 RMK=
041550Z AUTO 01005KT 320V060 9999NDV NCD 33/13 Q1017 RMK=
041650Z AUTO 02004KT 330V120 9999NDV NCD 32/15 Q1018 RMK=

METAR from Zurich Airport (LSZH)

041220Z 03005KT 270V090 9999 SCT065 FEW070TCU 35/14 Q1018 NOSIG=
041250Z 32014KT 9999 SCT065 FEW070TCU 33/16 Q1018 NOSIG=
041320Z 35009KT 9999 SCT060 FEW068TCU 34/16 Q1018 NOSIG=
041350Z 36008KT 320V030 9999 FEW068 FEW070TCU SCT120 34/16 Q1018 NOSIG=
041420Z 36008KT 320V040 9999 FEW070 FEW075CB 33/17 Q1018 NOSIG=
041450Z 36006KT 330V040 9999 FEW075TCU SCT130 33/16 Q1017 NOSIG=
041520Z 02009KT 320V060 9999 FEW075TCU SCT130 34/15 Q1017 NOSIG=
041550Z 36005KT 330V030 9999 FEW075TCU SCT140 33/13 Q1017 NOSIG=
041620Z 36005KT 320V040 9999 FEW075TCU SCT140 33/15 Q1017 NOSIG=
041650Z 36005KT 240V030 9999 FEW075TCU BKN200 31/16 Q1018 NOSIG=

A1.7.5 Forecasts

A1.7.5.1 General aviation weather forecast text from MeteoSwiss

At 07:00 and 13:00 LT, texts for the general aviation forecasts in Switzerland were issued in German and French.

The complete German texts are copied in the German version of this annex. Here, the French texts are copied. Only the core statements, which are underlined, are translated in a summary after the forecasts.

"*Prévision aéronautique pour la Suisse, valable du samedi 4 août, au mardi 7 août 2018. Bulletin de 5h00 UTC*

Situation générale :

léger affaissement de la dorsale en altitude mais toujours anticyclonique en surface.

Temps, nuages et visibilité entre 6 et 12 UTC :

Plateau et Jura : plutôt clair au début, hormis quelques nuages élevés. Développement à la mi-journée de 1-3/8, bases 7000-9000 ft/msl suivi d'averses isolées, voire orages. Visibilité supérieure à 8 km.

Préalpes et Alpes : encore parfois 3-4/8 de nuages résiduels au début dans les Alpes orientales, bases vers 10000 ft/msl, se dissipant rapidement, sinon clair. Développement à la mi-journée de 1-3/8, bases 7000-9000 ft/msl suivi d'averses isolées, voire orages. Visibilité supérieure à 8 km.

Sud des Alpes et Engadine : encore 3-5/8 de nuages résiduels au début en Engadine, bases vers 10000 ft/msl, se dissipant rapidement, sinon clair. Développement à la mi-journée de 1-3/8, bases 4500-6000 ft/msl au Sud, 7000-9000 ft/msl le long du massif alpin, 9000-11000 ft/msl en Engadine. Visibilité généralement supérieure à 8 km.

Dangers prévus entre 6 et 12 UTC :

Température supérieure à 30°C, altitude-densité élevée.

Evolution jusqu'à minuit, dangers compris :

Averses ou orages isolés au Nord cet après-midi et début de soirée. Dissipation en soirée. Augmentation du risque d'orage en soirée au Sud des Alpes.

Vent (en degrés et kt) et températures :

	Payerne		Zürich		Lugano	
	9 UTC	15 UTC	9 UTC	15 UTC	9 UTC	15 UTC
Au sol	NE / 2-5 KT		VRB / 1-4 KT		VRB / 1-4 KT	
05000 FT	055/010 PS20	055/010 PS22	020/005 PS19	060/005 PS22	150/005 PS18	230/010 PS22
10000 FT	040/015 PS07	020/010 PS09	030/010 PS06	335/010 PS08	025/010 PS08	015/015 PS10
18000 FT	350/015 MS05	320/015 MS06	355/015 MS05	335/015 MS06	030/015 MS05	025/015 MS05
30000 FT	290/010 MS33	295/015 MS33	275/010 MS33	280/020 MS33	040/020 MS33	315/005 MS32
39000 FT	290/015 MS55	265/020 MS55	280/010 MS55	265/025 MS55	020/010 MS54	315/010 MS54
53000 FT	335/010 MS60	280/005 MS60	330/010 MS60	270/005 MS59	005/005 MS60	350/005 MS60
Vent max	-----FT ---/---					
Tropopause	41000FT MS58					
Isotherme zéro	15000FT					

Tendance pour les trois prochains jours : […]

Prochaine actualisation : samedi, 4 août 2018, à 11h00 UTC=

Prévision aéronautique pour la Suisse, valable du samedi 4 août, au mardi 7 août 2018. Bulletin de 11h00 UTC.

Situation générale :

léger affaissement de la dorsale en altitude mais toujours anticyclonique en surface.

Temps, nuages et visibilité entre 12 et 18 UTC :

Plateau et Jura : 3-5/8, bases 7000-9000 ft/msl. Visibilité généralement supérieure à 8 km. Averses ou orages isolés sur le Jura avec abaissement temporaire du plafond et une réduction de la visibilité.

Préalpes et Alpes : 3-5/8, bases 8000-10000 ft/msl. Visibilité généralement supérieure à 8 km. Averses ou orages isolés sur les Préalpes avec abaissement temporaire du plafond et une réduction de la visibilité.

Sud des Alpes et Engadine : 3-5/8, bases 7000-9000 ft/msl, 9000-11000 en Engadine. Visibilité généralement supérieure à 8 km. Averses ou orages isolés sur les versants sud-alpins avec abaissement temporaire du plafond et une réduction de la visibilité.

Dangers prévus entre 12 et 18 UTC :

Averses ou orages isolés sur les reliefs. Température supérieure à 30°C, altitude-densité élevée.

Evolution jusqu'à minuit, dangers compris :

A nouveau clair par le nord-ouest, dernières averses ou orages isolés au Sud.

Vent (en degrés et kt) et températures au sol et en altitude :

	Payerne		Zürich		Lugano	
	12 UTC	18 UTC	12 UTC	18 UTC	12 UTC	18 UTC
Au sol	NE/ 5-10		N/NE 5-10		VRB/2-7	
05000 FT	045/010 PS21	050/020 PS22	285/005 PS21	025/015 PS21	235/010 PS20	245/005 PS22
10000 FT	040/020 PS08	030/010 PS09	005/020 PS07	340/010 PS08	025/015 PS09	020/015 PS09
18000 FT	355/010 MS06	335/010 MS06	340/010 MS06	320/015 MS06	005/010 MS05	020/010 MS06
30000 FT	270/015 MS32	300/015 MS33	275/020 MS33	290/015 MS33	025/010 MS32	295/010 MS32
39000 FT	270/015 MS54	255/020 MS55	265/015 MS54	260/020 MS55	040/005 MS54	290/010 MS54
53000 FT	005/005 MS60	295/015 MS60	325/005 MS60	305/010 MS59	015/005 MS61	315/005 MS60
Vent max	-----FT ---/---					
Tropopause	42000FT MS60					
Isotherme zéro	14300FT					

Tendance pour les trois prochains jours : […]"

End of the excerpts from the French version of the general aviation forecast.

<u>Summary</u>: In the two forecasts (the first valid for 08:00 to 14:00 LT, the second for 14:00 to 20:00 LT), the development of clouds over the Alpine region was described with initially 1 to 3 oktas, followed by 3 to 5 oktas with cloud bases between 7,000 and 9,000 ft AMSL, and 8,000 to 10,000 ft AMSL, respectively. For both periods, the visibility was estimated to be more than 8 km. The possibility for isolated thunderstorms was mentioned in the general texts, and in the warnings for the afternoon's forecast. In both warnings, the elevated density altitude was mentioned. The wind at 10,000 ft AMSL above Zurich and Lugano (as shown in the tables) was expected from the northern sector with 10 to 15 kt during the afternoon (no indication for above the Alps).

A1.7.5.2 Significant weather chart for the Alps

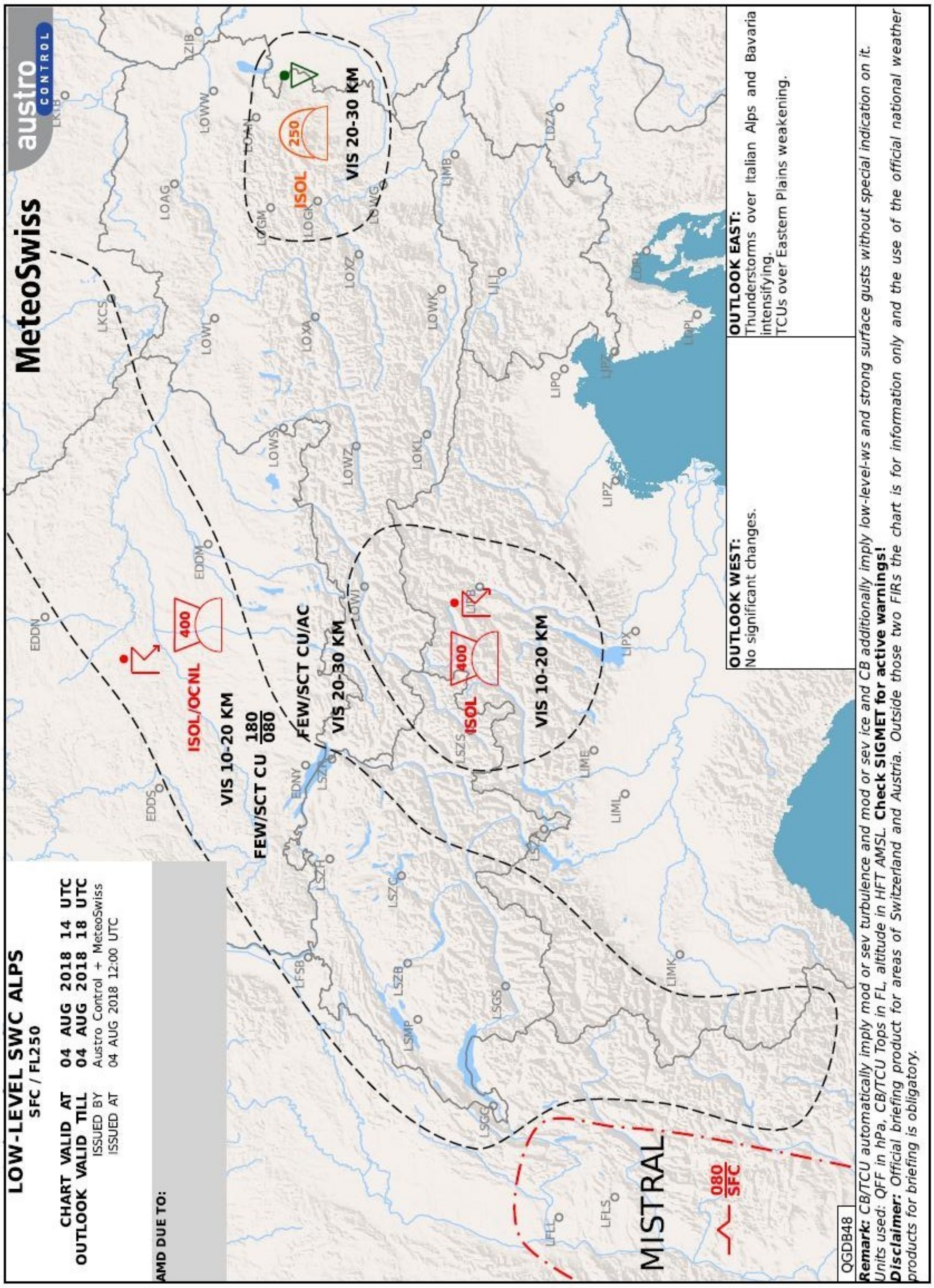


Figure 1: This LOW-LEVEL SWC ALPS was issued at 14:00 LT and was valid for 16:00 to 20:00 LT. The symbols are explained in the document from MeteoSwiss[12]. For south-western Switzerland, isolated showers and thunderstorms are shown with good visibility. Similarly, but only occasionally, this was indicated for the western region which included the destination airfield Dübendorf (south of LSZH).

[12] There is no English version available. However, this link is for a French description: https://www.meteosuisse.admin.ch/content/dam/meteoswiss/fr/service-und-publikationen/beratung-und-service/doc/Prospekt_Low-Level-SWC_F_v5.pdf

A1.7.5.3 General aviation forecast for the main VFR routes

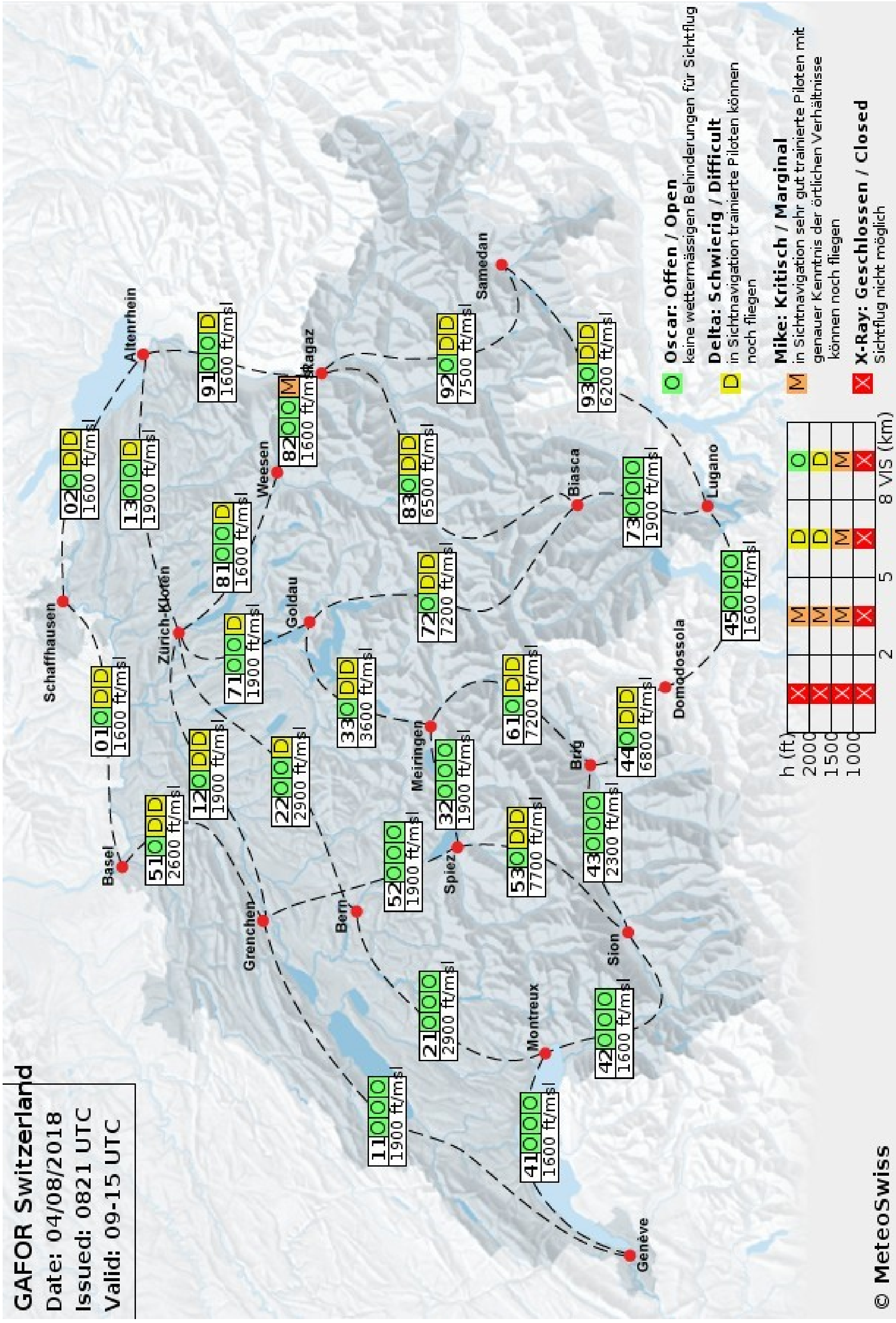


Figure 2a: The GAFOR charts for 11:00 to 17:00 LT (this page) and for 14:00 to 20:00 LT (next page) are not showing any closed routes. With the second GAFOR of the day (next page), there were also no marginal routes left. The route crossing the Segnes pass is between the routes no. 72 and 83. Each character in the boxes denotes two hours within the six-hour periods of the two GAFOR charts. The elevations indicated as 'ft/msl' are reference altitudes in ft AMSL for those routes (e.g. elevations of passes). The classifications O/D/M/X are explained on the bottom right of the chart. Continued in figure 2b.

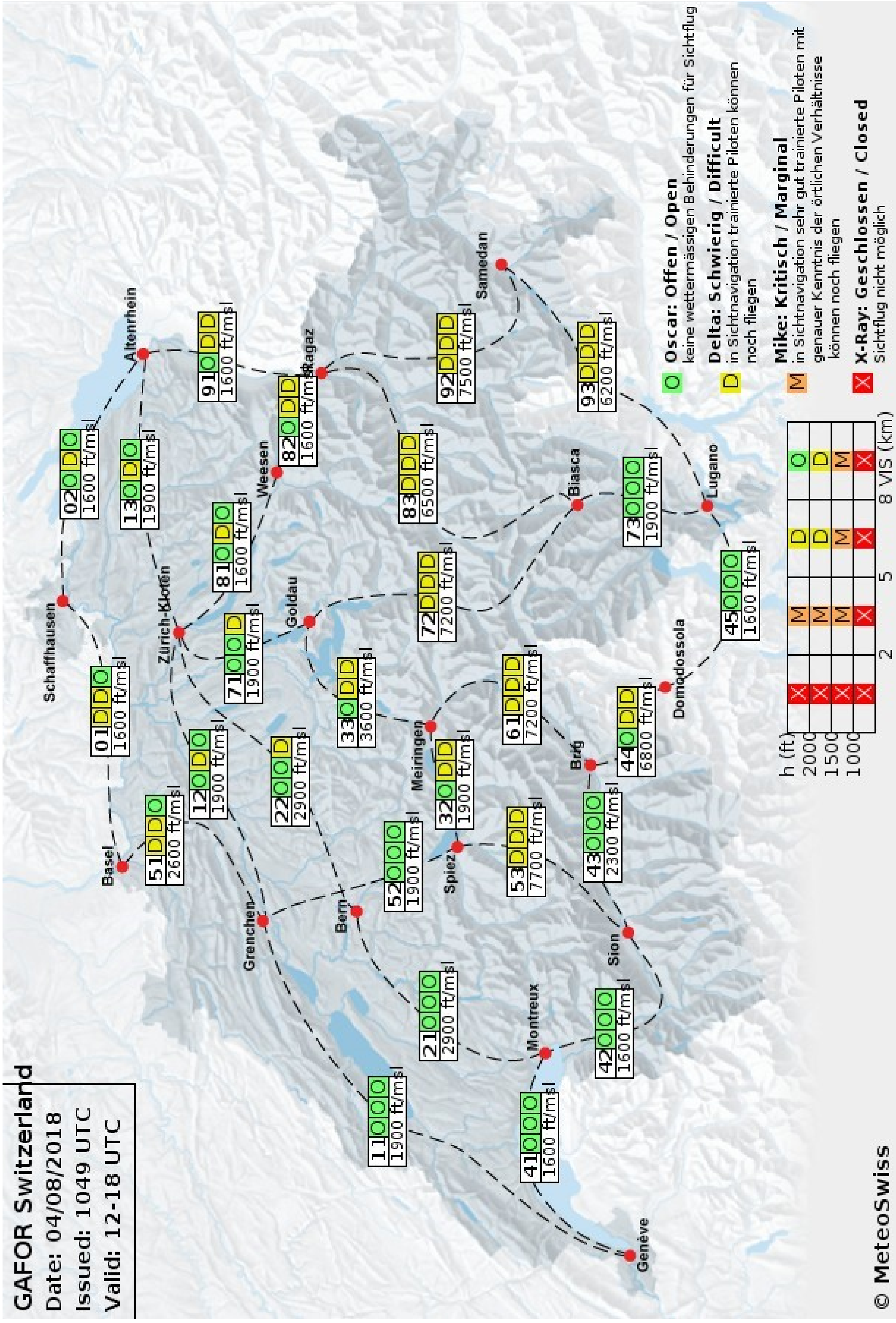


Figure 2b: Continued from 2a. More explanations about the codes can be found in the document of MeteoSwiss (see footnote 11 on page 4). Despite the good visibility, some routes (including 72 and 83) are classed as ‘difficult’, probably due to the possibility of isolated TCUs and CBs. Wind is not factored into these GAFOR charts. Source: Federal Office of Meteorology and Climatology.

A1.7.5.4 Terminal aerodrome forecast

During the hours before and after the accident (until after the planned landing time), the following terminal aerodrome forecasts (TAFs) were issued (times in UTC, i.e. the header 040825Z 0409/0418 is declaring that the forecast was published at 10:25 LT, valid for 11:00 to 20:00 LT on this day):

TAF SHORT for Lugano Airport (LSZA)
(for Locarno, no TAF is issued on weekends)

```
040825Z 0409/0418 VRB03KT CAVOK=
```

```
041125Z 0412/0421 20007KT 9999 FEW060TCU=
```

```
041425Z 0415/0424 20007KT 9999 FEW060 PROB40 TEMPO 0415/0424 SHRA
SCT060TCU PROB40 TEMPO 0418/0423 01015G27KT 4000 TSRA SCT050CB=
```

TAF LONG for the Dübendorf Airbase (LSMD)

```
040925Z 0410/0516 VRB03KT CAVOK TEMPO 0410/0420 9999 FEW070
PROB30 TEMPO 0412/0419 TSRA FEW050CB=
```

TAF LONG for Zurich Airport (LSZH)

```
040825Z 0409/0515 VRB03KT CAVOK TX34/0415Z TN17/0504Z TX34/0515Z
BECMG 0409/0412 9999 FEW050 PROB30 TEMPO 0412/0415 35010KT
FEW050TCU TEMPO 0414/0420 04007KT BECMG 0417/0420 CAVOK
BECMG 0510/0513 04008KT 9999 FEW050=
```

```
041125Z 0412/0518 VRB03KT 9999 FEW065 TX34/0415Z TN17/0504Z
TX34/0515Z PROB40 TEMPO 0412/0414 31013G25KT FEW060CB TEMPO
0414/0421 04007KT BECMG 0417/0420 CAVOK BECMG 0510/0513 04008KT
9999 FEW050=
```

```
041425Z 0415/0521 36008KT 9999 FEW068 FEW070TCU TX35/0415Z
TN17/0504Z TX34/0515Z PROB30 TEMPO 0415/0417 FEW065CB TEMPO
0416/0421 04006KT BECMG 0417/0420 CAVOK BECMG 0509/0512 9999
FEW050 TEMPO 0513/0521 04008KT PROB30 TEMPO 0512/0516 4000 TSRA
SCT050CB=
```

A1.7.6 Warnings

No AIRMET or SIGMET was issued for the time and the airspace of this flight. However, in the text for the general aviation forecast (see section A1.7.5), the elevated density altitude and the possibility for thunderstorms was mentioned.

A1.7.7 Weather descriptions by eyewitnesses

The pilot of the first rescue helicopter at the scene of the accident has described the wind situation 15 minutes after the accident at 17:10 LT. He encountered strong winds from the north-east when passing the Segnes pass and on its south side. He mentioned that the wind there was not laminar, and that south of the Martinsloch, the helicopter was hit by a gust. The pilot decided on an approach from the south-west into the wind. He pointed out that, during the flat approach, the wind became laminar at about 20 kt, and he felt the laminar mountain wind when leaving the helicopter.

The ambulance officer added that he could only use his mobile phone when protecting it with his jacket against the wind, which was blowing from the direction of Piz Segnas.

The pilot of the second rescue helicopter reported similar observations. The crew was guided for an approach from south to north and was informed about a strong wind from the north. The pilot estimated the base of 3 to 5 oktas TCUs at an altitude of about 9,000 to 10,000 ft AMSL and observed considerable horizontal and vertical movement within the clouds. The visibility was described as 'unlimited' outside of the clouds. During the approach, it seemed to the pilot that a thunderstorm might be imminent. However, this did not transpire and the clouds began to dissipate with lowering sun elevation. The wind at the location of the accident was described to be strong and laminar, with an estimated speed of 20 to 25 kt from the north, and from a north-eastern direction above the mountains. The pilot expected turbulence at the landing site behind the crests surrounding the small basin near Las Palas and Piz Segnas.

The instructor of a single-engine aircraft (Cessna 152), who crossed the Segnes pass with his student shortly before the Ju 52 aeroplane, described their impressions and decisions. They encountered extended downdraughts in the Flims region. He mentioned that it was difficult to maintain the planned altitude of about 9,100 ft AMSL (2,800 m AMSL). The instructor remembered a discussion with his student about the best way to enter the basin in front of the pass while always having an option for a safe return even if the downdraughts persisted. He reported that the Cessna was lifted again on their track along the western slope of the Swiss mountain called Atlas. He continued that shortly before crossing the pass, another downdraught interrupted the updraughts, before the ridge could be crossed at a safe height. The question as to whether extraordinary turbulence was encountered was answered negatively. The instructor added that clouds were not a problem throughout the day.

An image of the Cessna, captured shortly before crossing the Segnes pass, can be found in the main report (see figure 10).

The following description is an example from the public's response – in this case, from an experienced glider pilot with a professional background in meteorology. He mentioned that the Flimserstein high plateau and the ridge between Crap Sogn Gion and Crap Masegn is well known among glider enthusiasts in the Alps as one of the strongest and most reliable sources for thermals. In between, distinct and extended downdraught regions are well known, especially when there is a tendency for north-easterly winds aloft. He mentioned a personal experience about two weeks before the accident where he happily flew at 3,000 m AMSL near Flimserstein, expecting to cross the Segnes pass without any problems. However, he was washed down at between 5 and 8 km from the crest and was forced to change his route. He thought that the large-scale sinking on the downwind side was caused by forced lifting on the cooler northern side of the ridge. Within this widely sinking flow, only the strongest local thermals could persist.

Local people and our staff who worked near the two meteorological stations during the summer of 2019 (see section A1.7.14) confirmed that a robust downslope wind along the basin and the Segnas Sut high plateau typically developed during afternoons. The continuous meteorological measurements near a water catchment of Flims Electric AG on an elevation of 2,100 m AMSL provide objective evidence for this diurnal wind system (see section A1.7.14.3).

According to an experienced eyewitness on the Segnes pass, the wind speed was at least 60 km/h at the time of the accident. This account is supported by the above-mentioned observations and the fine-scale modelling (see section A1.7.15).

Selected images of clouds received from members of the public are copied in the main report and in other annexes (see e.g. annex A1.1). In the remaining collection, no relevant additional information supplementing the selected pictures and the webcam images has been found.

A1.7.8 Webcams

Figure 3: Three frames of the webcam on Mutta Rodunda[13] (see map in figure 4) viewing towards the north 17 minutes before the accident (16:40 LT, top frame) until three minutes after (17:00 LT, bottom frame). The orange pointer is marking the site of the accident, where the wreckage is faintly visible on the original image. The Segnes pass is marked by the red pointer. Left of the centre of the image is Piz Segnas with Atlas in front. On the right is the Trinserhorn (Piz Dolf) mountain (see map below).

[13] https://laax.roundshot.com/mutta-rodunda/ (for archive, see calendar icon on the right-hand navigation bar)

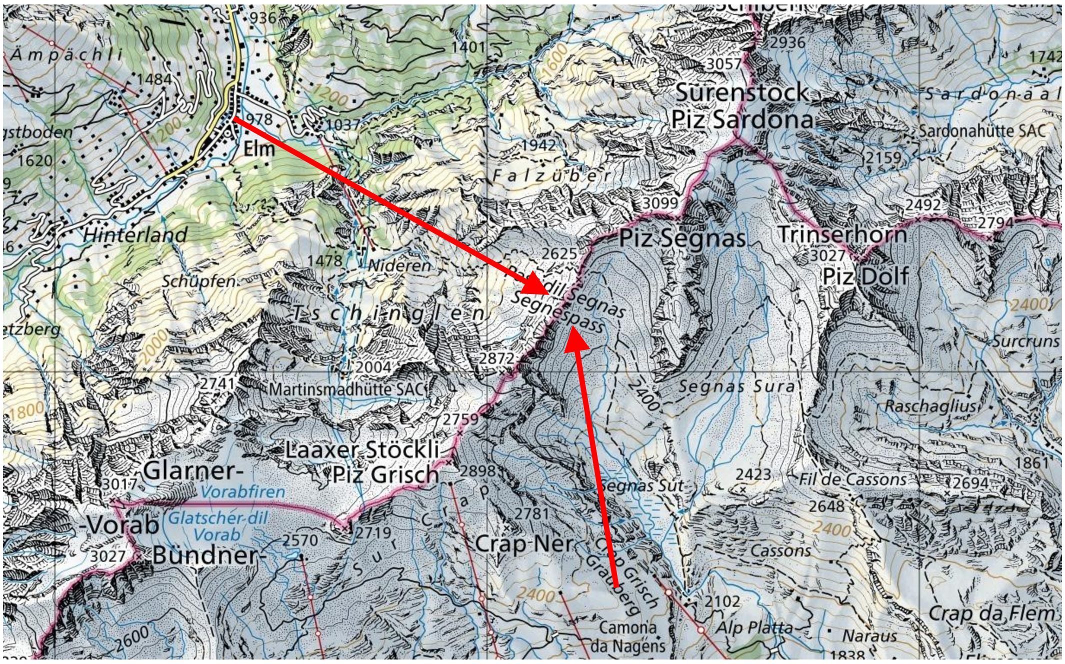
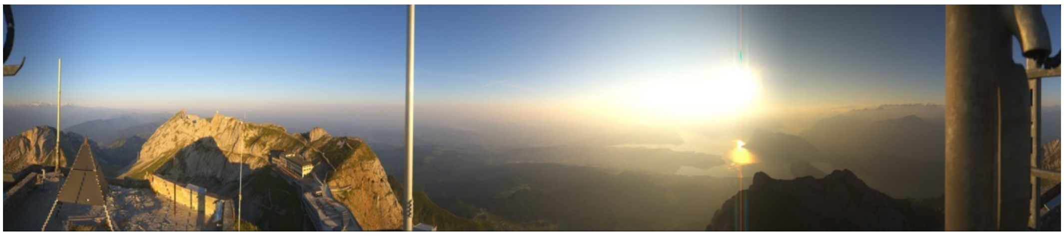


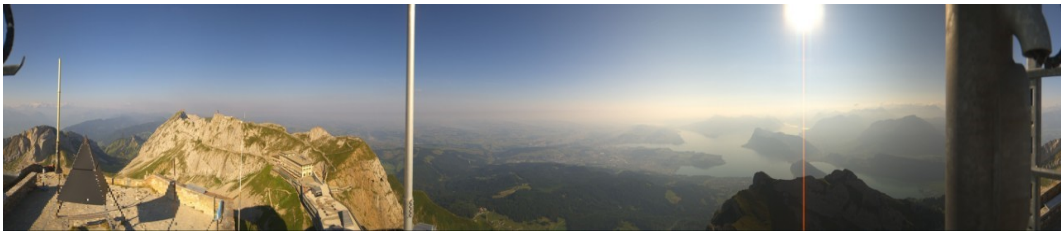
Figure 4: Positions and viewing directions towards the Segnes pass from the two webcams at Mutta Rodunda in the south (figure 3) and in Elm in the north-west (figure 5). Source of the map: Federal Office of Topography.

Figure 5: Two frames from the webcam in Elm around 16:00 LT (top frame) and at about 17:00 LT (bottom). The Segnes pass is within the ridge in the background, almost hidden by the mountain in front of it (solid red pointer). The prominent mountain peak just right of the centre of the images is the Grosses Tschingelhorn. The Martinsloch (dotted pointer) is visible on the webcam when the light is favourable. The site of the accident is behind the ridge between the Martinsloch and the Segnes pass. Based on the hourly imagery of this webcam, it can be concluded that the route from the Segnes pass to Elm was free of clouds during the afternoon, at least at the times of the images.

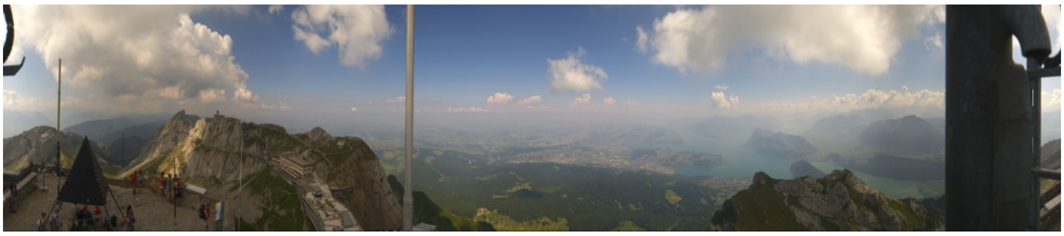
07:00 LT:



09:00 LT:



12:00 LT:



15:00 LT:

16:00 LT:

17:00 LT:

Figure 6: Roundshot webcam on Mount Pilatus[14] on 4 August 2018 between 07:00 and 17:00 LT. The images show the cloud development during the day in the wider Alpine area. The thin pole left of the centre roughly marks the north, whereas the south is behind the thick pole, i.e. the southern sector is split between the two edges of the images.

[14] https://pilatus.roundshot.com/ (for archive, see calendar icon on the right-hand navigation bar)

Disentis, viewing from left to right from NE via SE to west at 17:00 LT:

Brugnasco near Airolo, viewing to ENE (left), south and NW (right) at 16:30 LT:

Olivone, viewing towards the west to Punta di Larescia at 16:30 LT:

San Salvatore, viewing NNE (left) over Lugano (below centre) at 16:30 LT:

Montagnola, viewing to SW (left) via north to SE (right) at 16:30 LT:

Figure 7: Webcams on the south side of the Alps at 16:30 LT, and from Disentis in the Rhine Valley at 17:00 LT. This large collection of images is archived every 10 minutes by the Federal Office of Meteorology and Climatology.

A1.7.9 Satellite imagery

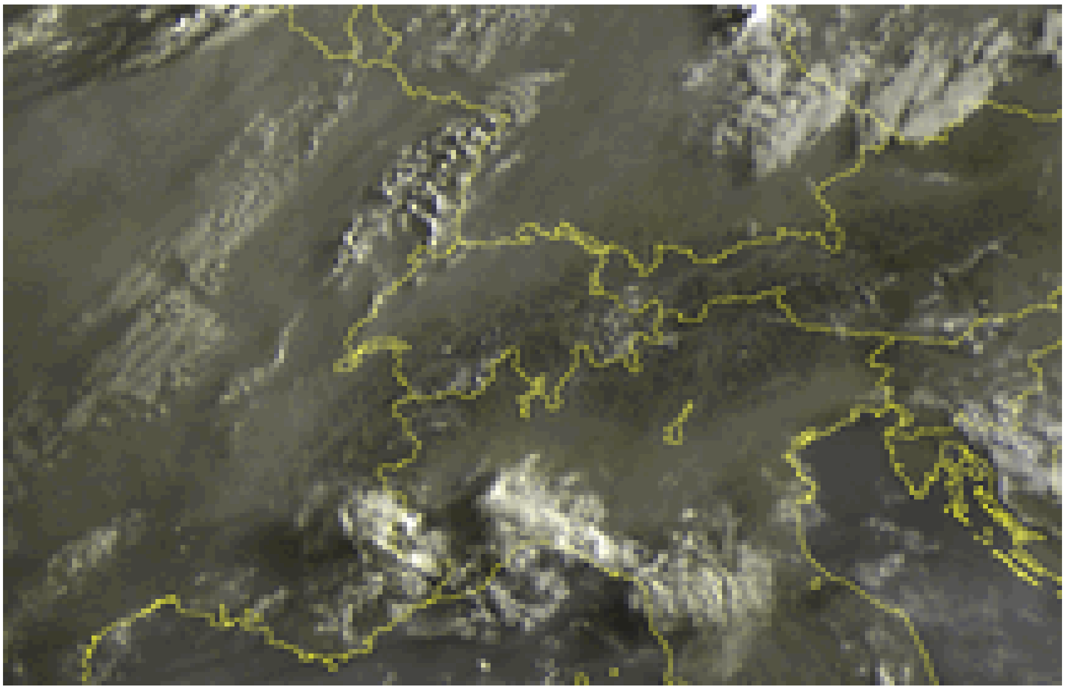


Figure 8: The (visible) satellite image from the geostationary satellite operated by EUMETSAT[15] shows haze over the Swiss Plateau (between Lake Geneva and Lake Constance). No clouds are visible over the Alps.

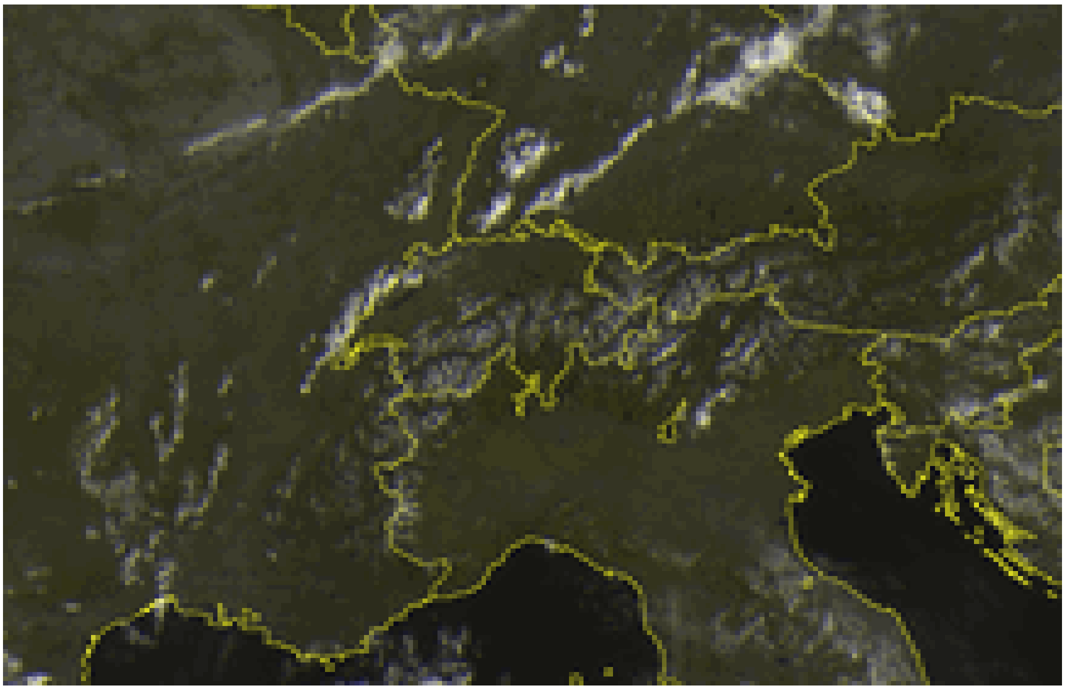


Figure 9: A first convective activity with cumulus clouds over the Jura mountains and north of Switzerland over the Vosges mountains, the Black Forest and the Swabian Alps is visible at 12:00 LT. The small cumulus clouds over the Alps (see figure 6) are not yet discernible due to this coarse resolution.

[15] https://www.eumetsat.int; Source for the satellite images: http://www2.sat24.com/history.aspx?culture=de

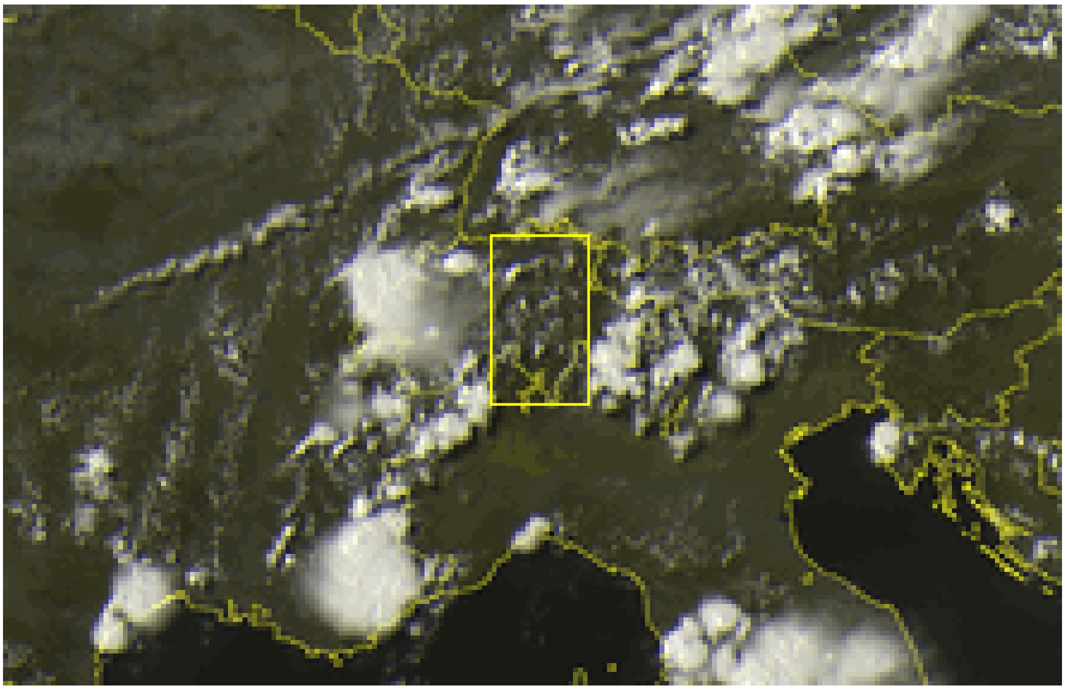


Figure 10: At 17:00 LT, convective areas with CBs had developed west and south-east of the region of interest (yellow rectangle between Ticino and northern Switzerland). Within this zone, around the planned flight, only a few CUs and possible TCUs, but no CBs are visible at the time of the accident.

The corresponding satellite images were screened for the day before, when HB-HOT was flown from Dübendorf in the north to Ticino in the south. This comparison shows a similar beginning to the day, with less convection in the afternoon. For both days, the infrared images showing cloud top altitudes were inspected. They confirm the finding from above in figure 10: there were no CBs in the vicinity of the planned flight.

Higher-resolution images from the lower orbiting Aqua and Terra[16] satellites were screened as well. However, due to their orbital schedule, their imagery was only available between 11:58 LT and 13:42 LT and is therefore not shown here.

A1.7.10 Weather radar imagery

The national weather service operates five weather radar stations that generate an almost complete composite image of the precipitation over Switzerland[17]. The process of generating these well-known images, based on the raw radar echoes, is quite complex. It is a challenge, especially within the Alps, to separate relevant signals (precipitation) from artefacts (e.g. ground clutter). During this process, weak local precipitation signals can sometimes be filtered out. Below the mountain ridges, precipitation can also be hidden. And, in any case, clouds without precipitation are not visible on radar imagery. For volumes in the atmosphere that can be seen from two or more radar stations, the signals can be combined. Please visit the link in the footnote for more details.

The radar station next to the region of interest is located on the Weissfluhjoch summit, about 45 km east of Piz Segnas. It offers a direct view into the Rhine Valley. Therefore, the reliability for the detection of showers was high.

[16] https://worldview.earthdata.nasa.gov/

[17] https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/atmosphere/weather-radar-network.html

Rain from cumulus clouds (CUs, TCUs and CBs) can only come from the formation of ice particles in the cloud. This means that precipitation in the cloud extends up to an altitude well above the freezing level (typically to above - 10 °C). Hence rainfall at the valley floor will be seen even in the case of radar obscuration because the radar will detect the formation of the precipitation above. Therefore, the radar imagery presented here is expected to show a complete picture of precipitation in the area of the accident.

The radar images were generated and archived every two to three minutes, i.e. the temporal resolution is quite high. First echoes on the day and in the region of the accident were visible between 12:40 LT and 13:00 LT near Ilanz. Figure 11 shows the peak activity of this weak shower with only 2 mm/h.

On the webcam, this weak precipitation is not directly visible. Only dark clouds over Ilanz are an indication. Therefore, the webcam image of this weak first shower is not included here.

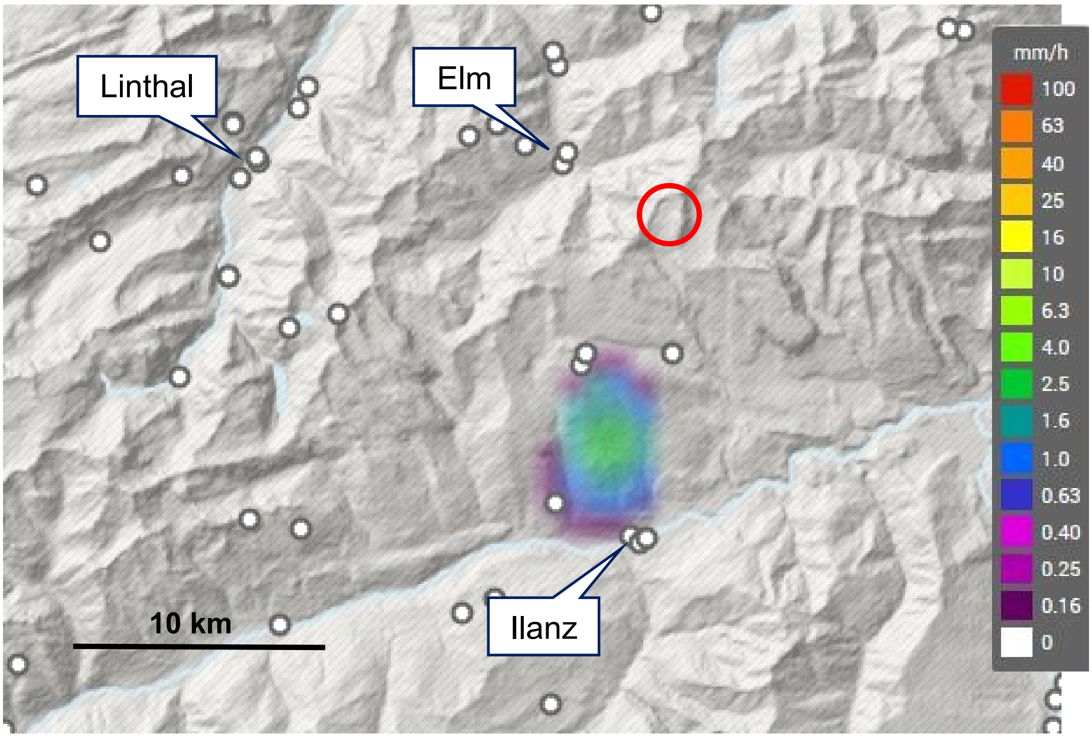


Figure 11: Precipitation radar image at 12:50 LT. The accident happened within the red circle. The small white circles mark the location of surface weather stations. See text below for more information. Source: Federal Office of Meteorology and Climatology, MeteoSwiss, via GIN archive[18].

[18] GIN: Natural Hazards Portal: https://www.natural-hazards.ch/home/about-us/federal-agencies-with-responsibility-for-natural-hazards.html

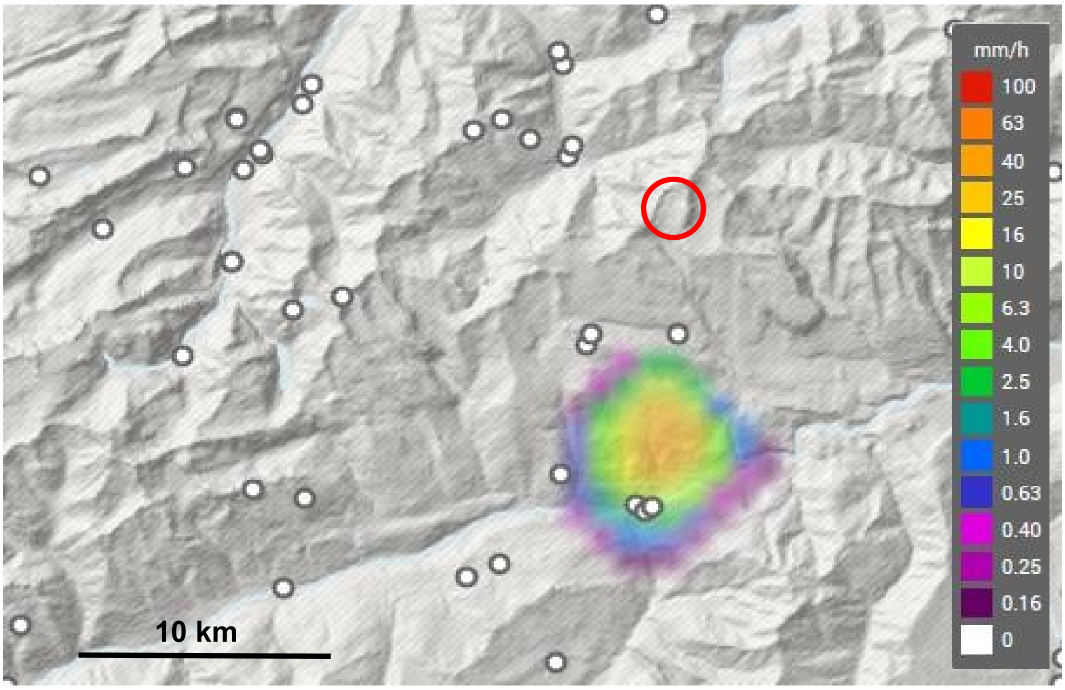


Figure 12: Precipitation radar image at 14:30 LT. The accident happened within the red circle. The small white circles mark the location of surface weather stations. See text below for more information. Source: Federal Office of Meteorology and Climatology, via GIN archive.

Figure 13: The shower at 14:30 near Ilanz as seen by the webcam at Mutta Rodunda[19] (red placemark on the map). The site of the accident is marked by the orange pointer on the image and on the map. The core of the shower (see figure 12) is marked by the blue circle. Source of the map: Federal Office of Topography.

Between 13:50 LT and 15:00 LT, stronger precipitation with up to 25 mm/h was detected near Ilanz, in the vicinity of the later flight. The radar image in figure 12 shows the maximum intensity (orange) during that period at 14:30 LT. This shower is also clearly visible on the webcam between 14:20 LT and 14:40 LT. Figure 13

[19] https://laax.roundshot.com/mutta-rodunda/ (for archive, see calendar icon on the right-hand navigation bar)

shows the shower at the same time that the radar image in figure 12 was generated. This demonstrates the isolated nature of the shower that was generating the prominent radar echo. The visibility outside of the shower remained excellent.

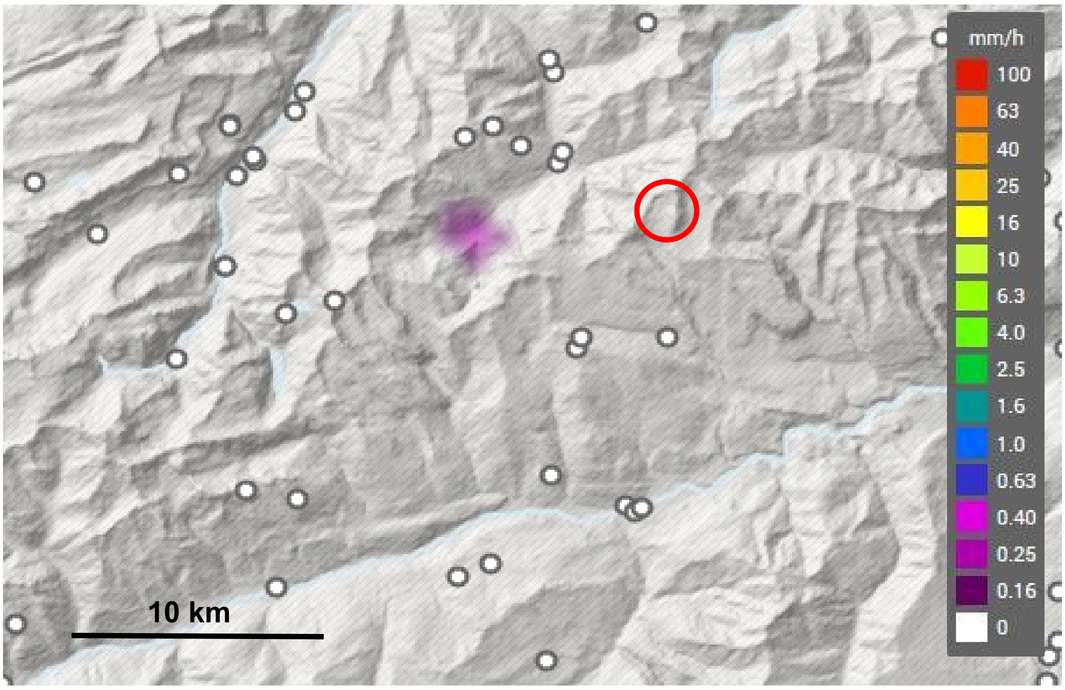


Figure 14: Precipitation radar image at 16:35 LT. The accident happened within the red circle. The small white circles mark the location of surface weather stations. See text below for more information. Source: Federal Office of Meteorology and Climatology, MeteoSwiss, via GIN archive.

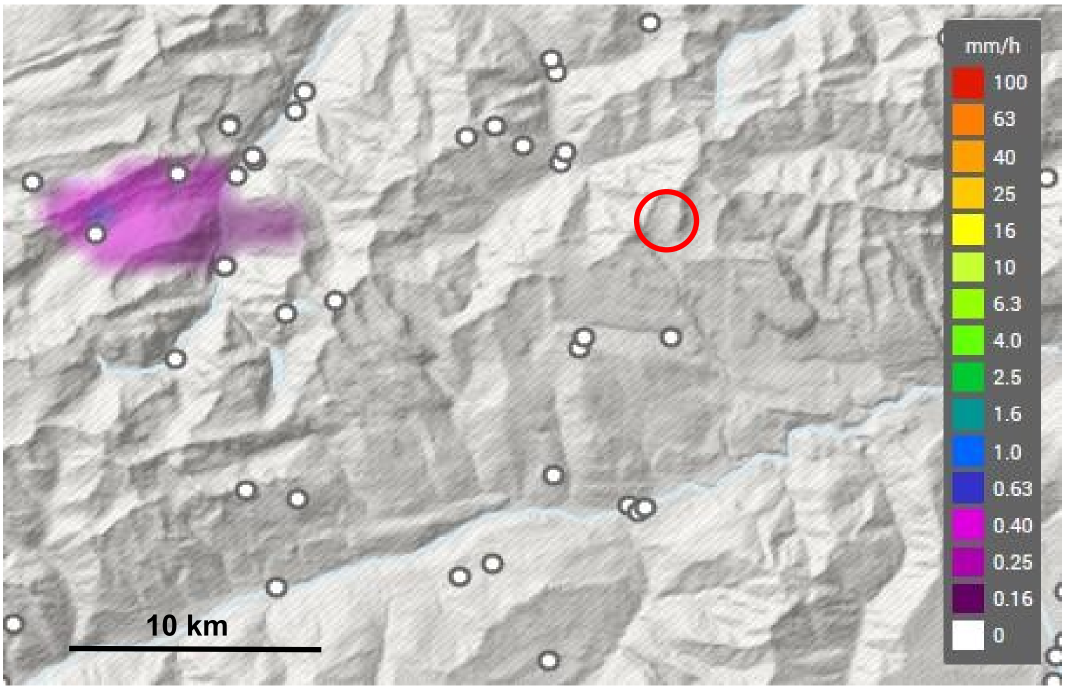


Figure 15: Precipitation radar image at 16:55 LT. The accident happened within the red circle. The small white circles mark the location of surface weather stations. See text below for more information. Source: Federal Office of Meteorology and Climatology, via GIN archive.

Shortly before and at the time of the accident, two weak showers of rain were detected 7 km west, and 15 to 20 km west of the Segnes pass (figures 14 and 15). Both showers were not visible by the webcam because they were behind the crest. However, only TCUs but no CBs are visible above.

A1.7.11 Weather charts, weather stations and balloon soundings

The three types of meteorological information mentioned in this title are essential for analysing a weather situation and creating a forecast. The information from different scales and types of instruments (e.g. according to sections A1.7.9 and A1.7.10) are integrated to form a synoptic view when the national and international weather services are feeding their models with this data (see section A1.7.12).

A1.7.11.1 Weather charts

The general weather situation as it was summarised in section A1.7.1 is characterised by the two charts in figure 16.

The upper air chart for 500 hPa (lower chart in figure 16) shows the centre of a high-pressure system west of Portugal (Azores anticyclone), which extends over Central and Eastern Europe. This pressure field generated northerly winds at about 5,880 m AMSL above the Alps.

The surface chart shows a flat pressure distribution over Central Europe, i.e. the pressure gradients and hence the winds on this scale are weak. However, on a smaller scale, not resolved by this type of chart, regional pressure differences define the wind field at lower altitudes (see section A1.7.13).

A large collection of other charts and numerical products on different scales was also inspected. However, for this general characterisation of the large-scale weather, these two charts are sufficient. More detailed analyses on the regional scale within the Alps are discussed in sections A1.7.12 and A1.7.13.

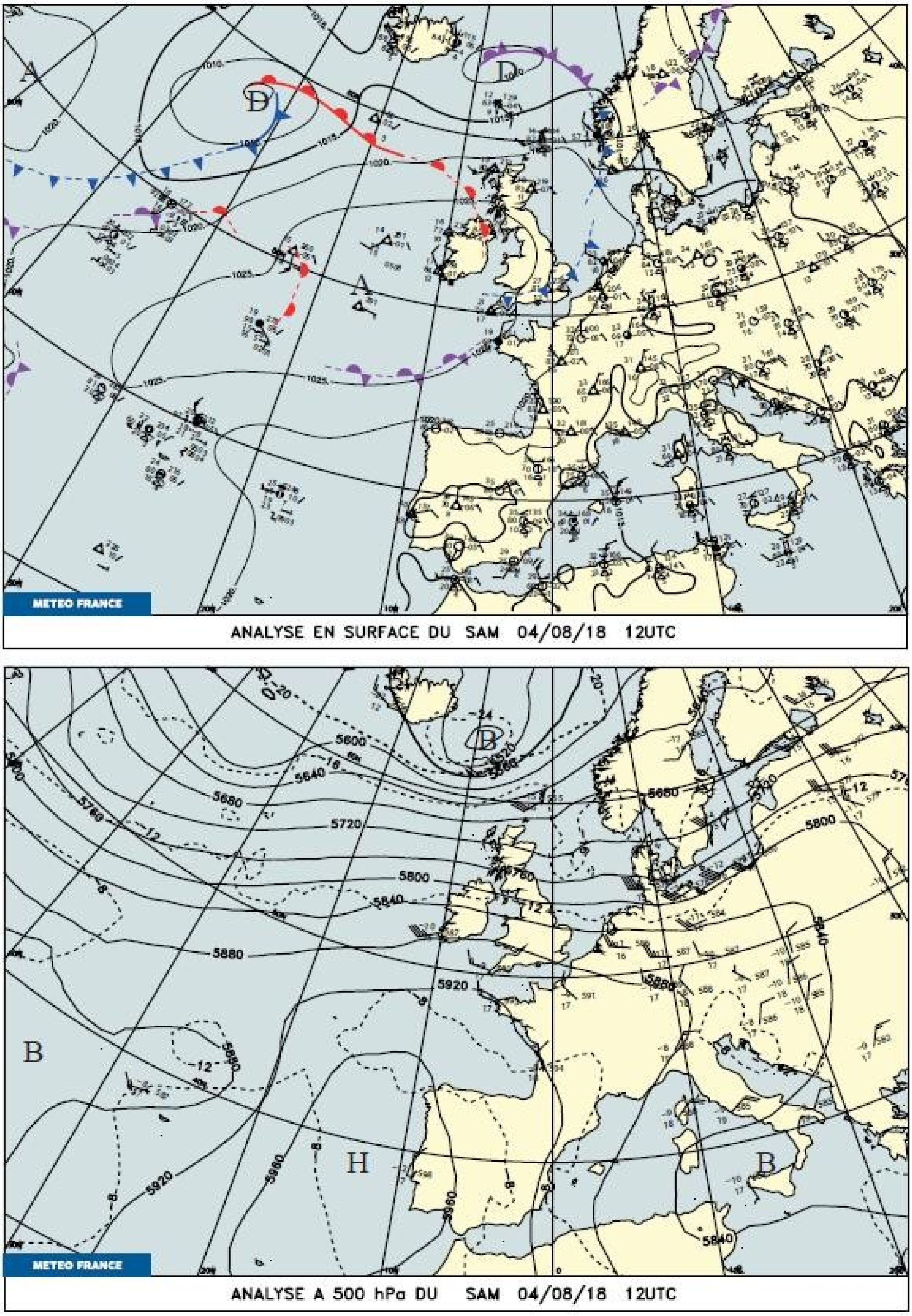


Figure 16: The European surface weather chart (top) and the upper air chart for 500 hPa (bottom). Source: Météo-France.

A1.7.11.2 Weather stations

MeteoSwiss operates a dense network of about 160 automatic surface weather stations. These are documented on its homepage[20]. Most readings are archived in

[20] https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/land-based-stations/automatisches-messnetz.html

intervals of ten minutes. One of the mountaintop stations is Crap Masegn, about 7 km south-west of the accident's site. The recorded measurements from this station were used for this investigation.

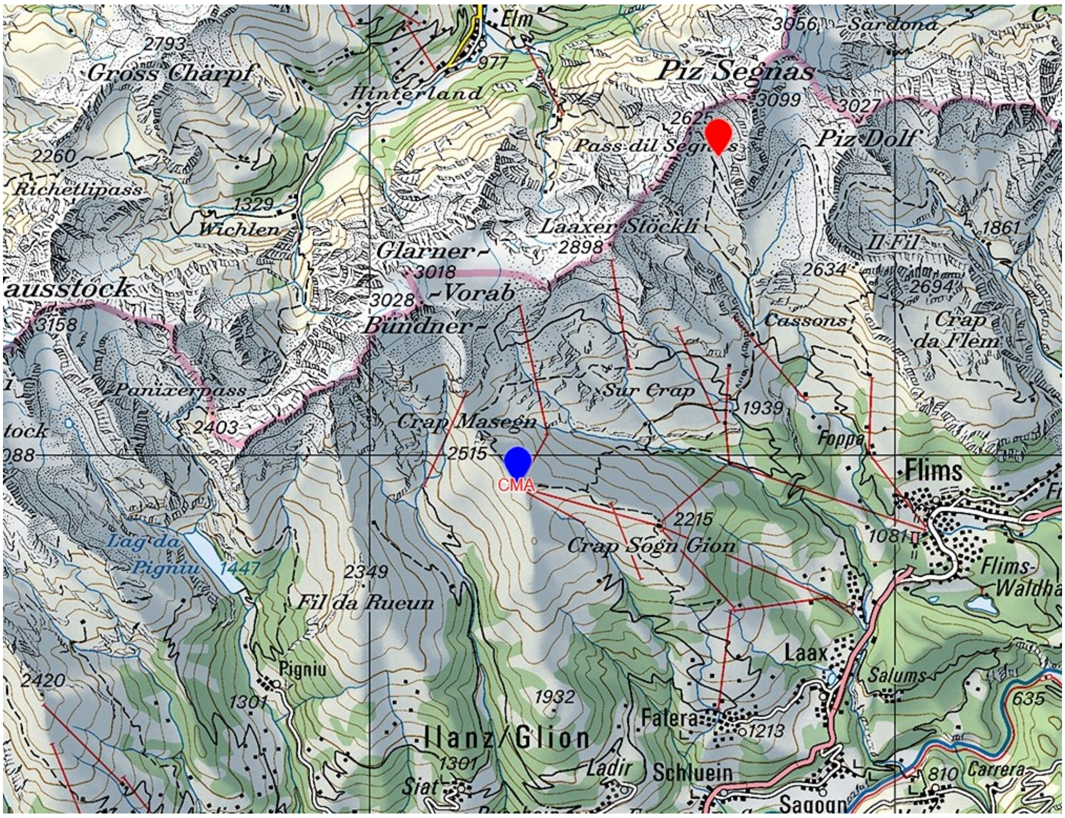


Figure 17: Position of the automatic weather station at Crap Masegn[21] (blue placemark) about 7 km south-west of the accident's site (red placemark), which are on a similar elevation of 2,480 m AMSL. Source of the map: Federal Office of Topography.

The measured values from this station were used in the summary of section A1.7.2. The exposure of Crap Masegn at the southern slope of the northern ridge of the Rhine Valley is comparable to the region south of Piz Segnas.

Table 1 lists the measurements of the wind and other parameters during the afternoon between 14:00 LT and 18:00 LT. This shows the evolution of the wind before the accident happened. The average wind speed from the northern sector (356° to 19°) decreased first from 10.5 m/s down to 5.1 m/s (i.e. from about 20 kt to 10 kt), before increasing again. Gusts with durations of one or three seconds reached about 25 kt within the two 10-minute intervals around the time of the accident (see the graphical display in figure 32).

[21] https://www.meteoswiss.admin.ch/home/measurement-values.html?param=messwerte-lufttemperatur-10min&station=CMA

	wind											
time	veloc.	direct.	gusts 3s	gusts 1s	temp	dew point	QFE	QNH	sun	globrad.	flash n	flash d
h LT	m/s	degree	m/s	m/s	°C	°C	hPa	hPa	%	W/m2	number	number
14:00	10.5	16	12.7	13.0	14.2	7.1	762.5	1031.1	100	1046	0	0
14:10	9.1	12	12.0	13.8	14.2	7.2	762.5	1031.1	100	1010	0	0
14:20	8.9	13	11.1	11.4	14.4	7.5	762.5	1031.1	100	979	0	0
14:30	9.5	18	12.1	13.0	14.5	7.4	762.5	1031.1	100	957	0	0
14:40	8.0	17	10.5	11.2	14.6	7.6	762.6	1031.2	100	941	0	0
14:50	6.3	19	10.2	11.4	14.6	6.8	762.7	1031.3	100	928	0	0
15:00	5.4	6	8.9	9.6	15.1	6.8	762.7	1031.3	100	912	0	0
15:10	7.1	19	10.9	12.9	14.7	7.5	762.6	1031.2	100	892	0	0
15:20	6.5	19	10.6	11.5	14.5	7.2	762.6	1031.2	100	867	0	0
15:30	6.0	12	9.1	9.5	14.7	6.9	762.6	1031.2	100	842	0	0
15:40	5.5	356	10.0	10.7	15.0	7.3	762.5	1031.1	100	835	0	0
15:50	5.1	17	8.7	9.5	14.9	6.8	762.5	1031.1	100	819	0	0
16:00	6.3	11	11.0	11.5	15.0	7.0	762.4	1030.9	100	805	0	0
16:10	7.7	13	10.5	12.2	15.2	6.8	762.3	1030.8	100	790	0	0
16:20	7.8	4	10.7	11.1	15.1	7.1	762.3	1030.8	100	767	0	0
16:30	6.0	6	10.7	11.6	15.0	6.0	762.4	1030.9	100	741	0	0
16:40	7.6	2	12.9	13.3	14.9	6.5	762.4	1030.9	100	713	0	0
16:50	8.2	9	13.0	13.4	14.9	6.7	762.3	1030.8	100	686	0	0
17:00	6.6	6	12.4	12.9	14.8	6.4	762.4	1030.9	100	654	0	0
17:10	7.0	6	12.2	13.4	15.0	6.1	762.4	1030.9	100	627	0	0
17:20	8.1	358	11.8	12.2	15.0	6.8	762.2	1030.7	100	607	0	0
17:30	7.5	4	12.7	13.5	14.9	6.7	762.2	1030.7	100	581	0	0
17:40	8.5	7	11.6	12.4	14.8	6.9	762.1	1030.5	100	521	0	0
17:50	6.5	3	10.8	11.6	14.6	7.6	762.2	1030.7	100	516	0	0
18:00	8.9	19	12.9	13.8	14.7	8.0	762.1	1030.5	100	440	0	0

Table 1: Selected parameters measured in 10-minute intervals between 14:00 and 18:00 LT at the Crap Masegn station. The temperature, dew point and pressure readings QFE[22] and QNH[23] are at the times listed in the first column. All the other parameters are averaged or summed up within the intervals before the given times. The two types of gusts (for 3 or 1 seconds) characterise the maximum wind speed persisting for 3 or 1 seconds, respectively. The intervals around the time of the accident are marked blue. More explanations about the parameters and a discussion can be found in the text below.

The temperature readings show the warm summer conditions at this altitude (16 °C higher than ISA), which is also reflected in the QNH for this reference altitude (see sections A1.7.2 and A1.7.13.2). This high QNH should not be confused with the QNH of the airfields at much lower reference altitudes. The dew point was well below the temperature, i.e. the air was relatively dry. Air pockets rising from this station would condensate at an altitude of about 3,500 m AMSL (cumulus cloud base). However, lower clouds in this region are possible because, in most cases, the cloud base is defined by the temperature and dew point lower in the valley. Based on other information (see section A1.7.12), the cloud base in the region was between 2,800 and 3,400 m AMSL.

100 % ‘sun’ (sunshine duration for the interval) indicates that no compact clouds south of the station were blocking the direct sunshine. The intensity of the sunshine, including the scattered radiation on a horizontal surface (the global radiation in column ‘globrad.’) decreases with the descending sun.

Finally, no flashes of lightning were detected near the station (‘flash n’ < 3 km away from the station) or more distant (‘flash d’ between 3 and 30 km). Precipitation is not measured at this exposed mountain station (see section A1.7.10 instead).

The relevance of these wind measurements at Crap Masegn for the wind south of the Segnes pass is discussed in section A1.7.14.3.

22 Pressure measured at the altitude of the barometer (2,482 m AMSL)

23 Pressure reduced from the altitude of the barometer to sea level by using the ICAO standard atmosphere (ISA)

A1.7.11.3 Balloon soundings

Vertical soundings in the atmosphere using balloons are still the 'backbone' of the global observation system. They are the only tool for establishing the structure of temperature, humidity and wind with the necessary accuracy, precision and vertical resolution worldwide. On the other hand, the horizontal resolution is poor outside of densely populated regions and over the oceans. Furthermore, vertical soundings are only made twice per day in most places (typically at 00:00 and 12:00 UTC[24]). In combination with ground-based measurements (including remote sensing such as radar) plus observations by aircraft[25] and satellites, they provide the basis for weather charts (see section A1.7.11.1) and numerical weather prediction (see section A1.7.12).

The two sounding stations Payerne[26] and Milano are relevant for characterising the atmosphere north and south of the Alps. They are available for the standard times 00:00 and 12:00 UTC (02:00 and 14:00 LT). Considering that the standard times are defined as when the balloons cross the tropopause (i.e. the launches are about one hour earlier), these soundings in figure 18 reflect the state of the lower atmosphere over the Swiss Plateau and the Po Valley for the early afternoon – about three to four hours before the accident. This does not impact the assessment of the thermal stability of the atmosphere, or wind at higher altitudes. However, the regional and local wind at lower altitudes – especially above the complex terrain of the Alps – is affected by short-term changes.

The changes forecast by the numerical weather prediction are expressed in the texts and tables in section A1.7.5.1. The vertical profiles of temperature and humidity are conditionally unstable, which means that the stratification was about neutral below the cumulus cloud base, but unstable as soon as condensation occurred. The consequence of such a stratification is that cumulus clouds – once triggered – will rapidly form into towering cumuli (TCUs) and thunderstorms (CBs) when no other meteorological processes stop them. Such processes exist and are the reason why the development of thunderstorms is different in different regions (see figure 10). On the north side of the Alps, a stable layer around 600 hPa (about 4,500 m AMSL) had to be overpowered.

Figure 18 on the next page: Thermodynamic diagrams show the vertical profiles of temperature, dew point and wind from the Payerne[27] and Milano[28] balloon soundings. The primary vertical coordinate (left-hand axis) is pressure. The altitudes indicated on the right-hand scale in km and 1,000 ft are calculated based on the present state of the atmosphere, i.e. they express true altitudes (not flight levels, FL). The isothermal lines on this skew-T-log-p-diagram (scale on the x-axis) are inclined, parallel to the red 0° isothermals. On both sides of the Alps – and most likely over the Alps as well – the stratification was conditionally unstable (see text). The wind in the north below 3,200 m AMSL was 10 to 15 kt from north-east, turning to north-west and west above. Over Milano, wind speeds of 10 to 15 kt were only observed above about 3,500 m AMSL.

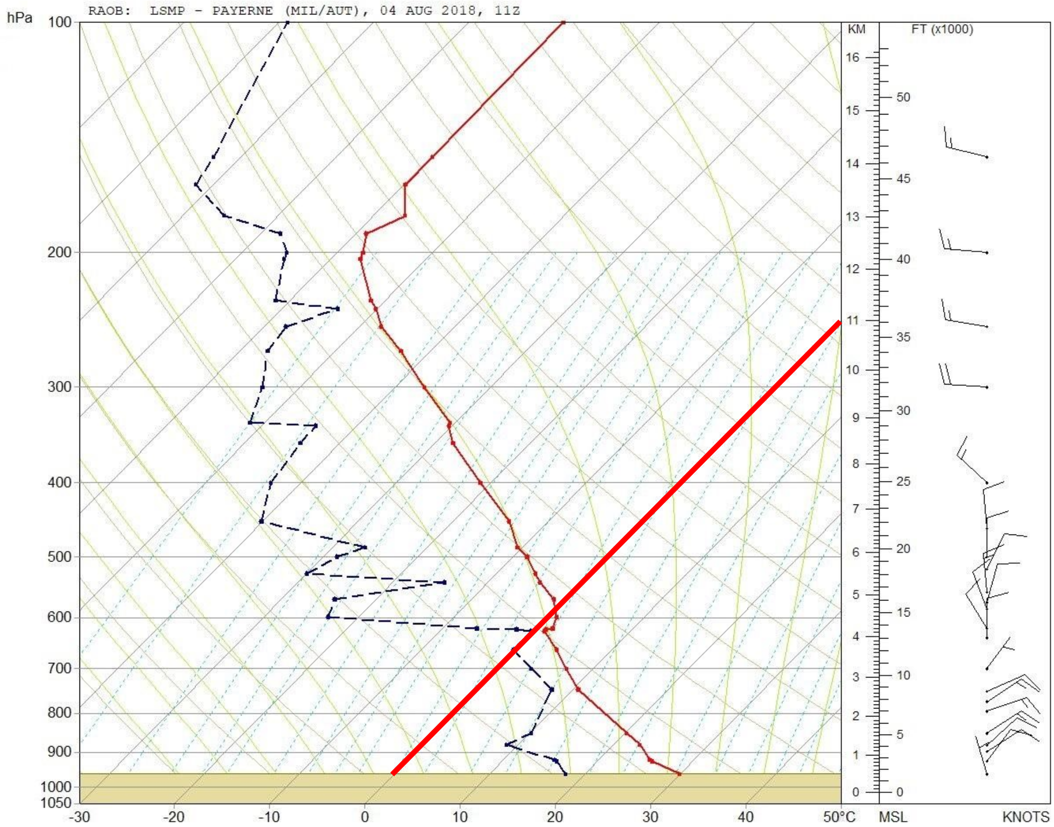
[24] Daily display of worldwide balloon soundings: https://www.ecmwf.int/en/forecasts/charts/monitoring/dcover?facets=undefined&time=2018080412,0,2018080412&obs=Temp&Flag=all

[25] https://www.ecmwf.int/en/forecasts/charts/monitoring/dcover?facets=undefined&time=2018080412,0,2018080412&obs=aircraft&Flag=all

[26] https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/atmosphere/radio-soundings.html

[27] Source: http://weather.uwyo.edu/upperair/bufrraob.shtml, using the software RAOB for a uniform display

[28] Source: http://weather.uwyo.edu/upperair/sounding.html, using the software RAOB for a uniform display



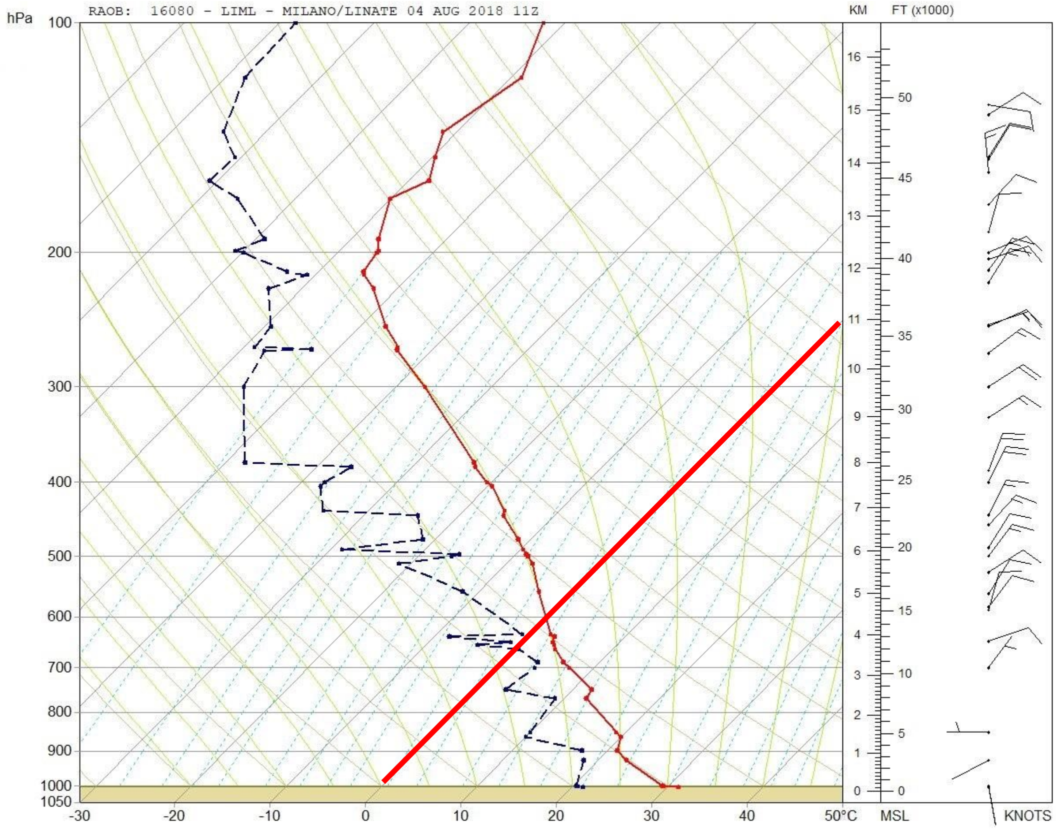


Figure 18: The caption is on the previous page.

A1.7.12 COSMO analyses

Weather stations, balloon soundings and ground-based measurements (see section A1.7.11), plus all the other measurements such as radar and satellite observations, can only characterise the atmospheric conditions over a limited area. They need to be integrated in a suitable way to establish a complete picture of the actual state of the atmosphere. Such a sophisticated integration is called assimilation. This is a crucial step before running a model for numerical weather prediction. The product of the assimilation is a three-dimensional analysis of the present state of the atmosphere. This is much more than a mathematical interpolation of different measurements. Such an analysis creates three-dimensional fields of temperature, humidity, pressure and wind that are physically consistent. They reflect the best estimate for the state of the atmosphere at the time of the observations. These fields are more reliable than forecasts. More information on numerical weather prediction and the COSMO-1 model of MeteoSwiss[29] is available on the websites of the specific weather services.

The hourly analysis from COSMO-1 was used to assess wind and other parameters of the flights of HB-HOT and other aircraft mentioned in the main report on the day of the accident, and the day before. These virtual flights through the gridded data[30] were also used to derive true altitudes from the transponder altitudes (see annex A1.19). In addition, charts for certain altitude or vertical profiles were extracted from the grid. Figure 19 shows the horizontal and vertical wind components at the altitude where HB-HOT entered the side valley south-west of Piz Segnas.

Even when this model analysis is a qualified approximation of the three-dimensional wind field at the time of the accident, the following limitations must be considered. Each value represents about one square kilometre during a certain average time, i.e. it cannot show a true value for the specified time. Based on general knowledge plus the measurements in 2019 (see section A1.7.14) and the fine-mesh model in section A1.7.15, wind speeds in the lowest layers vary typically ± 50% around their average values. This means that a given average wind speed of 10 m/s (about 20 kt) can include everything between 5 and 15 m/s (10 to 30 kt) for a specific moment. This is especially true for the vertical wind component (colour-coded in figure 19). A value of -2 m/s indicates that when flying through this square kilometre, a downdraught of -2 m/s is likely to be experienced, but the individual up- and downdraughts could vary over a wide range (see section A1.7.14.2, figure 28).

[29] https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/warning-and-forecasting-systems/cosmo-forecasting-system.html

[30] Numerical weather prediction models run on three-dimensional grids of different resolution. The horizontal grid spacing in COSMO-1 is about 1 km. The vertical coordinates are terrain-following, i.e. the lowest grid layer is about 10 m above the smoothed surface, with increasing distance between the layers above.

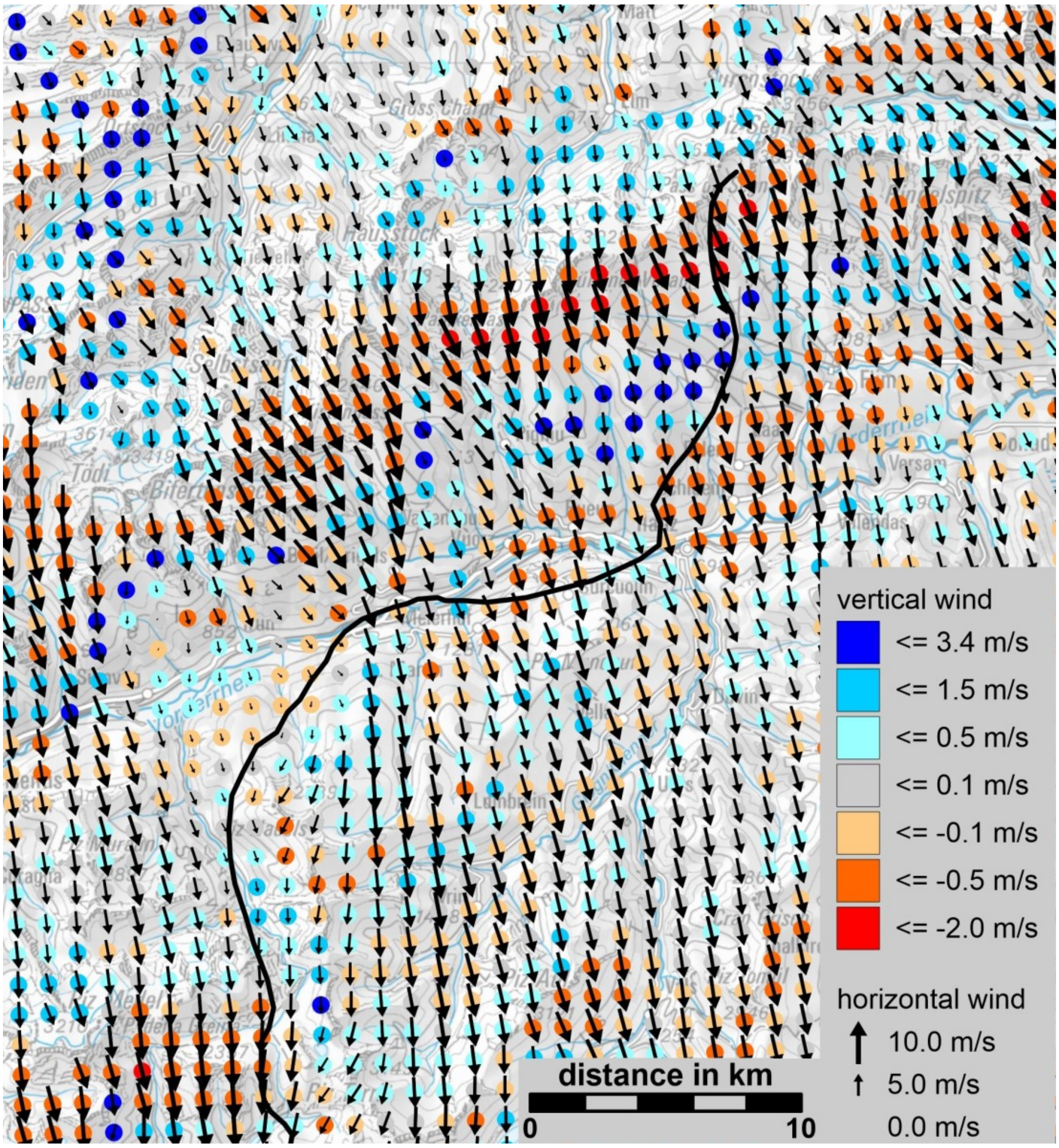


Figure 19: Three-dimensional wind around 17:00 LT at 2,800 m AMSL as interpolated from the terrain-following grid of the COSMO-1 analysis. The coloured points denote the average vertical movement of the air (not individual up- or downdraughts), whereas the arrows show the wind speed and direction (the maximum wind speed on this chart is 10.5 m/s or about 20 kt). The reconstructed flight track is drawn as a black line (see the main report for the official track). Source for the gridded COSMO-1 analysis: Federal Office of Meteorology and Climatology, MeteoSwiss; Source for the background map: Federal Office of Topography.

The conclusions from all this information are discussed in section A1.7.16 and in the main report.

A1.7.13 Regional pressure field

This section summarises basic knowledge about regional wind systems, and how they apply to this particular region.

A1.7.13.1 Theory

Any wind is generated by pressure differences along horizontal distances (= pressure gradients). Since wind moves enormous masses of air (one cubic kilometre has a mass of about a million tonnes), these pressure gradients are not acting instantaneously on the flow, but need a certain time until a new equilibrium with friction and other forces is established. On a scale of 10 to 100 km, this delay is typically up to one hour. Another important process is the coupling of wind between different layers. For example, turbulent friction between layers accelerates the wind at lower layers when the driving pressure gradient is aloft. On the other hand, the layer in contact with the surface is decelerated by the friction with the rough surface and with obstacles. This process is most pronounced during daytime, when rising thermals and sinking air in between (= convection) are responsible for this coupling of the different layers. Even for advanced models like COSMO-1 (see section A1.7.12) or even PALM (see section A1.7.15), it is still a big challenge to simulate these processes in a realistic way. Therefore, a simulated wind field is usually more reliable 50 to 100 m above the surface than below this height.

Pressure gradients can be caused by different processes on a large scale of 100 km and more. They are defining the pressure systems (highs and lows) that are depicted on weather charts. Below this scale, regional pressure gradients are forming due to different heating, e.g. in different valleys in and around the Alps. Also, different cloud covers over neighbouring areas can cause regional pressure gradients. Such small differences on scales below about 100 km are not captured by the weather charts in figure 16. However, such regional pressure gradients are responsible for thermal wind systems, known as valley and mountain wind, or sea breeze.

The biggest valley in Switzerland is the Swiss Plateau north of the Alps. The air above the plateau is heated less during the day than the air within the Alps. The main reason is pure geometry. While over the plateau, the whole volume of air up to a certain altitude must be heated, about half of the volume is replaced by the terrain within the Alps. The same amount of solar radiation per horizontal area has to heat up less air mass, and the surface of the terrain is absorbing less heat than the replaced volume of air would do. This volume-per-area-effect is especially pronounced near the bottom of valleys and decreases with altitude. Sunny slopes are not a reason for the enhanced heating within the Alps because they are balanced with slopes in shadow. However, there are a few other effects like the drier (and usually clearer) atmosphere over the mountains.

The ambient pressure near the surface and at any altitude above is exerted by the weight of the column of air above. When heating a column of air, this does not change its mass and therefore not the pressure below it. However, the following process takes place. Heating a volume of air causes it to expand by about 0.3 % per centigrade (or Kelvin). When the horizontal expansion is restricted (e.g. in valleys), then the expansion will lift the air above this volume. This means that at the altitude above the heated volume, the pressure is rising, causing the air at this elevated altitude to flow in a direction where the heating is less, i.e. out of the Alps towards the plateau. This reduces the mass of air over the heated valley, leading to a fall in pressure. Even when the heated air in the valley can expand horizontally, mass is lost and the pressure falls. The resulting pressure gradient then drives the valley wind – as it is well-known in the Rhine Valley – between Chur and Disentis, or in the Rhone Valley east of Lake Geneva. These pressure gradients between different Alpine valleys and the foreland can also generate wind across passes like the Segnes pass when the pressure gradients extend up to this altitude.

With an understanding of these basic processes, it can be concluded that valley winds are not produced locally via upslope winds on sunny slopes but are the result of inner Alpine pressure gradients on scales of 10 to 100 km. The same pressure gradients are responsible for accelerated wind across certain passes. By the same reasoning, valley winds in a contradictory direction can develop. The Maloja Wind and a similar wind in the Upper Rhone Valley blow from the more elevated part of their valleys towards the lower sections because the region with the most effective warming (the centre of the heat island, or the heat low) is situated in the opposite direction than would ordinarily be expected.

These mechanisms are not just restricted to hot summer days but can also cause regional flows in all seasons. However, only when the different warming reaches higher altitudes, are passes affected. Therefore, hot summer days are more prone to accelerated winds across passes and crests than in wintertime with shallow valley winds.

A1.7.13.2 Applying the theory to the Segnes pass

The dense network of meteorological stations in the Swiss Alps allows observation of the diurnal pressure gradients across valleys. Since vertical pressure differences are more pronounced than horizontal ones (typically 1 hPa across 10 m vertical versus 10 to 100 km horizontal), it is not possible to directly compare station readings. For surface weather charts, the pressure readings are reduced to sea level. However, this method is not suitable for the detection of regional pressure differences, because the errors introduced by the reduction are in the same order of magnitude (one or a few hPa) as the horizontal pressure differences of interest, regardless of whether QFF[31] or QNH[32] is chosen for the reduction.

However, this detour via pressure reduction to sea level is not necessary for comparing pressure readings in a certain range of elevations. In this case, it is much better to reduce these pressures to an average elevation in between the stations, or to the elevation of one of the stations. Even the subtraction of a seasonal average pressure for each station results in more realistic horizontal pressure gradients than when reducing to sea level. This recommendation is revisited in section A1.7.16.3. This introduction should allow an understanding of the following discussion.

With this knowledge, suitable weather stations were selected in order to quantify diurnal pressure differences between the Glaronese valleys in the north, and the Rhine Valley south of the Segnes pass. This was not only done for the day of the accident, but for comparable days in August 2018, and in the summer of 2019. ‘Comparable’ does not necessarily mean as hot as between 2 and 5 August 2018, but sunny summer days.

[31] QFF: Pressure reduced to sea level using the local temperature

[32] QNH: Pressure reduced to sea level using ISA, the ICAO Standard Atmosphere (see glossary as well)

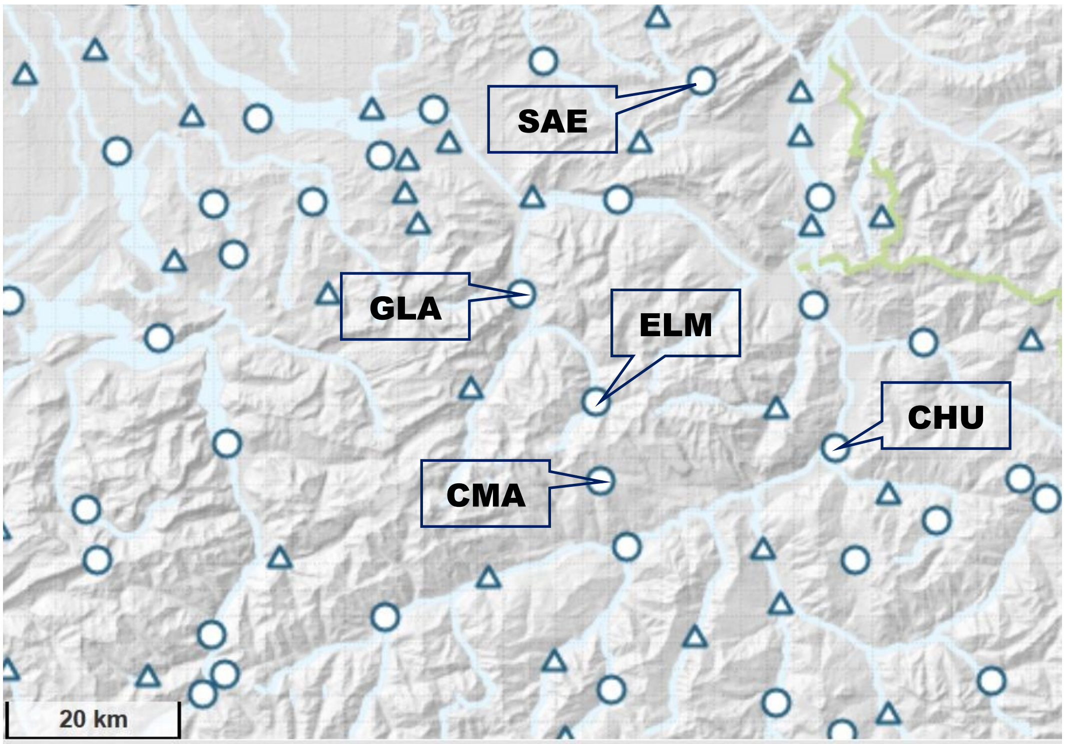


Figure 20: The surface weather stations used in this study – the mountain stations SAE (Säntis) and Crap Masegn (CMA), and the stations on valley floors Glarus (GLA), Elm (ELM) and Chur (CHU). Source and more information about the network of automatic surface weather stations: MeteoSwiss[33].

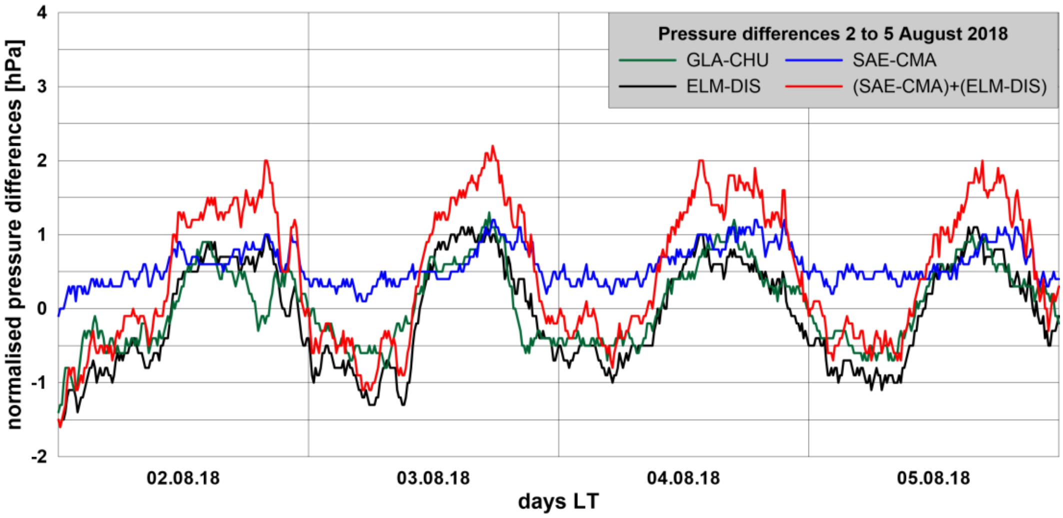


Figure 21: Diurnal pressure differences between selected stations in valleys and on mountains during four days around the day of the accident. See the map in figure 20 for the locations of the stations. Positive values show higher pressure in the north, i.e. from the Swiss Plateau towards the Alps. The pressure at Säntis (SAE) was reduced to the elevation of Crap Masegn (CMA); those at Elm (ELM), Glarus (GLA) and Chur (CHU) to the elevation of Disentis (DIS). The pressure difference SAE-CMA shows pressure differences at the altitude of higher mountains, where ELM-DIS and GLA-CHU show pressure differences between valley floors. The red curve shows the sum of the pressure differences at altitude and the ones between Elm and Disentis. For more information, see the text below.

[33] https://www.meteoswiss.admin.ch/home/measurement-and-forecasting-systems/land-based-stations/automatisches-messnetz.html

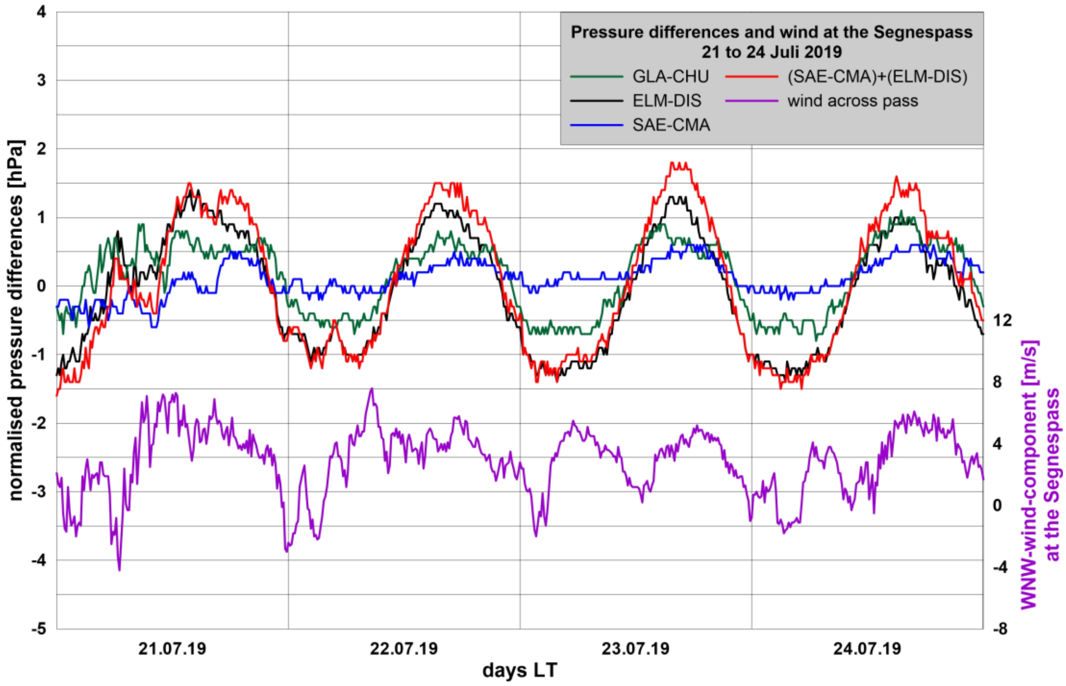


Figure 22: The pressure differences between the same stations as in figure 21, but for four comparable days in July 2019. Since the wind at Segnes pass was measured during that time in 2019, it can be shown in parallel. For more information, see the text below.

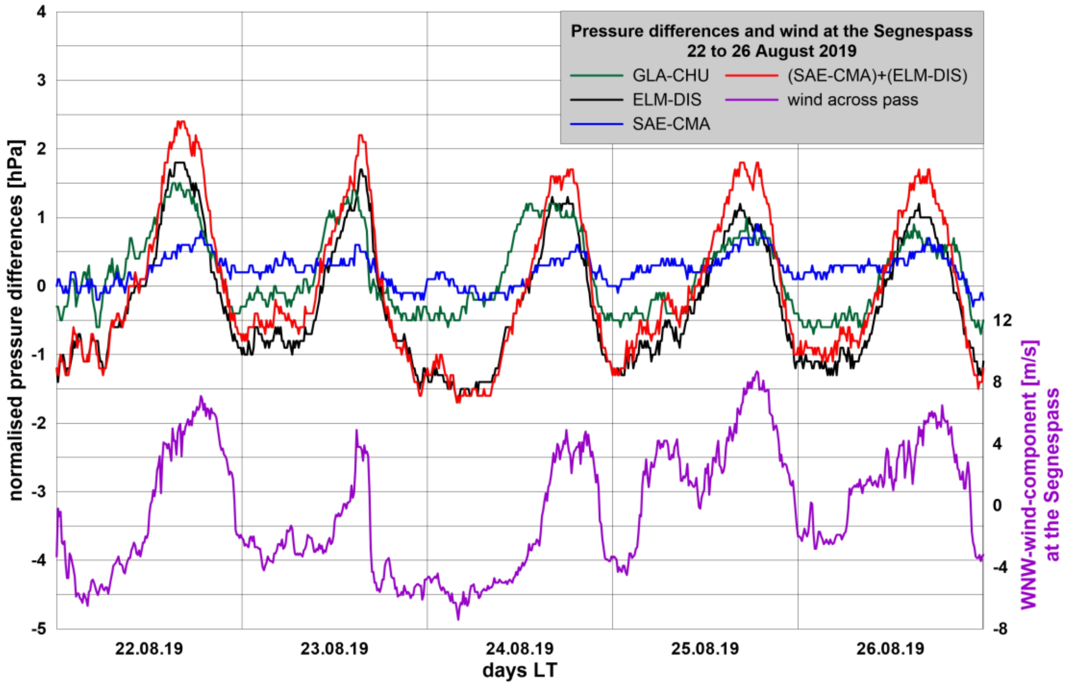


Figure 23: The pressure differences between the same stations as in figure 21, but for five comparable days in August 2019. Since the wind at Segnes pass was measured during that time in 2019, it can be shown in parallel. For more information, see the text below.

The time series in the figures 22 and 23 for nine summer days in 2019 show a similar pattern as during the four days in August 2018. Since the wind across the Segnes pass was measured in 2019 (see section A1.7.14), it can be compared with the diurnal pressure differences.

A typical diurnal pattern can be observed for these days. The pressure differences between Elm in the north and Disentis south of the Segnes pass increase during the afternoon. The differences are less pronounced at the altitude of the mountain peaks, but still clearly detectable. Additional stations were also inspected, but those selected here seem to be the best choice for documenting the effect of differential heating in neighbouring valleys and aloft. The sum of the pressure difference at lower and higher level is a combined indicator for the enhanced pressure in the north (red curves in figures 21 to 23).

A pressure difference of 1 hPa along less than 50 km (SAE-CMA) is sufficient for the acceleration of the air mass in between, i.e. to generate wind (7 kt after half an hour when calculated without friction). Of course, the even larger pressure differences between valley floors cannot act through the mountains. However, they drive the valley wind systems within the Alps. The comparison of the pressure differences with the wind across the Segnes pass, as measured in 2019 (figures 22 and 23), suggests that the diurnal pressure gradient does indeed drive wind across the Segnes pass as a shortcut.

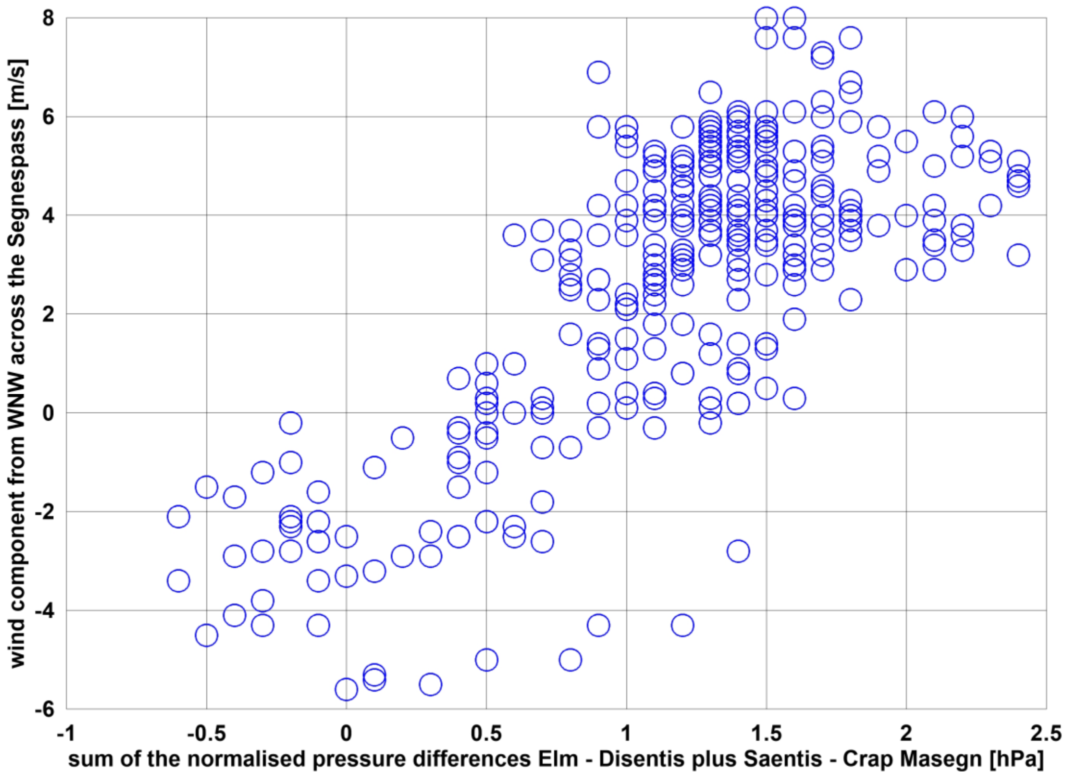


Figure 24: Scatter plot of wind speed across the Segnes pass against the sum of the pressure differences (red curves in figures 22 and 23) between 13:00 and 18:00 LT.

Even when the time series of wind and pressure differences look parallel, and the correlation is visible in figure 24, the relationship is not sharp. It is not possible to forecast an accurate wind speed across the pass based only on this pressure difference. The difference needs to be at least 1.5 hPa to define the direction of the flow. This is due to several reasons: (i) as explained in the theory, the pressure difference is not acting instantaneously; (ii) the wind aloft had different speed and directions during the nine selected days. The wind across the pass is a result of the upper-level wind, and the additional acceleration by the regional pressure gradient. During the sample days in 2019, the wind aloft did not reach the 10 or even 15 kt from the north as it did on 4 August 2018. Nevertheless, this additional contribution by the regional pressure gradient is quite important and robust.

This study shows that during sunny days in the summer of 2019, a north-westerly flow established across the Segnes pass, as a result of the diurnal pressure difference between the Glaronese valleys in the north and the Rhine Valley.

It is obvious that such a flow will be amplified when the synoptic wind from above is blowing from a northerly direction. Cooler air near the surface from the northern slope can additionally accelerate the downwind flow of the pass (see section A1.7.7).

All the processes described and analysed here are included in the numerical weather prediction model COSMO-1 as it was introduced in section A1.7.12. However, the basic theory in section A1.7.13 and the discussion of the measurements presented some additional empirical evidence.

The relevance of the wind and turbulence at the time of the accident is discussed in section A1.7.16.2.

A1.7.14 Meteorological measurements around the Segnes pass

The exact wind conditions along the flight of HB-HOT can neither be reproduced by measurements, nor by models. However, both can define typical patterns of the three-dimensional wind along the final minutes of the flight. Therefore, specific measurements were performed in the summer of 2019 (17 July to 14 September). The aim was to document wind and turbulence near the surface and at the altitude of the flight during conditions that were comparable with the day of the accident.

A1.7.14.1 Wind on the Segnes pass

A typical meteorological station was installed near the Segnes pass Mountain Lodge slightly east of the pass. It measured wind speed, wind direction, temperature and humidity on a six-metre-long pole at 2,650 m AMSL. This location allowed for the documentation of the direction of the flow across the pass, and typical wind speeds, even when such a measurement was influenced by the rocks at this place. The results from these measurements and their correlation with regional pressure gradients are discussed in section A1.7.13.

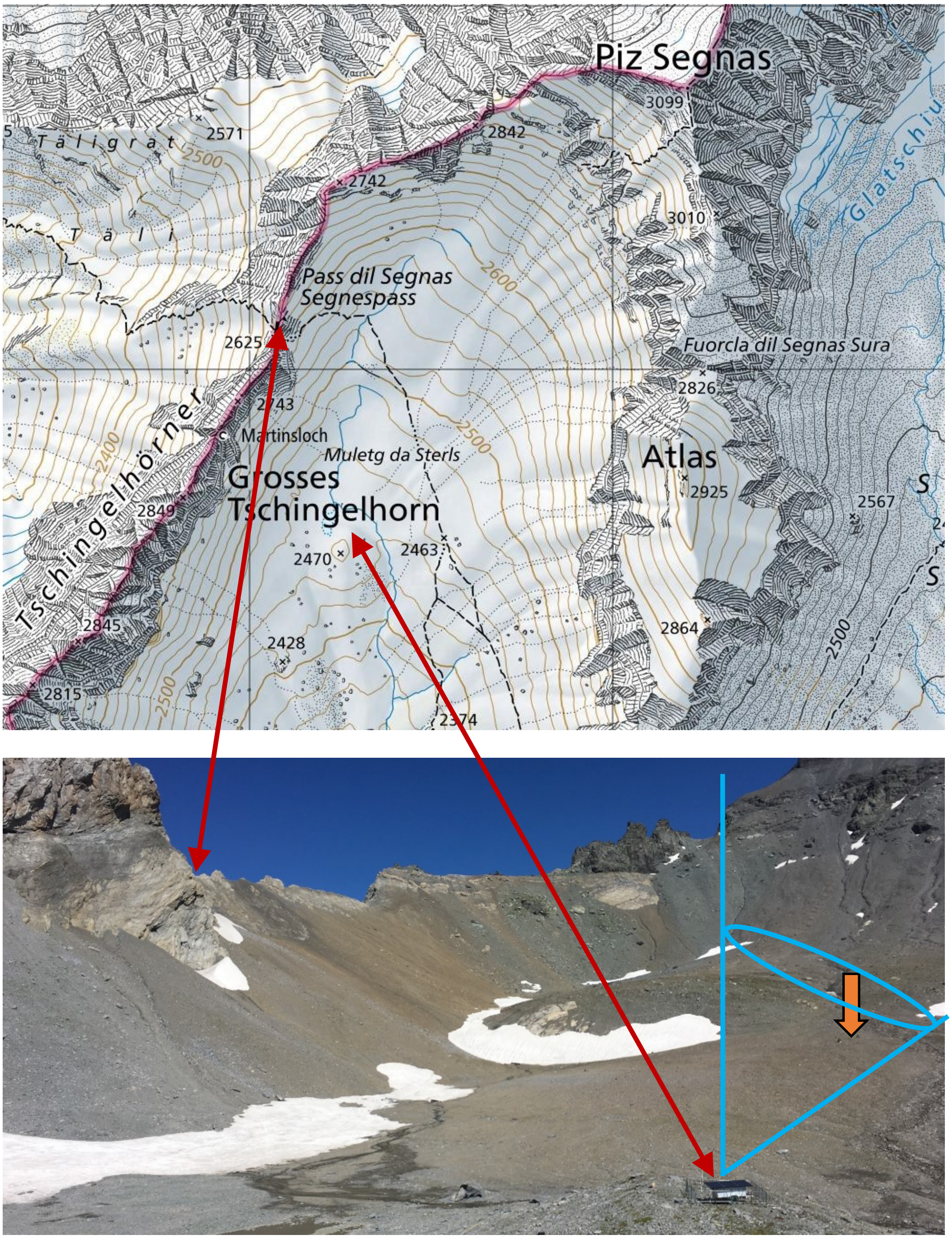


Figure 25: The positions of the meteorological station on the Segnes pass and the wind lidar[34] on a small hill not far from the site of the accident (orange pointer). The light blue lines denote the conical-shaped zone within which the lidar scans the sky up to a height of 200 m (see section A1.7.14.2). Source of the map: Federal Office of Topography.

On the following two pages, the recordings of wind, temperature and humidity are depicted for the seven weeks of the observations.

[34] Lidar: Light detection and ranging

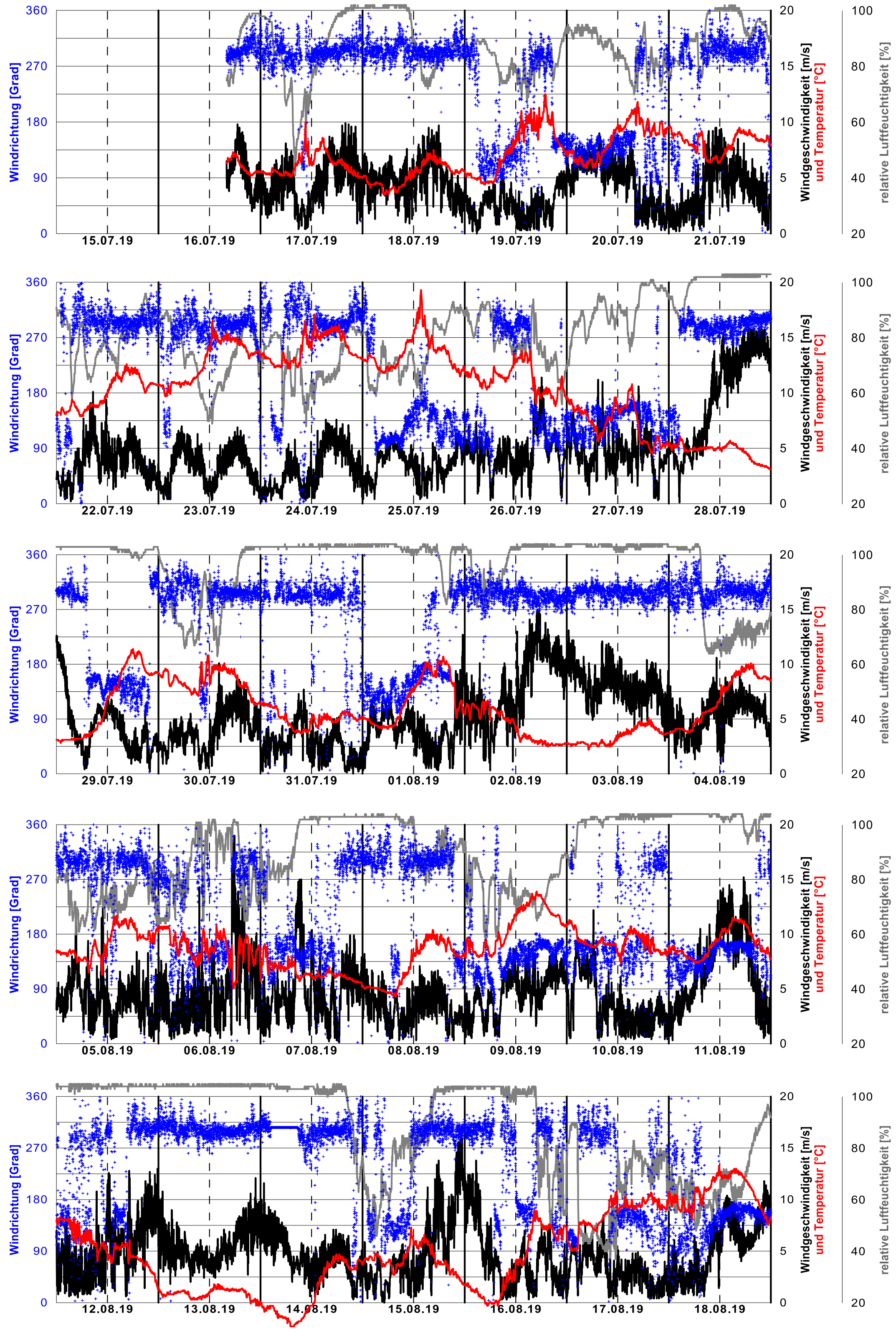


Figure 26: Seven weeks of measurements on the Segnes pass (for weeks 6 and 7, see next page). The vertical dashed lines mark local noon (12:00 LT). The black curves show the wind speed (‘*Windgeschwindigkeit’*, one-minute averages) on the first right-hand scale (10 m/s correspond to about 20 kt). The blue dots indicate the wind direction (‘*Windrichtung*’) on the left-hand scale. The red curve shows the temperature on the same scale as the wind speed. The grey line shows the relative humidity (‘*rlative Luftfeuchtigkeit*’) on the outer right-hand scale. Values around or above 100 % indicate clouds on the pass.

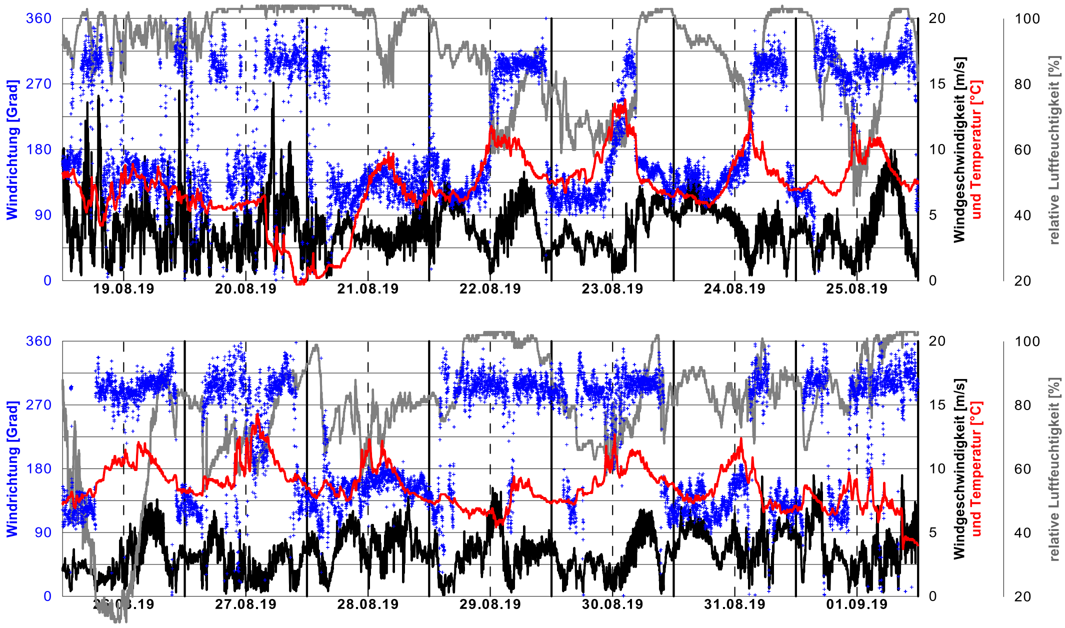


Figure 26, continued: See the caption on the previous page.

This time series shows that the wind across the Segnes pass during the afternoons was regularly blowing from the north-west. The velocities reached 5 to 10 m/s (10 to 20 kt) even close to the surface (6-m pole on a rock).

The summer of 2019 was less dry than the summer of 2018, and a synoptic wind aloft (not displayed here) was missing during the sunny days in this period in 2019. However, 13 days were identified as being comparable with 4 August 2018. The day of 25 August 2019 was ranked as the best, even though there was no stronger northerly wind above.

A1.7.14.2 Wind lidar below the Segnes pass

The measurements on the Segnes pass alone would not be sufficient to assess wind and turbulence along the flight of HB-HOT. However, a wind lidar can fill this gap by measuring the three-dimensional wind at high temporal resolution just below the flight track.

The wind lidar system[35] used here is designed for measuring wind in a relatively small volume above the instrument. It allows the measurement of wind and turbulence with a good spatial and temporal resolution: one wind vector per second at seven different heights, within a range of 10 to 200 m.

The laser scans around the cone outlined in figure 25. While doing this, it measures the radial speed of the air (the speed towards or away from the lidar) in a chosen distance 50 times per second. Despite the high accuracy (<0.2 m/s) of these raw Doppler measurements, the accuracy of the wind vectors calculated within the cone is limited by secondary geometrical and optical effects. Therefore, the lidar was installed in a way that one side of the cone was exactly vertical. This tilted installation and an optimisation of the software allowed for the most reliable measurement of the vertical wind component.

Wind, temperature and pressure close to the surface were measured on a small 2-m pole near the lidar. The time series of wind and temperature are shown in the same manner as the station readings from the Segnes pass.

[35] https://www.zxlidars.com/wind-lidars/zx-300/

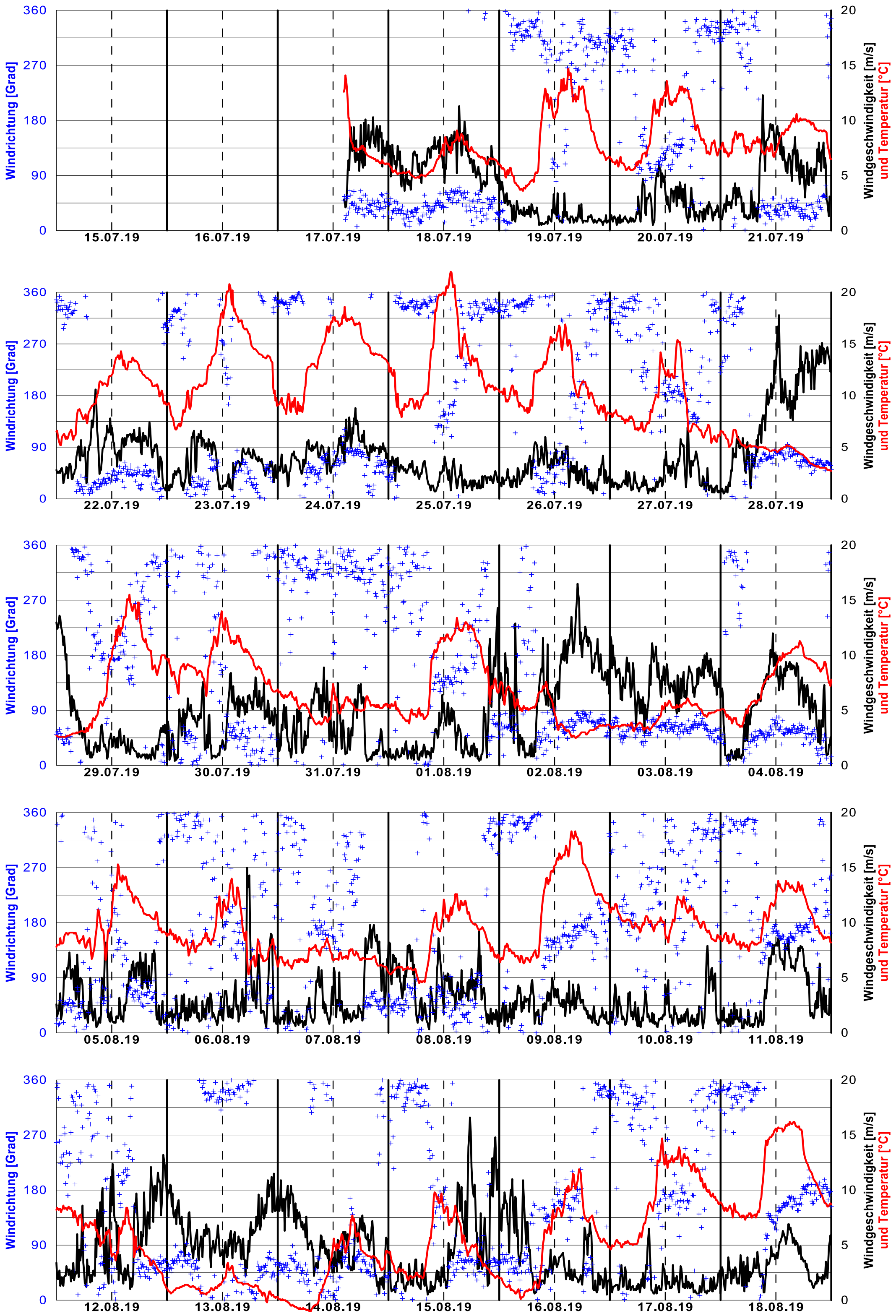


Figure 27: Seven weeks of measurements on the 2-m pole near the lidar (for weeks 6 and 7, see next page). The vertical dashed lines mark local noon (12:00 LT). The black curves show the wind speed (‘*Windgeschwindigkeit*’, ten-minute averages) on the right-hand scale (10 m/s corresponds to about 20 kt). The blue dots indicate the wind direction (‘*Windrichtung*’) on the left-hand scale. The red curve shows the temperature on the same scale as the wind speed.

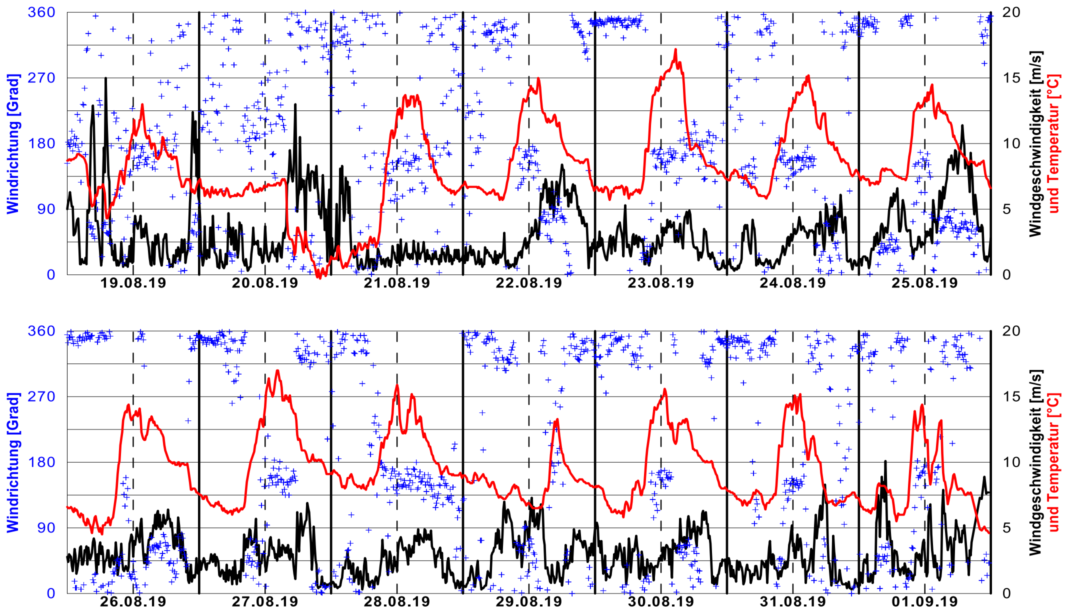


Figure 27, continued: See the caption on the previous page.

These additional measurements close to the surface document the typical occurrence of strong winds from the direction of Piz Segnas during afternoons. During several visits to the lidar station, the significant change between soft upslope winds around noon, and a cooler downslope wind shortly after this phase was also experienced subjectively. These measurements at the southern slope of the pass confirm that 25 August 2019 was the best day for comparison with 4 August 2018.

The lidar also recorded horizontal winds at seven heights within 10 and 200 m. However, due to the above-mentioned secondary effects, these are unreliable in this very heterogeneous flow such as rotors. Therefore, the focus of this study is on the reliable and more relevant vertical wind and turbulence measurements.

Figure 28 shows the time series of the vertical wind for the afternoon of 25 August 2019. The blue curve shows the vertical wind at an altitude of about 2,660 m AMSL, i.e. 50 to 100 m below the flight track of HB-HOT one year previously. Another 12 suitable days were identified for a statistical characterisation of the turbulence in this sector of the valley.

The vertical wind reflects the same diurnal evolution as discussed above for the wind near the surface. Shortly after noon, following a period with some turbulence caused by rising thermals (slope convection with positive vertical gusts between 1 and 3 m/s), stronger negative values were dominant. Based on the station readings from above, this was within the downslope flow from about 60° (see figure 27 for 25 August 2019). Between about 15:00 and 18:00 LT, the vertical wind varied between -6 m/s and +4 m/s.

The mechanisms generating this turbulence (thermals and rotors behind the ridges) during the afternoon suggest that the vertical wind speeds were not very sensitive to altitude, i.e. they would be the same 100 m higher. As such, the measurements taken one year later should not be projected directly to the day of the accident. The measurements describe typical conditions in a statistical way.

The primary question is: how often do such fast changes between downdraughts and updraughts occur within the flow at this location?

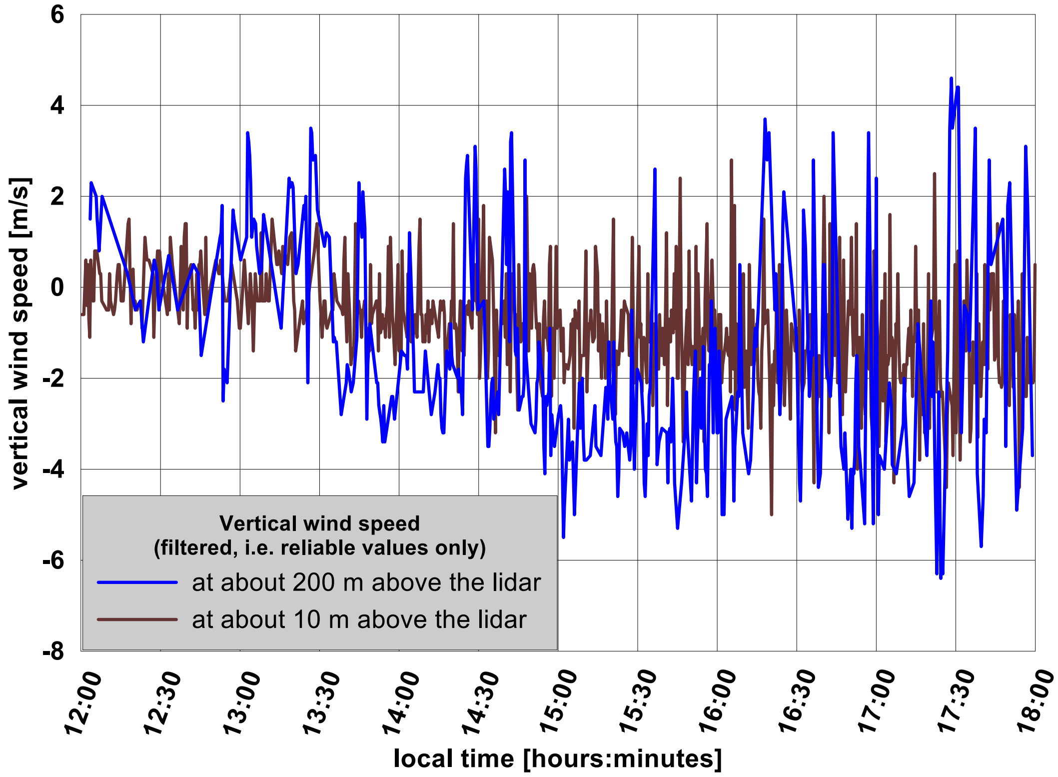


Figure 28: Time series of the vertical wind speeds (positive values are updraughts) at the lowest and highest altitudes measured during the afternoon of 25 August 2019. The 10 and 200 m above the lidar are at about 2,470 and 2,660 m AMSL respectively (8,100 and 8,700 ft AMSL, i.e. about 50 to 100 m below the flight track one year ago). In between these heights, five others were measured and processed. For further information, see the text below.

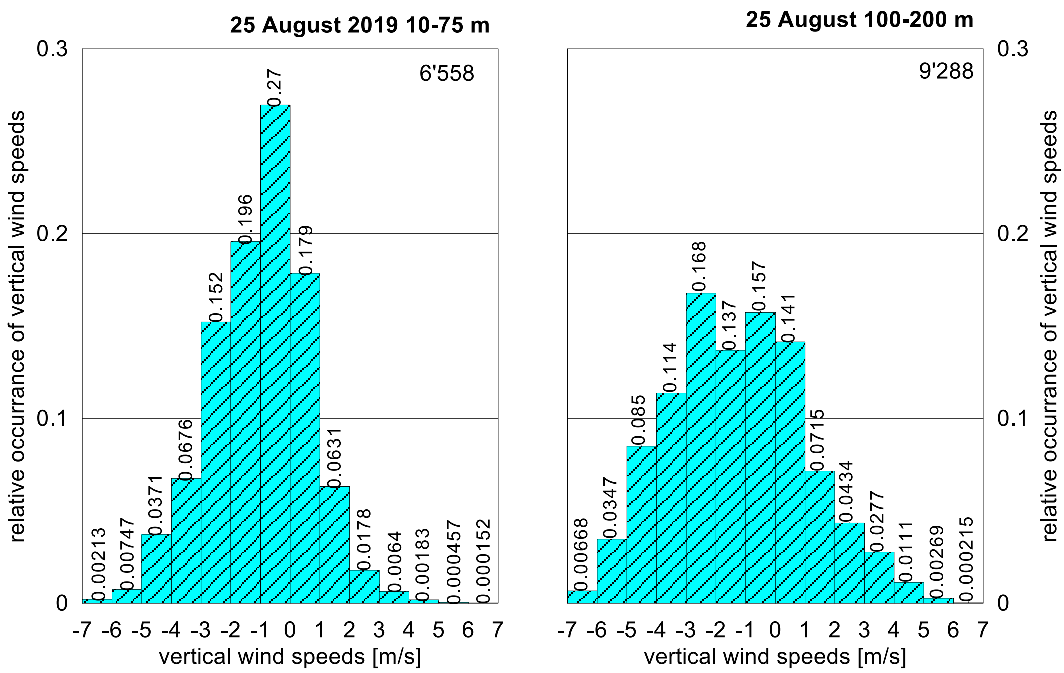


Figure 29: Histograms of the distribution of vertical wind speeds during the afternoon of 25 August 2019 (12:00–18:00 LT) in two height ranges above the lidar: 10 to 75 m (left) and 100 to 200 m (right). The numbers in the top-right corners are the numbers of individual measurements. The vertical axis and the values on top of the bars indicate the relative occurrence, i.e. downdraughts between -2 and -3 m/s dominated with 16.8 % occurrence in the range between 100 and 200 m above the lidar.

Such a statistical evaluation was made with all the 13 days that were selected. An example is presented in figure 29. The bars in the histograms indicate the relative occurrence of the different ranges of up- and downdraughts. At heights below 100 m above the lidar, weak downdraughts dominated with 27 %. Stronger up- and downdraughts exceeding ±3 m/s were encountered more frequently higher up. This is plausible and supports the assumption that these values will not be much different another 50 to 100 m higher up (where HB-HOT flew through a year ago). Even 8.5 % of downdraughts ranging between - 4 and - 5 m/s were detected, and - 5 to - 6 m/s occurred during 3.5 % of the observation time. Updraughts exceeding 3 m/s were found in 3.7 % of the time (sum of all ranges > 3 m/s).

Finally, the question is: how often did fast changes between down- and updraughts occur (because the horizontal shear of the vertical wind speed was a key parameter for the analysis of the accident)? For this purpose, all reliable vertical wind measurements on 25 August 2019 in the higher altitude range were examined. With the assumption that an aircraft flies through this sequence of vertical winds with a true airspeed of 50 m/s, the following probabilities were found for steps of at least 5 m/s (positive or negative) within 3 or 5 seconds, respectively: 1.0 % and 1.8 %. The consequences of these probabilities are discussed in section A1.7.16.2.

A1.7.14.3 Comparison with the operational measurements

As introduced in section A1.7.11.2, the well-exposed meteorological station Crap Masegn 7 km south-west of the accident is considered to be representative for the wind south of the ridge. For the observation period in the summer of 2019, these measurements can be compared with those on the Segnes pass, and at the lidar station below the flight track. An additional measuring station was operated by Flims Electric AG about 4 km south of the accident on an elevation of 2,100 m AMSL, near the Segneshütte mountain restaurant at the southern edge of the Segnas Sut high plateau. Wind and temperature data from this station was available both for 2018 and 2019.

Figure 31 shows the onset of the downslope wind during 4 August 2018, which was stronger than the day before. Ahead of the increasing afternoon winds, periods of weak winds are identifiable, most likely due to initial upslope winds, as discussed in A1.7.14.2. During the afternoons, the downslope winds dominated at this lower station in the same way as higher up in this side valley south of the Segnes pass. During the night before 4 August 2018, a reasonably intensive shower was recorded. The weak shower at 12:50 LT, that is visible on the radar imagery in figure 11, clearly also reached the high plateau, even though the radar echo near Ilanz was smaller. Vice versa, the stronger shower at Ilanz at 14:30 LT (see figures 12 and 13) did not reach the station of Flims Electric. In summary, these precipitation events in the very dry season led to a patchy distribution of soil moisture that enhanced the contrasts in thermal activity and supported the formation of cumuli above the local crests.

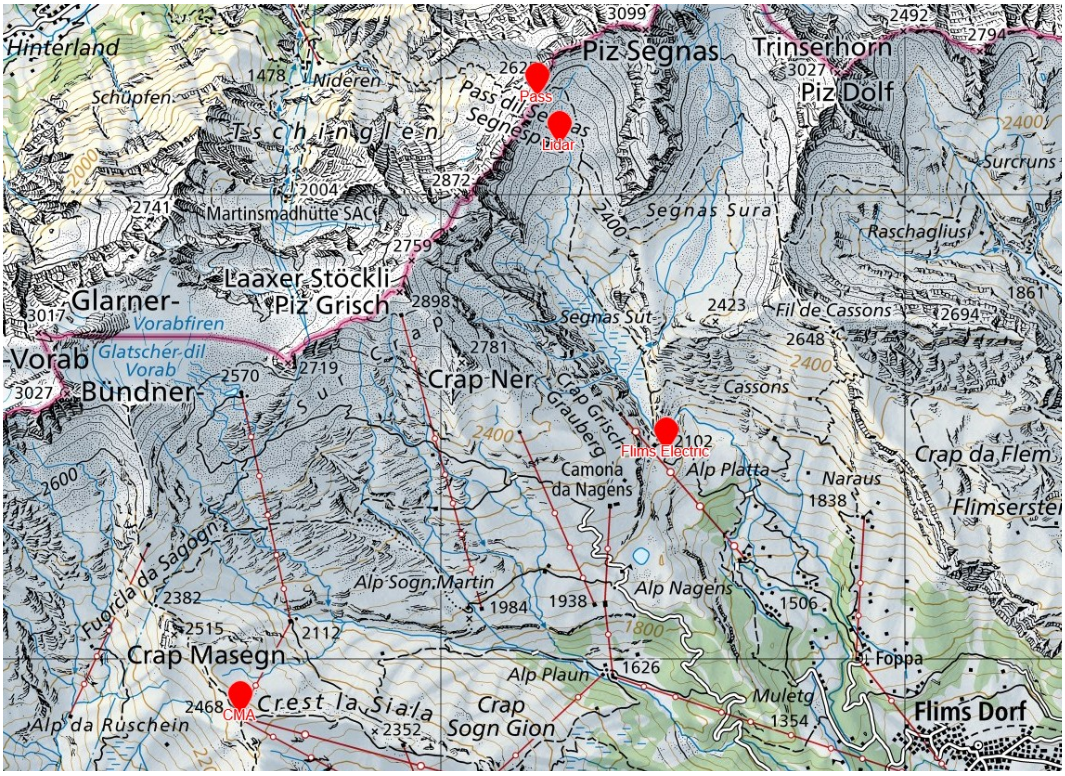


Figure 30: The four meteorological stations discussed in this section. Source of the map: Federal Office of Topography; station CMA see section A1.7.11.2).

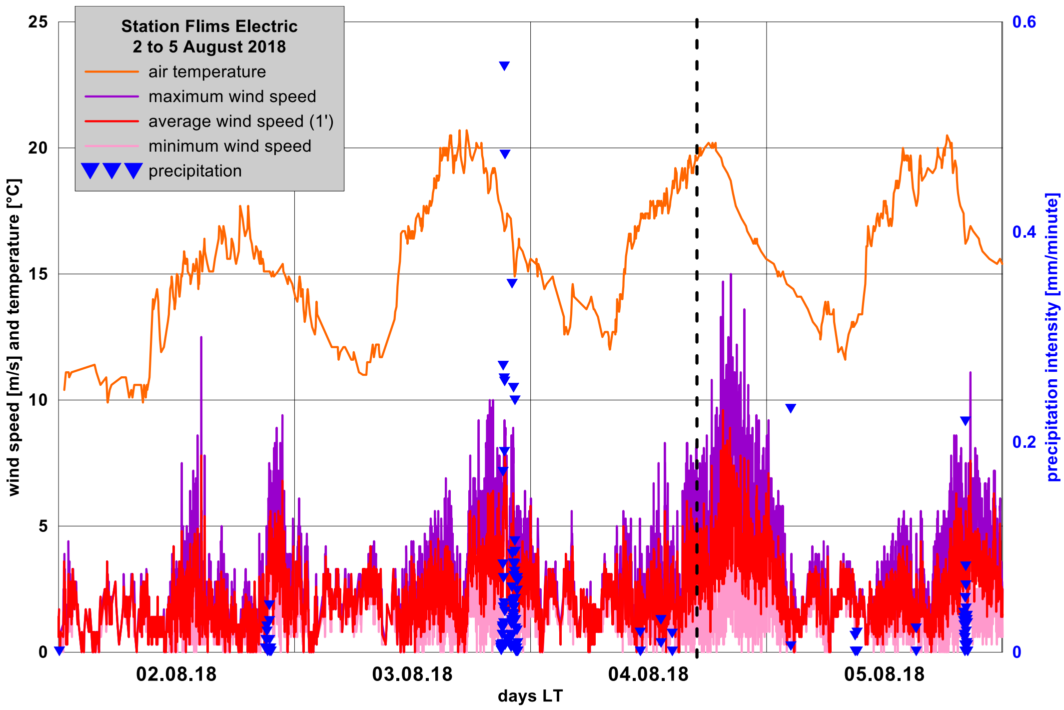


Figure 31: Wind, temperature and precipitation about 4 km south of the accident site at an elevation of 2,100 m AMSL (black dashed line at the time of the accident). The red curve shows the one-minute averages of the wind speed (5 m/s correspond to about 10 kt), whereas pink and purple indicate minima and maxima within the minutes. The wind direction was not recorded but confirmed by the operator to be downslope during the afternoons. The orange curve is for the temperature, and the blue triangles indicate rain according to the right-hand scale (mm/min to be multiplied by 60 for mm/h).

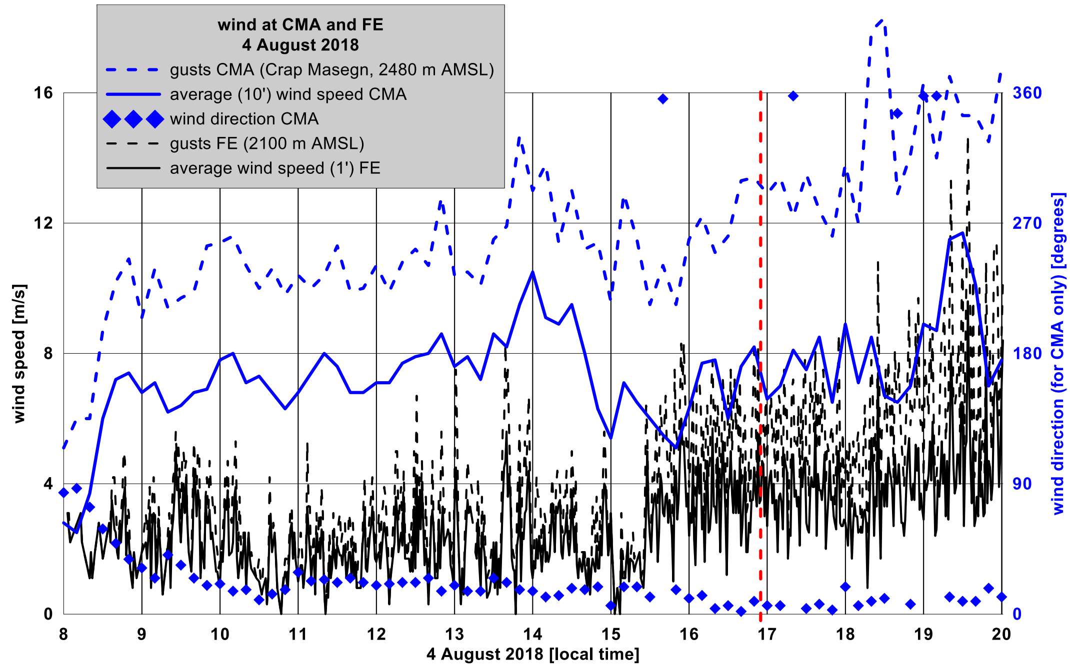


Figure 32: Wind at the two stations Crap Masegn (CMA) and Flims Electric (FE) on the day of the accident. The blue curves and points are for CMA (solid line: 10-minute averages of wind speed; dashed line: 1-second gusts; diamonds: wind direction on the right-hand scale). The one-minute averages and maxima are shown as solid and dashed lines in black. 8 m/s correspond to about 16 kt. Both the average wind speed and the gusts at CMA are about twice as high as at the FE station below the high plateau.

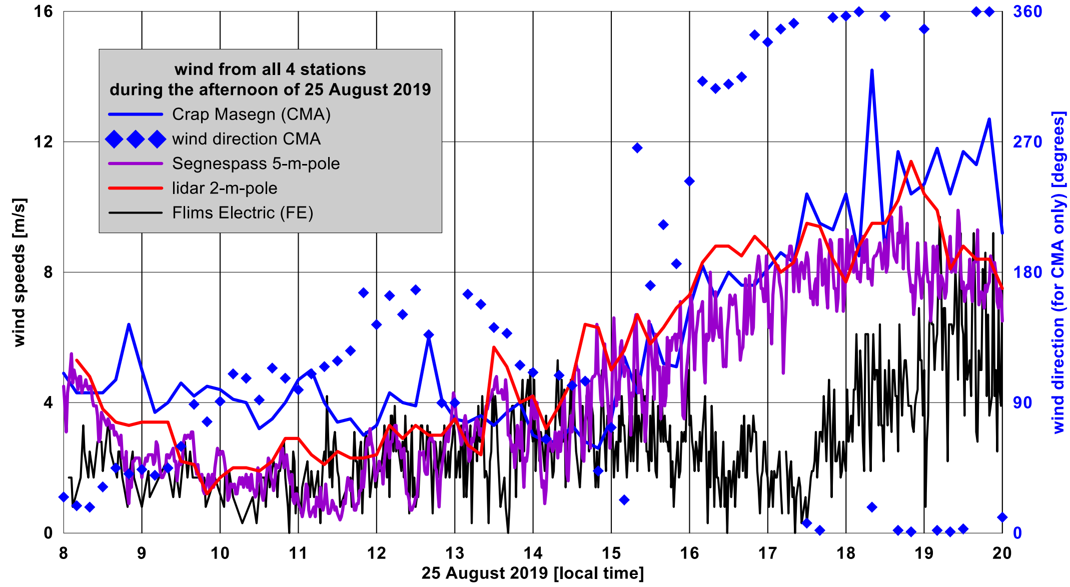


Figure 33: The average wind speeds of all the four stations discussed in this section (see figure 30). The 25 August 2019 was the day with the closest similarity to 4 August 2018. The gusts are not shown here in order to keep the graphics simple. They reached about 50 % above the 10-minute averages on both days (4 August 2018 and 25 August 2019).

Within the observations in summer 2019, 25 August 2019 was selected to have the closest similarity to 4 August 2018. This day allowed a direct comparison between the two operational stations and the two stations closer to the site of the accident operated in 2019 only. Figure 33 demonstrates that the wind at the Segnes pass closely followed the wind at Crap Masegn (CMA). This is a strong indication that the wind at Crap Masegn is representative of the wind across the Segnes pass for the day of the accident.

The FE station at the southern edge of the high plateau recorded about half of the wind speed observed at Crap Masegn during both days. This shows that the lower station is not fully exposed to the stronger downslope wind higher up in the valley. It decreases even more after 17:00 LT. The FE station would have been more important had the winds at the Segnes pass and at Crap Masegn not correlated so well. Then the wind at the Segnes pass could be estimated by doubling the speed measured at the FE station.

A1.7.15 Fine-scale wind field modelling using PALM

The regional COSMO-1 model of MeteoSwiss was introduced in section A1.7.12. This model, with a horizontal grid resolution of about 1 km, is able to analyse and predict the weather on a scale larger than a few kilometres. This is sufficient for depicting the general flow across the mountain range (figure 19). However, for simulating the turbulent flow within the basin south of the Segnes pass, it is necessary to have a much better resolution.

PALM[36] is a Large Eddy Simulation model (LES) allowing a chosen grid resolution of 10 m in order to simulate eddies with a diameter of 50 m or more. The LES is comparable to a CFD[37] model used in aerodynamics. PALM was adapted to the region around the Segnes pass at the Centre for Aviation at the Zurich University of Applied Sciences (ZHAW[38]). The model incorporates the topography of the terrain at this high resolution as well as other surface properties like soil moisture and albedo. The goal was to simulate the three-dimensional wind field, which is only partly known from the descriptions by eyewitnesses at the time of the accident (section A1.7.7).

The flow and the thermodynamic properties on the larger scale were taken from COSMO-1. Within PALM, three nested grids with horizontal spacings of 160, 40 and 10 m were introduced in three domains. In the following, only the inner domain (child domain) centred south-west of Piz Segnas is shown (figure 34).

At the beginning of the simulations, a sensitivity study assessed the influence of slightly different boundary conditions than offered by COSMO-1 (three wind directions and two stability classes). This study confirmed that the resulting flow patterns are quite robust. However, the best correlation with the observed winds was achieved by using the unchanged boundary conditions, including the neutral temperature profile.

[36] PALM: Parallelized large-eddy simulation model, https://palm.muk.uni-hannover.de/trac

[37] CFD: Computational fluid dynamics, with applications in aerodynamics and other disciplines in engineering

[38] https://www.zhaw.ch/en/engineering/institutes-centres/zav/

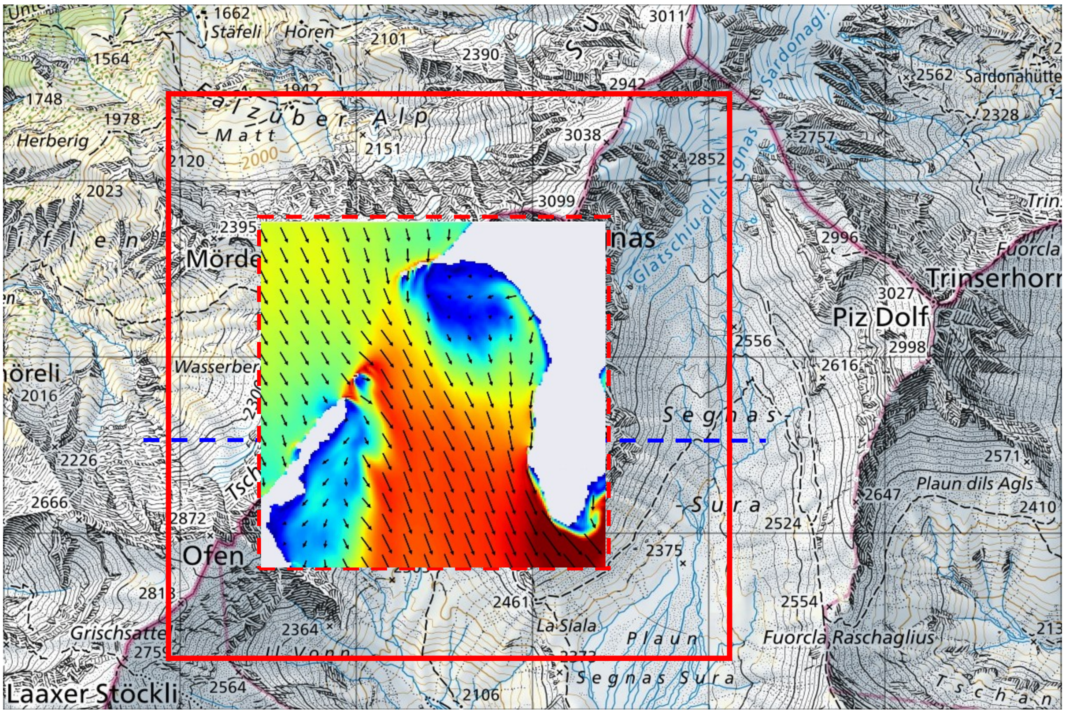


Figure 34: The square drawn with the solid red line is the inner domain (child domain) of PALM where the simulation was performed at the full resolution. The smaller square with the dashed boundary and a size of 2 km defines the area where the results are shown in figure 35. These are added here as a faint overlay for ease of orientation. The blue dashed horizontal line marks the position of the cross-sections shown in figure 36. Source of the map: Federal Office of Topography (swisstopo).

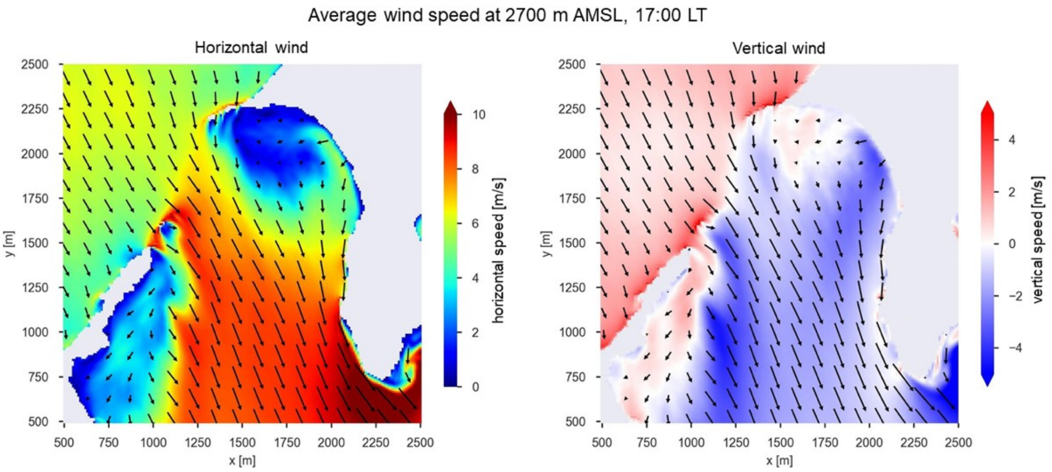


Figure 35: The horizontal wind field (left) and the vertical wind component (right) at 2,700 m AMSL as simulated by PALM (averages between 16:30 and 17:00 LT). The arrows depict the horizontal wind on both frames, but the colour coding is for horizontal wind speed on the left and vertical wind speed on the right. See further information below.

The main results for the three-dimensional wind field on 4 August 2018, around 17:00 LT, can be summarised by observing figures 35 and 36. It is important to note – even when the results are highly plausible – that this is not exactly the wind field encountered by HB-HOT. Therefore, the reconstructed flight track is not integrated in the graphs. This simulation shows – in combination with the measurements presented in section A1.7.14 – the general structure of the flow, with the ranges of values for wind speeds and turbulence both in the horizontal and vertical.

Since these are 30-minute averages, the position and strength of the main elements such as up- and downdraughts can vary. However, these averaged wind fields show tendencies, i.e. locations where lifting or sinking flows dominated.

The illustrations demonstrate that a rotor flow with considerable downdraught most likely developed on the downwind side (lee) of the western crest, whereas at the northern slope of the basin, updraughts dominated. The horizontal wind along the centre of the valley was enhanced (8 m/s or 16 kt), with maxima over the Segnes pass and at the southern edge of Atlas. A zone with much less wind is associated with the zone in the north, where thermal lift was active. Therefore – even when not projecting any details onto the reconstructed flight track – the following scenario is plausible. Initially, when entering the basin from the south, nose-wind and sinking were dominant. When approaching the Segnes pass, the zone with less wind and some thermal lift was encountered.

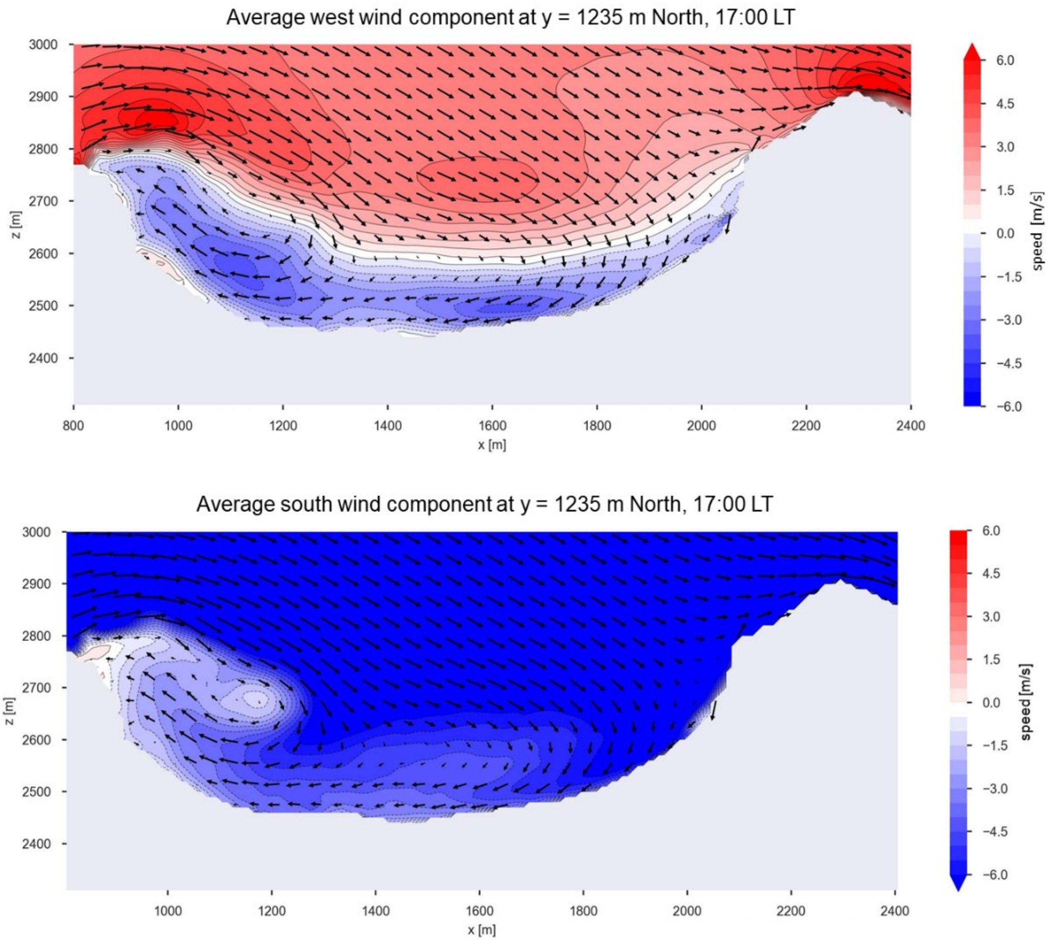


Figure 36: Vertical cross-section from west to east along the blue dashed line in figure 34. The arrows depict the flow on this plane in both frames, clearly showing the rotor behind the western crest (the Tschingelhörner range of mountain peaks on the map). The colours according to the scales on the right-hand side show the wind from the west (negative values from the east) in the upper frame, and the wind component from the north by the negative values in the lower frame. The wind components above the crest were about 7 m/s from the west and 8 m/s (outside of the colour scale) from the north, i.e. a north-westerly wind of about 21 kt above the basin. Near the western slope of Atlas in the east, the wind near the surface was from the north-east.

The two wind components near the surface in figure 36 are both about 5 m/s, resulting in roughly 15 kt from the north-east. This correlates with the wind observed[39] after the impact (17 kt from 060 to 070°), and is also in accordance with the descriptions of the eyewitnesses 15 minutes after the accident in section A1.7.7. The estimate of 60 km/h for the very local flow across the Segnes pass is plausible as well and is in the same order of magnitude as the maxima measured in 2019. The wind field shown in figure 35 is 75 m above the pass. For such comparisons, it is important to note that the results shown here are average wind speeds, whereas the observations are representative for shorter periods.

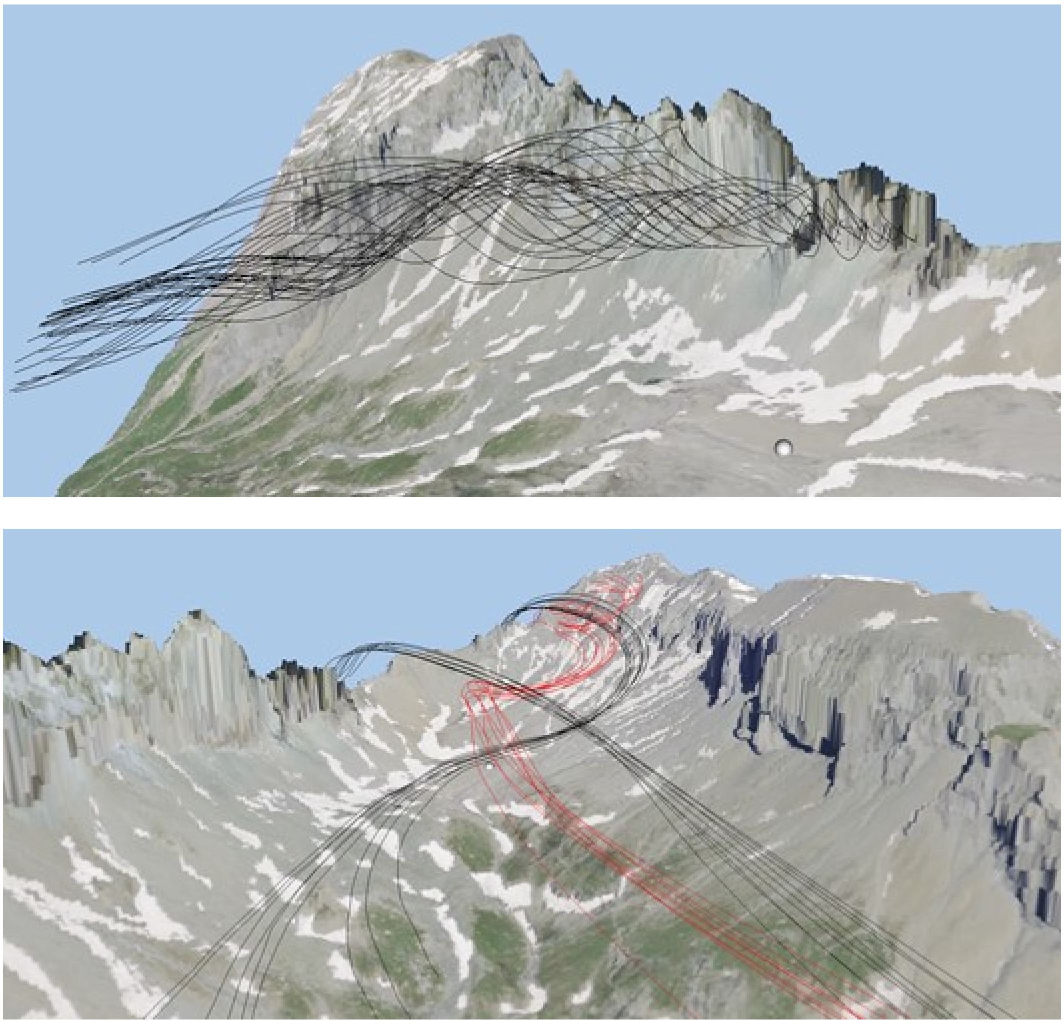


Figure 37: Three-dimensional display of selected streamlines in the region of the last minute of the flight. The site of the accident is marked by the white spheres. Top frame: Turbulent flow in the core of a rotor behind the western crest (the Tschingelhörner peaks on the map) seen from the east. Bottom frame: More laminar stratified flow near the surface. The lowest streamlines pass the site of the accident at a height of 10 m; the red ones at 100 m, and the higher black ones at 200 m. The north-easterly flow along the slope of Atlas and the north-westerly flow aloft are clearly visible. As emphasised above, this is a plausible flow pattern that can vary in time and space and must not be projected in detail to the reconstructed flight track.

[39] The wind was calculated by analysing the displacement of the dust cloud after the impact of HB-HOT to the ground.

PALM was also applied to five selected days from the summer of 2019, where continuous measurements on the Segnes pass and from the lidar station lower in the basin were available (see section A1.7.14). They compared well with one exception and therefore verified the reliability of the model adapted to this region.

This study shows that vertical wind speeds, as measured in the summer of 2019, were not exceptional and could therefore have been encountered at the time of the accident.

A1.7.16 Assessing some meteorological aspects

A1.7.16.1 Comparison of the actual weather conditions with the official forecast

The aviation weather forecasts – available on the morning and just before the flight (see section A1.7.5) – did not show any extraordinary or especially difficult conditions along the planned flight. The weather encountered during the flight was in accordance with the forecasts.

The forecast advised to be vigilant for possible showers or thunderstorms along the route. Considering the experience of the flight crew and the general weather conditions, it was clear that isolated showers or thunderstorms could have been avoided based on decisions during the flight. There was no risk that all VFR routes between Locarno and Dübendorf were closed. An alternative route along the Rhine Valley via Chur would have been possible if the Alpine ridge was in clouds. The crew was not forced to continue the flight across the Segnes pass. Even a return to Locarno or Lugano was possible at any time if the weather in the north deteriorated.

The convective activity with showers and a likelihood of thunderstorms was more pronounced than the previous day and was most likely to be observed visually.

A1.7.16.2 Turbulence during the last phase of the flight

The wind across the Segnes pass and over the basin south of it usually blows from the north-west during sunny afternoons (see sections A1.7.13 and A1.7.14.1). Enhanced afternoon wind speeds are also common in other Alpine passes.

Even more widely known, is the fact that downwind (in the lee) of ridges, turbulence should be expected. Additionally, at this time of the day, thermal activity with vertical wind speeds of ±3 m/s are normal. Dedicated measurements of the vertical wind (see section A1.7.14.2) show that even ±4 m/s are frequent, and extreme downdraughts up to -6 m/s are possible. The risk of encountering a sequence of rapidly changing vertical wind – which is a dangerous combination – cannot be excluded (see section A1.7.14.2). This risk for a change of 5 m/s or more within three or five seconds was quantified for 25 August 2019 to be one or two per cent, respectively. When flying 100 hours in comparable conditions, the exposition time to an enhanced risk is between one and two hours. This purely statistical view for a comparable day does not consider stationary shear zones like rotors or more wind as it was reported for 4 August 2018.

The wind at the time of the accident was stronger than a few hours earlier when the crew flew through the same region during their ferry flight from Dübendorf to Locarno in a single-engine aircraft. As recorded by the measuring station at Crap Masegn (see figure 32), the northerly wind had an increasing tendency. This increased wind at crest height most likely intensified the turbulence in the south-west of Piz Segnas.

The text forecast for general aviation (see section A1.7.5.1) indicated such a development of the upper-level wind, and the crew could have recognised it as a crosswind from the left while flying along the Rhine Valley and when entering the side valley south-west of Piz Segnas.

A1.7.16.3 Predictability of wind across Alpine passes

Thermal wind systems not only act on slopes and along valleys, but also lead to air mass exchange between different valleys, i.e. wind across passes. This is especially pronounced during summer, when the diurnal heating reaches higher altitudes (see section A1.7.13). It is possible to see these local winds in publicly-available weather prediction products. However, they are not part of a standard aviation weather briefing. Sometimes the pressure difference between Lugano and Zurich Airport is consulted as an indicator for a North- or South-Foehn events. However, this indicator is not specific for wind across Alpine valleys and can often lead to unexpected events.

Contents

A1. Factual information

A1.12 Information on the wreckage, impact and accident site

A1.12.1 Accident site

The accident site was located in the basin south-west of Piz Segnas, approximately 1.2 km from its summit and at an altitude of 2,480 m AMSL. The Martinsloch, a natural rock window in the Tschingelhörner range of mountain peaks, is located approximately 500 m west of the accident site. At this point, the Tschingelhörner peaks form the border between the cantons of Glarus in the north-west and Grisons in the south-east. The accident site falls within the municipality of Flims in the canton of Grisons (see annex A1.1).

Figure 1: Final position of the wreckage. Looking east towards the scene of the accident.

A1.12.2 Impact

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

A1.12.3 Technical findings on the wreckage

A1.12.3.1 General

Section A1.12.3 describes findings that are illustrative examples of a much larger number of comparable findings on the wreckage. Not all findings made as part of this safety investigation are listed here.

At the scene of the accident, it became apparent that none of the structural components or control surfaces of the aircraft were missing. The wreckage was flown down into the valley, where it was cleaned, sorted according to its components and then subjected to separate detailed examinations.

A1.12.3.2 Findings on the fuselage

The forward fuselage including the cockpit was destroyed on impact. It was therefore not possible to perform an integral assessment of the mechanics of the control surfaces and the engines.

The fuselage, centre wing and tail, including empennage, were examined in detail. For this purpose, the connecting linkages of the control system and parts of the centre wing were cut out.

The layer of paint applied to prevent corrosion had flaked off or was missing, especially inside the fuselage and in places that are not visible on an intact aircraft.

Important structural parts had become corroded, i.e. those made of steel had rusted and those made of aluminium had partially oxidised to powder. The corrosion found was particularly pronounced in the non-visible inner area of hollow sections, in areas of contact between two layers of sheet metal and under the wooden cabin floor (see figures 2 to 8). Several places on the structure of the fuselage exhibited areas that had been repaired using self-fabricated components.

Parts of the fuselage structure were then examined in the laboratory (see annex A1.16).

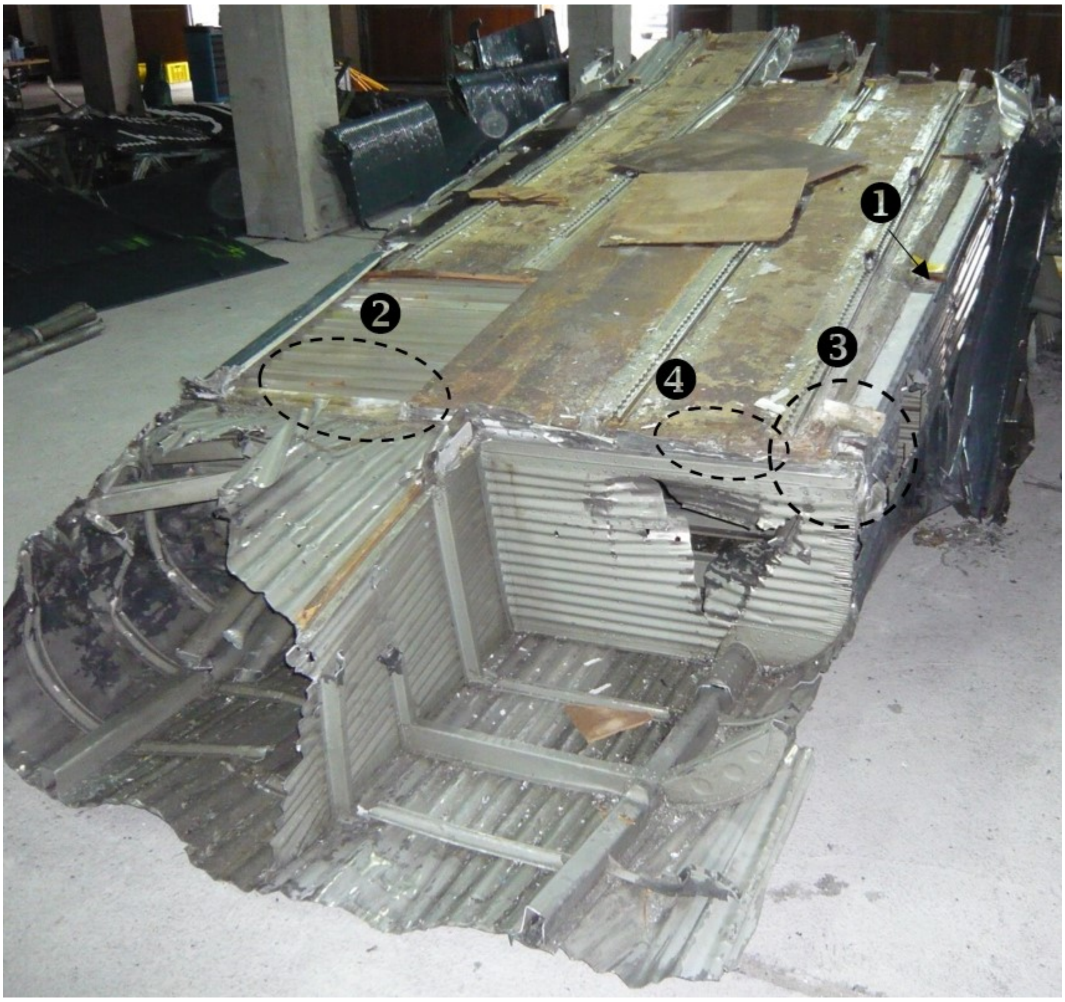


Figure 2: Aft bottom fuselage including cabin floor – severely corroded hinges of the cargo door (1) and (3), as well as severely corroded fuselage structure (2), (3) and (4).

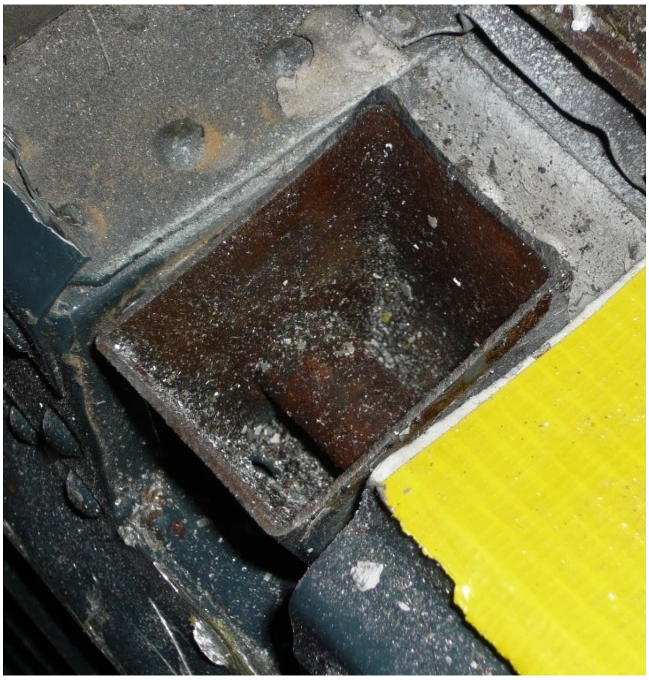


Figure 3: Close-up of figure 2 number (1) – severely corroded hinge of the cargo door on the right-hand side of the fuselage.

Figure 4: Close-up of figure 2 number (2) – severely corroded floor structure and bolts (red circle).

Figure 5: Close-up of figure 2 number (3) – rotten wooden floor (zone marked in yellow), severely corroded hinge of the cargo door (red circle) and severe corrosion on the fuselage structure (powdery, whitish patches of aluminium oxide).

Figure 6: Close-up of figure 2 number (4) – severely corroded floor structure with fracture (red circle).

Figure 7: Close-up of figure 5 – severely corroded hinge of the cargo door (red circle).

Figure 8: Severely corroded bolt for mounting a seat rail.

A1.12.3.3 Findings on the wing

Parts of the wing wreckage consisting of the centre wing and the two outer wings were sorted, laid out and collated. The components were then visually inspected and, if marked for more detailed assessment, examined further in the laboratory.

All parts of the wing had originally been given a coat of paint to prevent corrosion. There was no evidence to suggest that this coat had been renewed or restored after the aircraft had been manufactured. In many places, the surface protection was no longer intact or was missing altogether.

Many of the spar tubes examined showed signs of contact wear. This was particularly pronounced where the panelling was riveted to the spar tube.

Some of the sheet steel joints and many of the steel rivets were rusty (see figures 9 and 10).

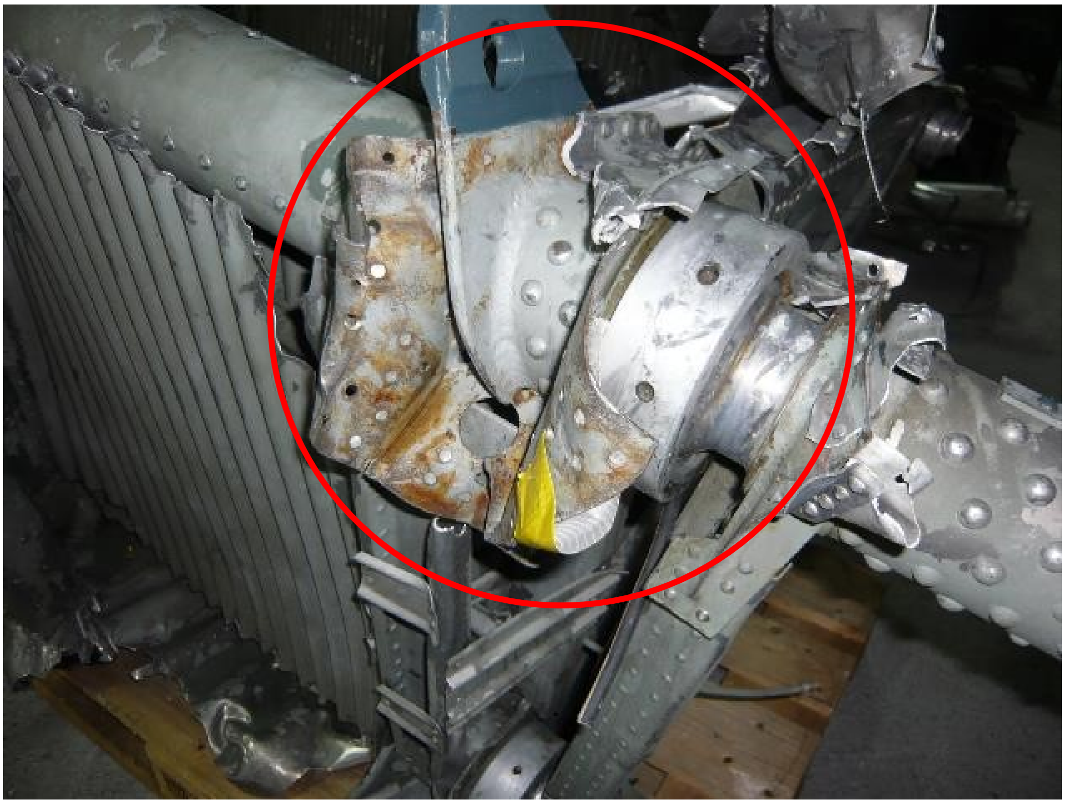


Figure 9: Corrosion over the entire area connecting the outer wing to the centre wing (red circle).

Figure 10: Corrosion in an area connecting the outer wing to the centre wing.

Examination found broken rivets exhibiting corroded fractured surfaces and rivets that were already loose before the accident (see annex A1.16) as well as rivet holes with missing rivets.

The results of the borescope inspection conducted in February 2017 confirmed that rivets were broken or missing (see annex A1.6).

Many of the areas of contact between joined and riveted components had become corroded. The corrosion was particularly pronounced at points of contact between different, unfavourable material pairings and in places that lacked corrosion protection.

Components subjected to high loads and stress were found to have been repaired (see figure 11). This included sheet aluminium parts that had been attached using blind rivets and sheet-metal screws.

Figure 11: Repairs carried out in the centre wing, apparent by the greenish-yellow structural parts and the golden yellow connecting elements.

The visual assessment of the spar tubes identified cracks, which were then examined in the laboratory to assess whether the damage existed prior to impact (see annex A1.16).

An area featuring fractures was found near the engine frame on the lower spar tube of spar I on the left outer wing (see figures 12 and 13). These fractures were examined from a metallurgical point of view (see annex A1.16).

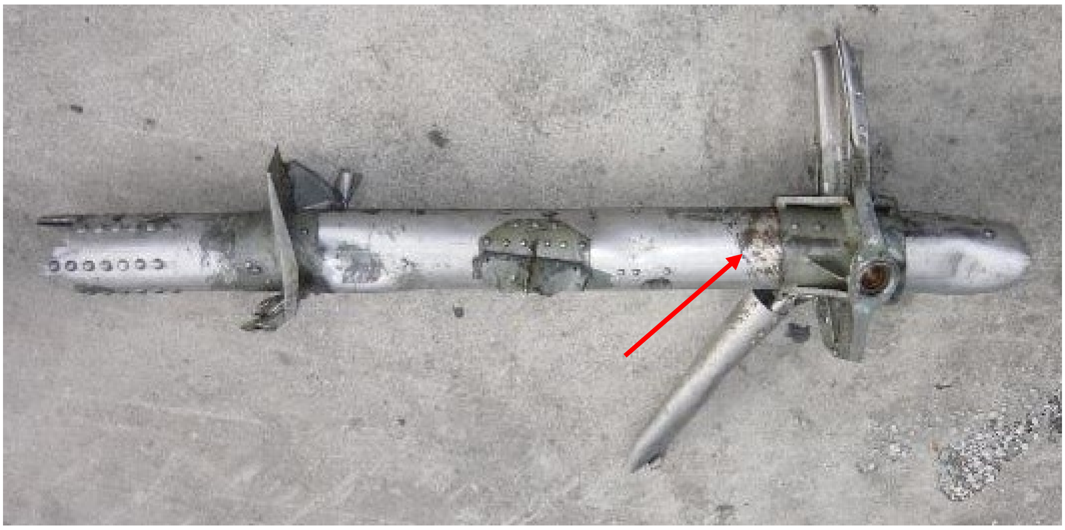


Figure 12: Lower spar tube of spar I on the left outer wing. The arrow points to the area of the spar tube with fractures. The outer diameter of the spar tube is 90 mm.

Figure 13: Close-up of the inside of the spar tube where fractures were found.

A1.12.3.4 Findings on the empennage

A1.12.3.4.1 Elevator, horizontal stabiliser and horizontal-stabiliser support strut

The elevator was still attached to the horizontal stabiliser following the accident.

The connecting flanges of the elevator's actuating element were assembled using nuts, bolts and washers. Nylon locknuts had been fitted instead of castellated nuts with locking pins. The thread of the bolts was too short for the use of locknuts (see figure 14).

On the inside of the horizontal stabiliser, the anti-corrosion paint had partially flaked off (see figure 15).

On the inside of the left elevator, the anti-corrosion paint had flaked off extensively (see figure 16).

In general, the components were severely corroded. Corrosion was also present under some rivet heads.

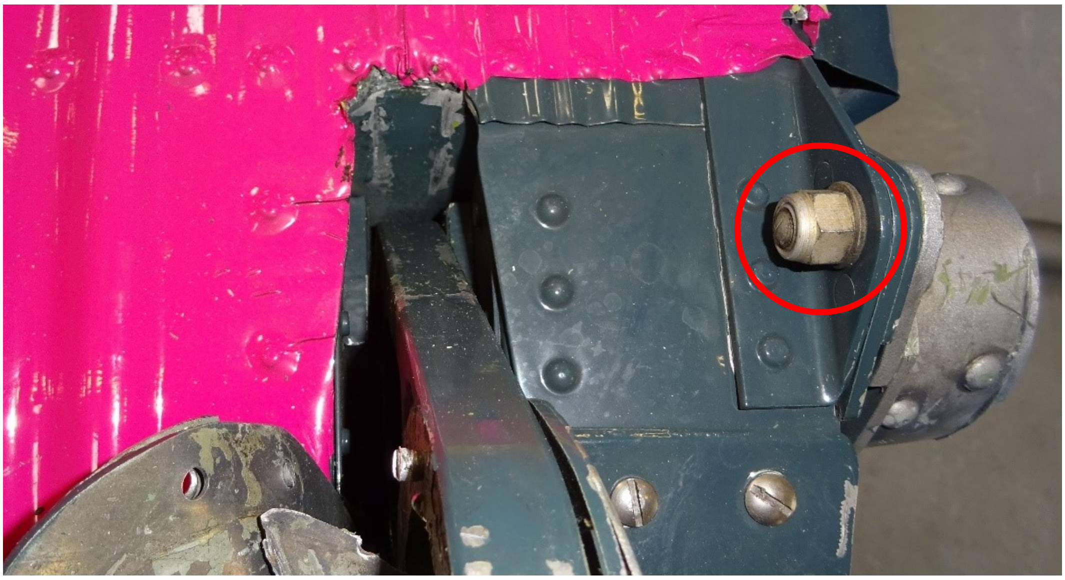


Figure 14: Right-side elevator with connecting flange of its actuating element, which was mounted using a nylon locknut on a thread that was too short for this purpose (red circle).

Figure 15: Inside of the horizontal stabiliser – areas where the anti-corrosion paint had partially flaked off.

Figure 16: Flaked off anti-corrosion paint on the inside of the left elevator.

A1.12.3.4.2 Rudder and vertical stabiliser

The rudder is connected to the vertical stabiliser by two brackets and additionally attached to the end of the fuselage.

Inside the rudder and vertical stabiliser, the anti-corrosion paint had flaked off in many places and the sheet metal had become corroded (see figures 17 and 18). The bolts at the joints had been secured using nylon locknuts, but the bolt threads were too short to use this kind of nut. Moreover, they were not tightened properly and could be loosened by hand.

A hardened piece of water hose had been used as a stop buffer for the rudder. Some of the rivets were loose. Blind rivets had also been used. This indicates that repairs had been carried out, as such rivets were not yet in use when the aeroplane had been manufactured.

Figure 17: Inside of the rudder – head of the bolt for attaching the central hinge; lack of anti-corrosion paint; corrosion on sheet metal, rivets and bolt (label text reads central hinge).

Figure 18: Flaked off anti-corrosion paint on the inside of the rudder.

A1.12.3.4.3 Ailerons and flaps

The left and right ailerons as well as the two flaps were each connected to the wing by four brackets. Some of these connections were torn off during impact. All joints were visually inspected and some were disassembled.

The right-hand flap was not identical to the left-hand flap (see annex A1.6).

Individual joints of the aileron connections as well as joints of the flaps exhibited wear and play, and some of the hinge pins were corroded. The majority of the castellated nuts used to secure the bolts had locking pins that were too small for the size of the nut. In addition, the locking pins were improperly fitted. The threads and locknuts of the adjustable ends of the push-pull rods used to operate the ailerons, flaps and flap trim tabs had been partially painted over. This suggests that no adjustments were made to these components after the aircraft had been repainted.

A1.12.3.5 Findings on the controls

A1.12.3.5.1 Elevator, rudder and aileron controls

The connecting linkages for the controls were removed from the wreckage and visually inspected. The control elements in the cockpit were severely damaged in the accident. It was therefore not possible to assess the condition of these parts.

All examined connecting linkages used in controlling the aircraft were in working order but in poor condition. Many elements exhibited corrosion, and rivets were loose or missing. The protective coat of paint had flaked off almost all parts, and the corrosion protection was therefore insufficient (see figure 19). The control cables were old: their production method is consistent with the time when the aircraft was manufactured (see figure 20).

Replaced locking pins had not been fitted properly. In some cases, nylon locknuts had been used instead of the castellated nuts with locking-pin retention from the aircraft's original design. The rubber stop buffers for limiting the control travel had hardened due to their age.

The adjustable ends of the push-pull rods to control the left and right ailerons were completely screwed in. This raises doubts about the ability to use the correct setting for the ailerons as the range was exhausted on one side.

The oil shock absorber for the auxiliary-wing (ailerons and flaps) adjustment safety device had no oil. The following was written on the oil shock absorber in felt-tip pen: "*last inspection 1981*".

The hooks of the springs for the auxiliary-wing adjustment safety device were heavily worn and were at risk of breaking (see figure 21).

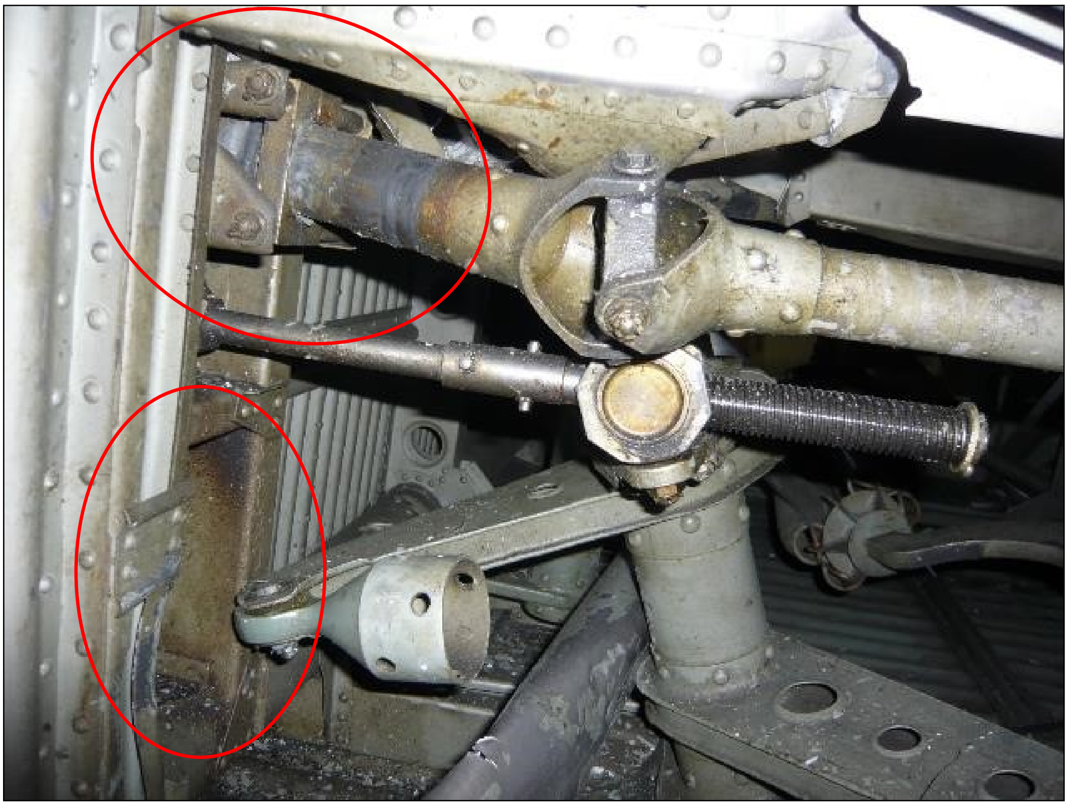


Figure 19: Corrosion (circled in red) in the centre wing and the control elements.

Figure 20: Old control cables, whose production method was consistent with the time when the aircraft was manufactured.

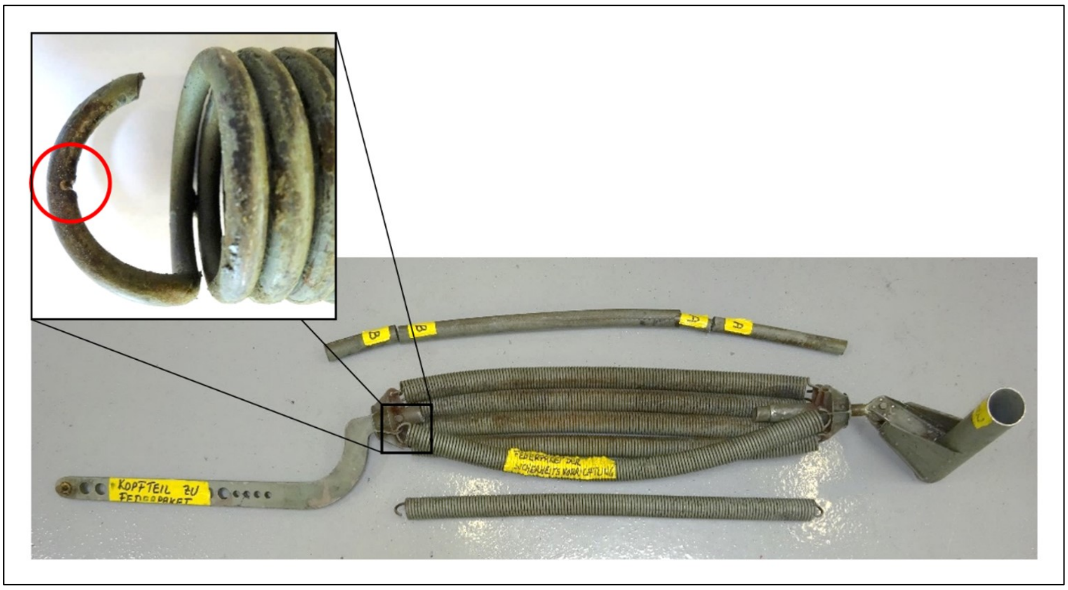


Figure 21: Spring assembly (auxiliary-wing adjustment safety device); spring hooks weakened by wear and tear.

A1.12.3.5.2 Horizontal-stabiliser adjustment

On the left-hand side of the aft fuselage near the leading edge of the horizontal stabiliser, there is a plaque marked with angles from - 2½ to + 3½ degrees. The angle set for the horizontal stabiliser can be read using a pointer mounted on the leading edge of the horizontal stabiliser.

It was possible to establish that the horizontal-stabiliser adjustment on the wreckage displayed an angle of approximately + 1½ degrees.

A1.12.3.5.3 Horizontal-stabiliser adjustment spindle

The pivoted horizontal stabiliser is operated using a horizontal-stabiliser adjustment spindle and an adjustable push-pull rod (see figure 22). Information regarding horizontal-stabiliser adjustment is described in the aircraft's operating instructions.

The angle of the horizontal stabiliser is displayed in degrees on an indicator in the cockpit. On the horizontal stabiliser, at the end of the fuselage, there is an additional indicator, which also shows the horizontal stabiliser's angle. Both displayed values must match when the angle is set.

The horizontal-stabiliser settings must be adjusted based on the limit positions and the zero position of the stabiliser. The adjustment is made using the push-pull rod sleeve (1) and the locknut (2).

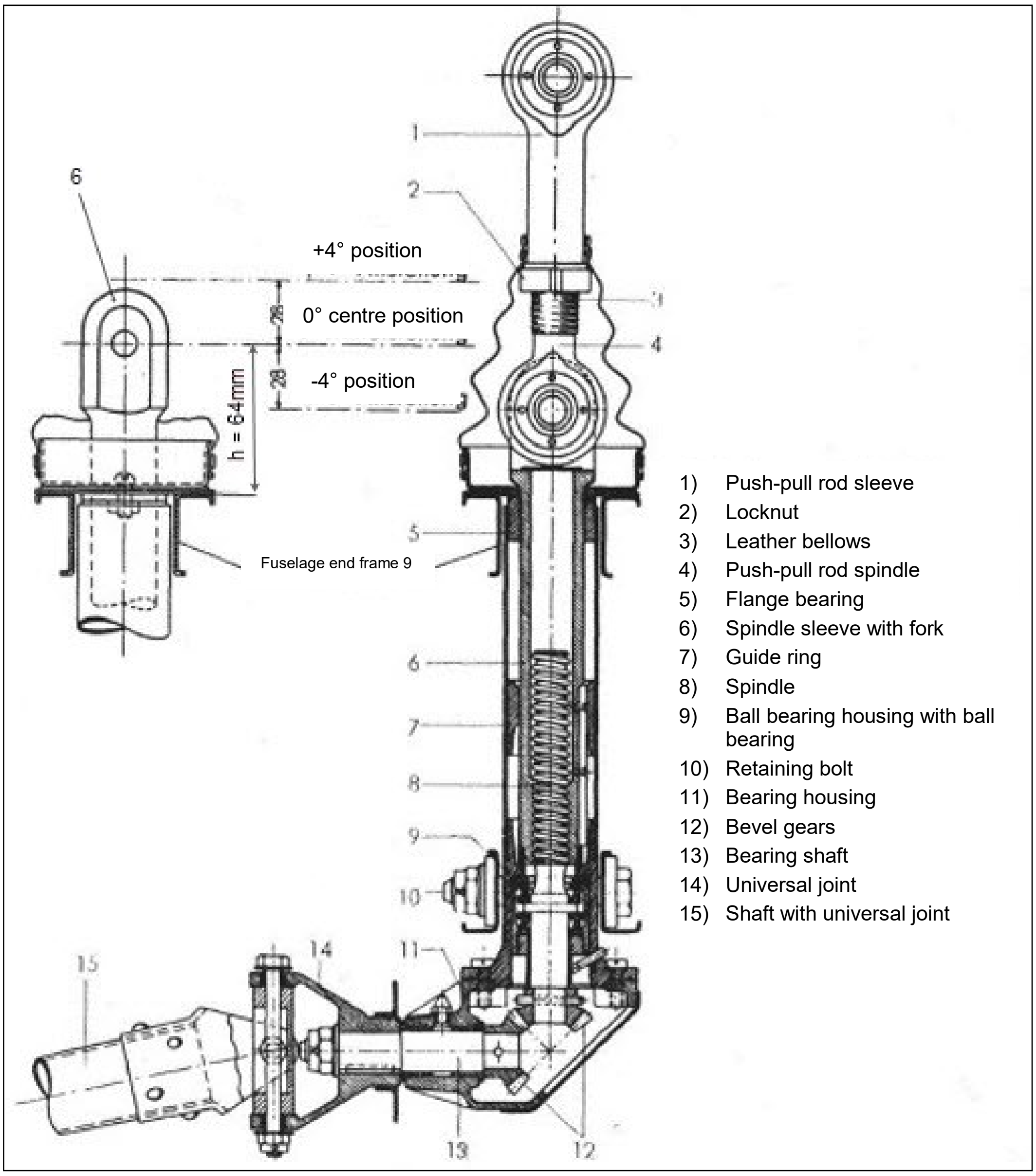


Figure 22: Dimensioned drawing for determining the horizontal stabiliser's angle. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

The adjustment spindle and the bevel gear were not damaged in the accident. In order to determine the condition and position of the horizontal stabiliser at the time of the accident, the adjustment spindle – including bevel gear – was first removed from the tail of the wreckage, measured and dismantled. A functional check was also carried out.

The detailed examination revealed the following:

- The assembly was in working order.
- No damage could be identified.
- No abnormal wear and tear was found.
- The axial play of the spindle was 0.2 mm.

The measured distance between the hole in the spindle sleeve's fork and the fuselage frame 9 (h = 56.53 mm) equates to an angle of -1.03 degrees for the horizontal stabiliser. Since the indicator in the cockpit for the horizontal stabiliser's angle setting was destroyed in the accident, no displayed value for the position of the stabiliser could be determined.

The horizontal-stabiliser position of approximately + 1½ degrees determined at the aft fuselage was approximately 2½ degrees greater than that calculated based on the spindle sleeve measurement.

During repairs to the elevators and ailerons on 11 March 2003, various work was also carried out on the horizontal-stabiliser adjustment spindle, which was removed and reinstalled in the process. The question of whether any misadjustments were made during this work remains open. No misadjustments were found during the last progressive inspection.

Since the tech logs did not contain any complaints regarding the functionality of the horizontal-stabiliser trim during the last months prior to the accident, it can be concluded that the misadjustment of the horizontal-stabiliser adjustment spindle did not lead to any restrictions in flight.

A1.12.3.6 Findings on the engine frames

The frames of the three engines were severely damaged in the accident and were torn off from the corresponding wing and fuselage connection frames where they had been attached. All three engine frames were plastically deformed upon impact and broke up into several pieces.

An initial visual assessment of the engine frames revealed the following findings:

- The fractures as well as the type of plastic deformations were not consistent in all three of the engine mounts.
- The material thickness of the engine mount for the right engine was different to that of the other engine mounts.
- The surface structure of the three engine mounts was different.
- All three engine frames exhibited several areas that had been repaired (see figure 23).
- Parts of the engine frames were painted differently.

All three engine mounts were then subjected to metallurgical examinations in the laboratory (see annex A1.16).

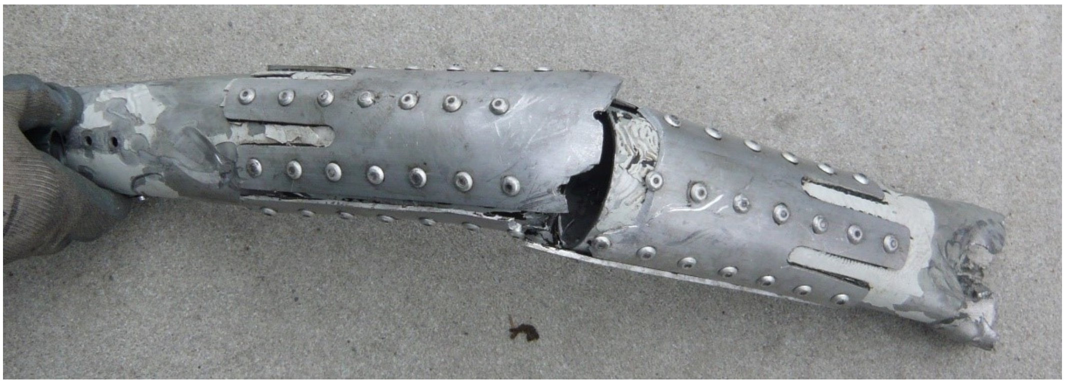


Figure 23: Tubular strut from the centre engine frame repaired with a doubler (see annex A1.6).

A1.12.3.7 Findings on the engines

A1.12.3.7.1 General

Prior to the investigation, the engines were cleaned whilst still assembled using dry-ice blasting (see figure 24). The advantage of this minimally abrasive and non-corrosive process is the low amount of damage to the material being cleaned.

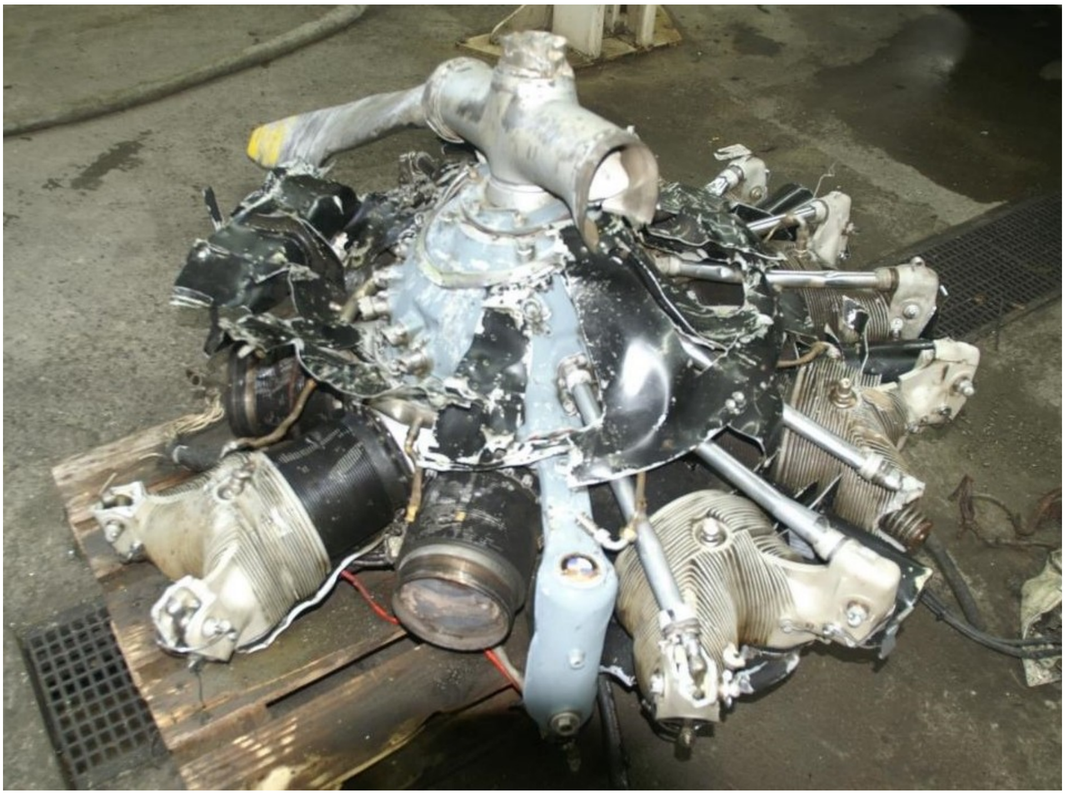


Figure 24: Engine cleaned using dry-ice blasting.

Due to the high degree of damage, dismantling some parts of the engines was difficult. Nevertheless, their condition before the accident could still be assessed. However, it was not possible to check the function of the magnetos from any of the engines as they had been destroyed.

In several cases, nylon locknuts had been used (see figure 25) instead of the castellated nuts with locking-pin retention as per the aircraft's original design. Firstly, the bolt threads were too short to use this kind of nut as the thread does not engage sufficiently with the nylon insert. Secondly, the use of nylon locknuts is not permitted on engine parts that see an increase in temperature. For the castellated nuts fitted, wire had been used instead of locking pins. This method of securing the nut is not standard in the aviation industry.

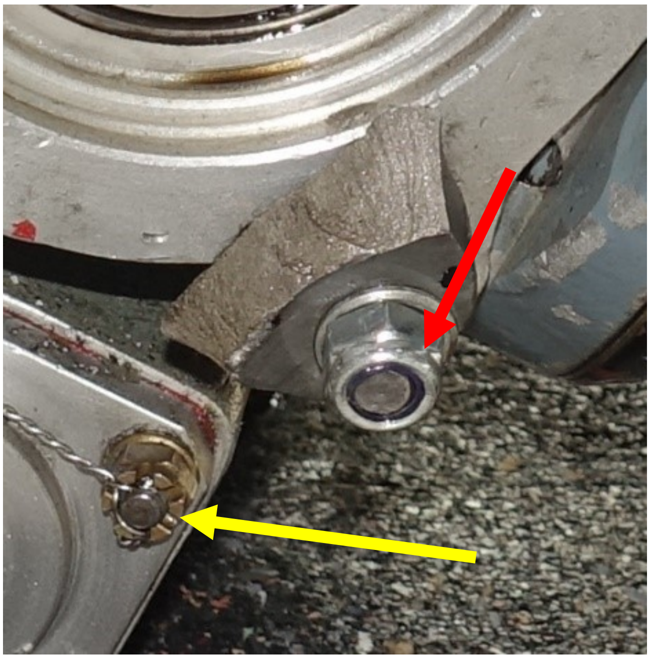


Figure 25: Engine housing – a nylon locknut (red arrow) on a bolt with a thread that is too short, and a castellated nut secured by wire (yellow arrow).

A1.12.3.7.2 Pistons and cylinders

All three engines were dismantled and generally revealed a similar picture. Burn residue was prominent on the pistons and in the cylinders' combustion chambers (see figure 26).

Figure 26: Pistons in cylinder positions 1, 2 and 3 in the right engine.

The condition of the cylinder bores was first assessed visually. In a large number of the cylinders, fine surface cracks distributed in a net-like pattern were visible in the bores. On some cylinders, the bores had a red discolouration. Subsequently, three cylinders were subjected to metallurgical investigations (see annex A1.16).

A1.12.3.7.3 Cam discs

The cam discs are part of the cam drum. On the running surfaces of the cam discs from the centre and the right engines – which had been manufactured according to service bulletin no. 1028 by a company not certified to provide parts for use in aviation – clearly visible machining marks were found (see figure 27). The quality of the surfaces was poor. In several places, the running surfaces of the cam discs for the exhaust and intake valves had broken away.

Figure 27: Cam discs from the centre engine – the machining marks (regular, finely grooved surface) and the chipping on the upper running surface are clearly visible.

The quality of the running surfaces on the cam discs from the left engine was much better than that of the discs from the other two engines. No chipping could be identified on the cam discs from the left engine. This cam drum came from one of a total of three engines that Ju-Air had purchased from the collection of a German historic-aircraft enthusiast and restorer at an earlier date. According to Ju-Air, this was an original cam drum.

The cam discs of the three engines were measured on a measuring machine and the height of the four intake and exhaust cams was determined in relation to the cylindrical part of each disc. Taking into account a valve clearance of 0.25 mm, the tappet stroke and the opening stroke of the valve could be determined.

There were significant differences in the tappet strokes of all three engines' cam discs – this applied for both the exhaust and intake valves. The differences were up to 12% for the left engine's cam discs, up to 4% for the centre engine's cam discs and up to 10% for the right engine's cam discs. This had an unfavourable effect on engine power.

A1.12.3.8 Findings on the bearings

A1.12.3.8.1 General

The specifications of the original bearings were not known. In order to compensate for the different dimensions of the bearings that had been procured over the years, spacers and bushings had been manufactured. This does not make any sense from a technical viewpoint and is not permitted.

The bearings installed were standard spare parts used in general mechanical engineering and, according to Ju-Air, had been selected in collaboration with the various manufacturers based on their conformity with specifications for their particular area of use. In 2017, a supplier wrote the following note on the invoice for supplying several types of bearing: "*Warranty only for the delivered product, not for the application!*"

A1.12.3.8.2 Propeller bearings

The engine's single-pin crankshaft has three bearings. Either side of the crank webs features a roller bearing, while a ball bearing – referred to as the propeller bearing – positioned directly behind the propeller hub is subjected to both propeller thrust and radial loads.

The engines were fitted with propeller bearings that did not correspond to the designation stated in the approved service bulletin (SB) no. 1007 (see table 1).

	Bearings found		
Designation according to service bulletin no. 1007	Left engine	Centre engine	Right engine
43M-6218/P6	FAG 6218ZR	FAG 6218ZR	FAG 6218 USA

Table 1: Overview of the propeller bearings.

After dismantling the engines, the propeller bearings were visually inspected and were found to be worn and corroded. A crack was found on the outer race of the propeller bearing from the centre engine before disassembly. After disassembling the engine, it became apparent that the outer race was broken into two pieces (see figure 28). When comparing bearings from the left and the right engines, it was evident that the bearing used in the centre engine had eleven balls, but the ball bearings from the other two engines only had ten. All three bearings were subjected to metallurgical investigations (see annex A1.16). These investigations revealed that there was a high risk of failure for these bearings.

Figure 28: Broken outer race of the propeller bearing from the centre engine.

A1.12.3.8.3 Supercharger bearings

The bearings installed in the superchargers were of different origins and were also marked differently. None of the supercharger bearings were broken. Bearings number 3, 4 and 5 (see figure 29) of the high-speed supercharger shaft from the left engine were subjected to metallurgical investigations (see annex A1.16).

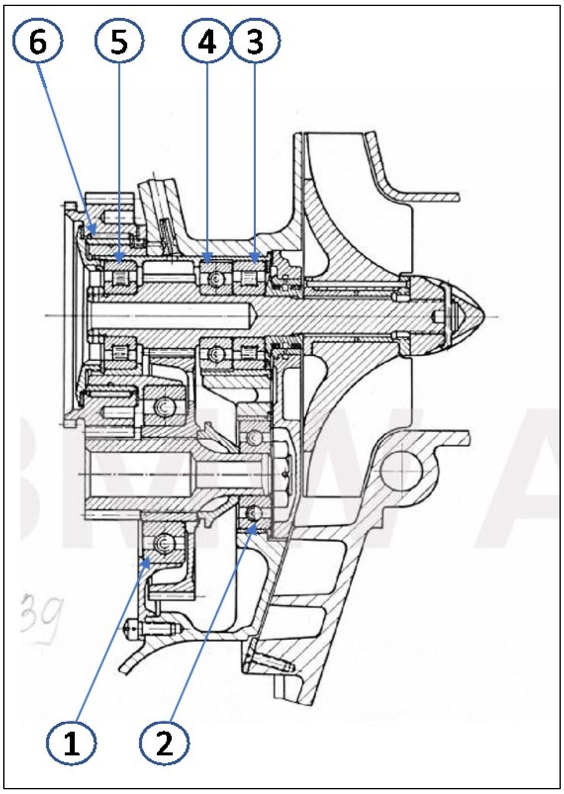


Figure 29: Cross-sectional diagram of the supercharger with bearing nos 3, 4 and 5 on the supercharger shaft. Source: BMW 132-A3 engine operating instructions.

The bearings used in the supercharger had different speed ratings, but none of the three supercharger-shaft bearings met the necessary specifications for speeds of up to 20,500 rpm, which the shaft can be subjected to when running.

None of the bearings in the supercharger corresponded to the designation according to the approved service bulletin no. 1015 (see annex A1.6).

			Bearings found		
Pos.	Description	Designation according to service bulleting	Left engine	Centre engine	Right engine
1	Deep-groove ball bearing for the counter gear	SKF 6209	FAG X.HB 6209	FAG 6209	FAG6209 Korea
2	Deep-groove ball bearing for supercharger shaft	FAG 6304	FAG Y.HB 6304	FAG 6304 Z.HB	FAG 6304 Korea
3	Roller bearing for supercharger shaft	FAG N304 EM1 C3 F96	746011	NM-20 FJG Germany	SKF HE NM20 Germany
4	Deep-groove ball bearing for supercharger shaft	FAG 6304	FAG Y.HB 6?04	FAG 6304 Z.HB	FAG 6304 Korea
5	Roller bearing for supercharger shaft	FAG N304 EM1 C3 F96	FAG 593670 Germany	NM-20 FJG Germany	SKF 198031 Germany
6	Needle rollers for supercharger counter gear	INA NRA 3 x 19.8:	No marking	No marking	No marking

Table 2: Overview of the supercharger bearings.

A1.12.3.9 Fuel systems

A1.12.3.9.1 Lines

The fuel and oil lines were up to 30 years old and in some cases showed considerable signs of decay due to age (see figures 30 and 31).

Figure 30: Lines show obvious signs of decay due to age.

Figure 31: Hardened fuel line dated 11 November 1988.

A1.12.3.9.2 Electric fuel pumps

The electric fuel pumps had not been in operation for several years. The fuel therefore did not flow through the pump body but through the bypass. Both pumps were found to have solidified grease in them after dismantling and defective seals due to their age (see figure 32).

Figure 32: Electric fuel pump gear.

A1.12.3.9.3 Fuel filter

Each outer wing was fitted with a fuel filter. However, following the accident, it was not possible to determine which one they had come from. While one set of filter elements was clean, the other set was found to be heavily contaminated (see figure 33). According to the technical files, these filters were last checked and cleaned on 19 June 2018, some 42 flight hours before the accident. The manufacturer's operating instructions stipulate that the filters must be checked every ten flight hours.

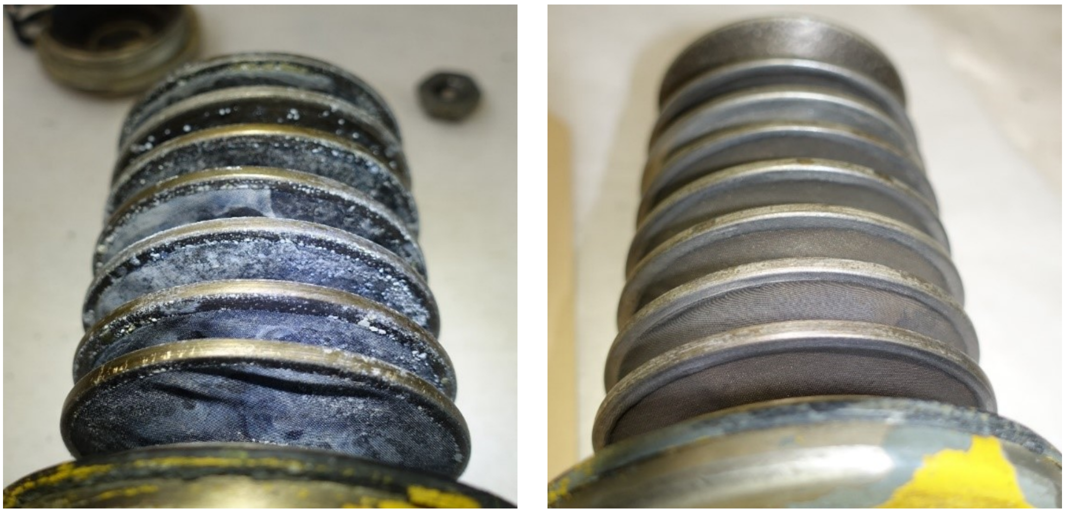


Figure 33: Fuel filter elements.

From the different condition of the two fuel filters and the fact that all tanks were filled with the same fuel, it can be concluded that the contamination did not originate from the fuel. The nature of the contamination in the one fuel filter indicates that deposits from one of the tank systems had led to the contamination.

There is no evidence to suggest that the contamination in the one fuel filter had any influence on the performance of the engine during the accident flight. However, there was a risk of restricted fuel supply.

A1.12.3.9.4 Oil filter

Each engine had an oil filter, which was fitted with a magnet in the housing cover (see figure 34). Loose pieces of red sealing compound were found in the oil filter element of the right engine. Metallic debris was found in all of the oil filters.

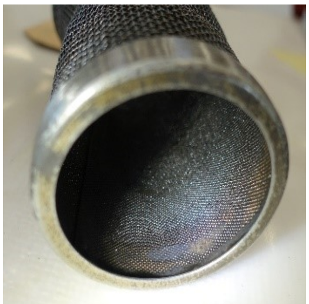
Left engine	Centre engine	Right engine
Oil filter		
		
Housing cover with magnet		
		

Figure 34: Oil filter and housing cover with magnet from all three engines.

A1.12.3.10 Findings on the propellers

A1.12.3.10.1 Propeller-blade pitch

Due to the high degree of damage, the pitch of the propeller blades could not be reproduced. Traces of a red marking could be seen on one propeller blade (see annex A1.6).

Upon removing the anti-corrosion paint, an adjustment scale became visible on the propeller hubs (see figure 35), which is intended to be used to adjust the pitch of the blades once they are installed on the aircraft. The maintenance team had no knowledge of this scale.

Figure 35: Adjustment scale on a propeller hub.

A1.12.3.10.2 Propeller blades

Blade 2 of the left propeller was still attached to the hub. All the other propeller blades had broken off at the root. The propeller blades all exhibit a similar degree of damage. The marks indicate that the three propellers were rotating on impact (see figures 36 to 38).

Propeller 1 (left)

Blade 1

Blade 2 – this blade was the only one still attached to its hub

The hub was cut open for examination purposes

Newly stamped different serial number on the hub (see annex A1.6)

Figure 36: Propeller 1 – blades and hub.

Propeller 2 (centre)

Blade 1

Blade 2

Hub

Serial number on the hub

Figure 37: Propeller 2 – blades and hub.

Propeller 3 (right)

Blade 1

Blade 2

Hub

Newly stamped different serial number on the hub (see annex A1.6)

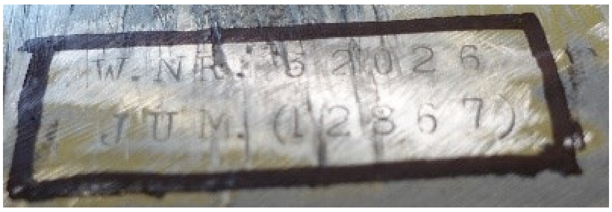


Figure 38: Propeller 3 – blades and hub.

A1.12.3.11 Findings on the airspeed indicator system

The pitot tube was severely damaged in the accident (see figure 39). Its functionality could no longer be assessed.

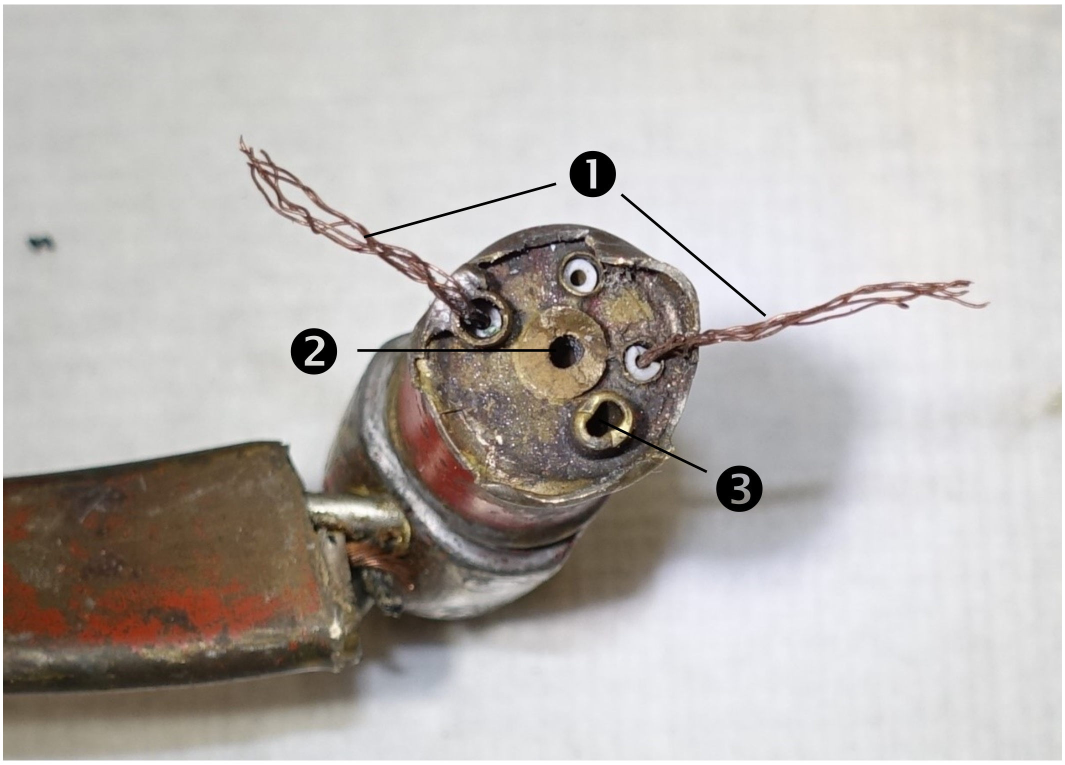


Figure 39: Severely damaged pitot tube. (1) Pitot tube heating element wires; (2) borehole for dynamic and static pressure; (3) borehole for static pressure.

A1.12.4 Luggage in the wreckage

36 pieces of luggage were recovered in the wreckage of HB-HOT – ranging from small handbags to large wheeled suitcases. It could be determined that 12 of these pieces of luggage (a total of 106 kg) had been stowed as ‘checked luggage’ in the rear underfloor storage compartment (see figure 40). Furthermore, it could be ascertained that a 15-kg wheeled suitcase, also ‘checked luggage’, had been stowed in the front rear-storage compartment during the flight (see figure 41). The remainder (around 40 kg of hand luggage) was spread across the passenger compartment and in the cockpit during the flight.

Figure 40: View of the HB-HOT wreckage – underside of the fuselage at the wing root, and luggage in the rear underfloor storage compartment.

Above – red box: Approximate section shown in the lower photo. 1: Wooden storage-compartment floor panel (removed for lower photo). 2: Wheeled suitcase (removed for lower photo).

Below – view into HB-HOT's rear underfloor storage compartment at the scene of the accident after removing the wooden storage-compartment floor panel. The corrugated panelling of the rear underfloor storage compartment had already been ejected during impact. Seven larger pieces of luggage can be identified in particular: six wheeled suitcases (grey, shiny royal blue, red, green, matt blue, black) and a travel bag (black with white print).

Figure 41: View into the fuselage structure below the toilet. A 15-kg dark-blue wheeled suitcase can be seen under a blue and white plastic bag and a brown woollen blanket. The wheeled suitcase ended up in this position after having moved from the front rear-storage compartment during impact.