Statens haverikommission
Swedish Accident Investigation Authority

Final report SHK 2023:03e

Accident at Örebro Airport, Örebro County, on 8 July 2021 involving the aeroplane SE-KKD of the model DHC-2 Mk III, privately operated in connection with parachute operations

File no. L-47/21

2023-01-30

SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on SHK´s web site: www.havkom.se

ISSN 1400-5719

This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.

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Content

General observations

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

Investigations of aviation incidents are governed mainly by Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation and by the Accident Investigation Act (1990:712). The investigation was carried out in accordance with Annex 13 of the Chicago Convention.

The investigation

SHK was informed on 8 July 2021 that an accident involving one aircraft with the registration SE-KKD had occurred at Örebro Airport, Örebro County, the same day at 19:21 hrs.

The accident has been investigated by SHK represented by Mrs. Jenny Ferm, Chairperson, Mr. Mats Trense, Investigator in Charge, Mr. Johan Nikolaou, Operational Investigator, Mr. Sakari Havbrandt, Technical Investigator until 1 April 2021, Mr. Tony Arvidsson, Technical Investigator and Mr. Tomas Ojala, Investigator Fire and Rescue Services.

Ms Nora Vallée from the Transportation Safety Board of Canada (TSB) participates as an accredited representative for Canada. She was assisted by advisor Mr Dennis Pollard from the type certificate holder Viking Air Limited and Mr Robert Duma as advisor from engine manufacturer Pratt & Whitney Canada Corp.

Mr Jason Aguilera from the National Transportation Safety Board (NTSB) was participating as an accredited representative from the USA. He was assisted by Mr Les Doud as an advisor to the propeller manufacturer Hartzell Propeller Inc.

Mr Anders Bjørn Kristensen from the AIBD was participating as an accredited representative from Denmark.

SHK was assisted by Magnic AB as an expert in sound and image analysis, Ms Liselotte Yregård as an expert in aviation medicine and Mr Kristoffer Danèl as an aeronautical expert.

Mr Helder Mendes participated as an adviser on behalf of the European Union Aviation Safety Agency (EASA).

Mr Magnus Axelsson has participated as adviser on the behalf of the Swedish Transport Agency.

The Swedish Transport Agency and the EASA participated in advisory capacities and have continuously been kept informed of the investigation.

The following organizations have been notified. The International Civil Aviation Organization (ICAO), EASA, the European Commission, NTSB, TSB and the Swedish Transport Agency.

Investigation material

Interviews have been conducted with e.g. the air traffic controller who was on duty, witnesses, representatives of the Swedish parachute association and parachute clubs, the instructor and examiner who was responsible for the pilot's training and several of the pilot's proficiency checks, as well as pilots who have experience of flying the aircraft type.

The accident site and the aircraft have been investigated. Technical investigations have been carried out on the relevant parts of the aircraft as well as relevant material that was on board.

The engine and propeller have been disassembled and inspected.

Registrations from a GPS, radar registrations from Swedish Air Navigation Services Provider (LFV) and the Swedish Armed Forces and sensor data from Flightradar24 have been analysed. Furthermore, sound recordings from the air traffic control and from a private film recording have been analysed.

Reference flights have been performed with the same aircraft type.

An information meeting was held for the relatives of the victims on 27 January 2022.

Two factual meetings were held on 16 and 17 of June 2022. At the meetings, SHK presented the factual background that was available at the time.

Final report SHK 2023:03e

Aircraft:	
Registration, type	SE-KKD, DHC-2
Model	De Havilland Canada DHC-2 Mk III
Class, Airworthiness	Normal, Certificate of Airworthiness and Valid Airworthiness Review Certificate (ARC)1
Serial number	1629 TB17
Owner/Holder	Kalle David Flyg AB/South Sweden Flight Academy AB
Time of occurrence	08/07/2021, 19:21 hrs in daylight Note: All times are given in Swedish daylight-saving time (UTC[2] + 2 hours)
Place	Örebro Airport, Örebro County, (position 69°13N 015°02E, 58 metres above mean sea level)
Type of flight	Private/parachute lift
Weather	According to METAR[3]: Wind 230˚/ 4 knots, visibility >10 kilometres, clouds few towering cumulus with base at 4,000 feet and scattered clouds at 8,500 feet, temperature/dewpoint +23/+14°C, QNH[4] 1021 hPa
Persons on board:	9
crew members	1
passengers	8
Injuries to persons	9 fatalities
Damage to aircraft	Destroyed
Other damage	None
The Pilot:	
Age, licence	63 years, PPL[5]
Total flying hours	1,049 hours, of which 556 hours on type
Flying hours previous 90 days	22 hours, of which 20 hours on type
Number of landings previous 90 days	61, of which 47 on type

[1] ARC – Airworthiness Review Certificate.
[2] UTC – Coordinated Universal Time.
[3] METAR – METeorological Aerodrome Report.
[4] QNH – Question Nil Height (The atmospheric pressure adjusted to the mean sea level).
[5] PPL – Private Pilot License.

SUMMARY

The intention of the flight was to drop eight parachutists from an altitude of 1,500 metres. It was the twelfth and planned to be the last flight of the day. The weather conditions were good. The parachutist bench to the right of the pilot had been replaced with a pilot's seat to distance the parachutists from the pilot as a Covid-19 precautionary measure. The pilot had no ability to perform a mass and balance calculation with the available information.

After take-off, the aircraft climbed to an altitude of 400 to 500 feet above ground before changing course 180 degrees to the left. The aircraft turned around quickly in a descending turn with a high bank angle. During the final phase, the aircraft dived steeply and then slightly levelled off before impact. Upon impact, the landing gear was teared off, after which the aircraft skidded on its belly 48 metres straight ahead and caught fire. All nine persons on board sustained fatal injuries.

SOS Alarm was alerted and a rescue operation was initiated.

No technical fault with the aircraft that may have affected the accident has been identified. Nothing has emerged from the medical examinations to indicate that the pilot's mental or physical condition was impaired before or during the flight.

The elevator trim was set in an abnormal position for take-off and the aircraft's mass and balance were outside the approved area. High stick forces and reduced longitudinal stability contributed to handling difficulties of the aircraft. In connection with retracting the wing flaps, control of the aircraft was probably lost. Due to the low altitude, control of the aircraft could not be regained.

In the investigation, several latent threats have been identified. The threats have emerged during a long period of time and several safety procedural drifts in the operation have resulted in a reduced safety margin. A proper risk analysis would probably have identified these latent threats. It may be questioned whether pilots operating flights in non-commercial parachute operations have been provided with adequate tools to perform such a risk analysis.

Overall, SHK is of the opinion that a formal training that leads to a special rating should be introduced for pilots who carry out flights in parachute operations.

Causes/Contributing Factors

Control of the aircraft was likely lost in connection with the wing flaps being retracted in a situation where the stick forces were high due to an abnormal elevator trim position, while the aircraft was unstable due to being tail-heavy and abnormally trimmed. Due to the low altitude, it was not possible to regain control of the aircraft.

The cause of the accident was that several safety slips occurred in the operation, which resulted in that the safety margin was too small for a safe flight.

SAFETY RECOMMENDATIONS

EASA is recommended to:

- Consider introducing formal training leading to a rating for pilots in parachute operations where the rating is maintained through refresher training (see Section 2.9 and 2.10). *(SHK 2023:03 R1)*

- Take measures to ensure that the oversight of non-commercial specialized aviation activities within parachute operations is conducted in such a way and to such an extent that it has an effect on compliance with the regulatory framework and thus has a safety-enhancing effect (see Section 2.11). *(SHK 2023:03 R2)*

The Swedish Transport Agency is recommended to:

- Within the framework regarding oversight of airports with the Basic Airport concept or equivalent, verify whether the airports have taken adequate measures to ensure that the response time of the airport's rescue services complies with regulations (see Section 2.12). *(SHK 2023:03 R3)*

- With support of SFF, take measures to ensure that appropriate risk assessment is carried out by pilots according to checklist and applied during flights in relation to parachute operations (see Section 2.9 and 2.10). *(SHK 2023:03 R4)*

The Swedish parachute association (SFF) is recommended to:

- In conjunction with the parachute clubs, take measures to ensure that mandatory information and training is received by all pilots (see Section 2.9 and 2.13). *(SHK 2023:03 R5)*

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Preconditions

The intention of the flight was to drop eight parachutists from an altitude of 1,500 metres. It was the twelfth and last flight of the day. Earlier that same day, the pilot had performed six parachute lifts from Örebro Airport alternately with another pilot. The flight prior to the accident flight was conducted by another pilot and it was followed by a ground stop.

Before the flight, the pilot received a printed load sheet in which the parachutists' weights were stated.

In the control tower at the airport, an air traffic controller was on duty.

The weather conditions were good with a light south-westerly wind.

1.1.2 Sequence of events

The pilot taxied from the general aviation part at the aero club via taxiway A for take-off from runway 19. After take-off, the aircraft climbed to an altitude of 400 to 500 feet above ground before changing course by 180 degrees to the left.

According to witnesses, the aircraft turned around quickly in a descending turn with a high bank angle. During the final phase, the aircraft dived steeply and then levelled off slightly before impact.

Upon impact, the landing gear was teared off, after which the aircraft skidded on its belly 48 metres straight ahead and caught fire. The flight lasted 46 seconds after the initiation of the take-off roll.

All nine persons on board sustained fatal injuries.

The accident occurred at position 59°13N 015°02E, 58 metres above sea level.

1.2 Injuries to persons

	Crew members	Passengers	Total on-board	Others
Fatal	1	8	9	-
Serious	-	-	0	-
Minor	-	-	0	Not applicable
None	-	-	0	Not applicable
Total	1	8	9	-

1.3 Damage to aircraft

Destroyed.

1.4 Other damage

None.

1.4.1 Environmental impact

Fuel and oil spills and combustion residues on the ground.

1.5 Personnel information

1.5.1 Pilot's qualifications

Pilot in command

The pilot in command was 63 years old and had a PPL with a valid rating on type and a valid medical certificate. He also had an Aerobatic rating.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	4	4	22	1049
Actual type	4	4	20	556

Number of landings on actual type the previous 90 days: 47.

Type rating

The pilot completed the training on the DHC2 SET[6]/SP[7] and received the rating after an approved Skill test on May 8 2006. The training documentation prove that the pilot attended a technical course and wrote a test on the type. The documentation also prove that all the required manoeuvres were performed during the training.

Proficiency checks

In order to maintain the proficiency on type, a proficiency check (PC) must be carried out every two years. The pilot performed his last PC on the type on May 30 2020, and the rating was valid until May 31 2022. In a previous proficiency check the following remark, among other things, was noted: *Use the checklist so that important items are not forgotten.*

[6] SET – Single Engine Turbine.
[7] SP – Single Pilot.

Mass and balance are included as an item in the Swedish Transport Agency's proficiency check form. It is not a mandatory item, which means that it does not need to be checked. According to the documentation of the pilot's last two proficiency checks, the pilot’s ability to perform a mass and balance calculation had not been checked.

The pilot's flights during the day of the accident

In the morning of the day before the accident the pilot flew to Örebro from Kristianstad. During the afternoon and evening the same day he subsequently carried out five flights with parachutists. The last landing was at 22:20.

On the day of the accident, the pilot performed the first take-off with parachutists at 09:31. The pilot then performed five lifts before the accident flight at 19:21.

1.5.2 Medical information about the pilot

The pilot had undergone annual heart examinations for some years due to previous episodes of atrial fibrillation. After treatment with medication of a preventive nature that began in 2017, no further episode has been documented.

The pilot had a valid class 2 medical certificate with no operational limitation. The last examination for the medical certificate was carried out in March 2021. According to medical expertise nothing has emerged to suggest that the pilot's state of health had deteriorated after the last medical examination. According to reports, the pilot was doing well and was physically active before the accident.

Shortly before the accident flight, the pilot had a conversation with another pilot who did not notice anything unusual with the pilot's condition and who perceived the pilot to be in a good mood.

During the forensic chemical examination, blood and hair samples were analysed for the presence of alcohol, medicines and drugs. The analyses regarding alcohol and drugs were negative. Presence of the medications that the pilot was medicated with could be proved.

1.6 Aircraft information

The aircraft was of the model De Havilland Canada DHC-2 Mk III (see Figures 1 and 2). The model is a high-wing aircraft and is powered by a turboprop engine. It is 10 metres long and has a wing span of just over 14 metres.

The aircraft was modified for parachuting, which i.e. means that there were no passenger seats in the cabin. There was room to accommodate ten parachutists and one pilot.

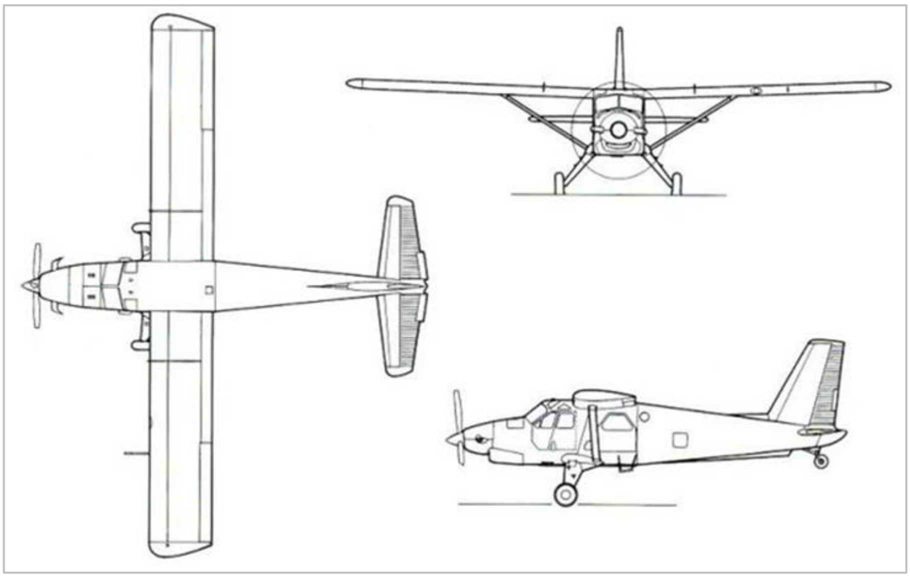


Figure 1. Three-plane sketch of the aircraft type DHC-2.

Figure 2. The aircraft before the accident. Image: Mikael Jacobsson

1.6.1 Airplane

TC-holder	Viking Air Limited
Model	DHC-2 Mk III
Serial number	1629 TB 17
Year of manufacture	1966
Gross mass, kg	Max. take-off 2 436, actual 2 524
Centre of gravity	Outside of the mass- and balance diagram.
Total flying time, hours	14 538
Flying time since latest inspection	56
Number of cycles	25 605
Type of fuel uplifted before the occurrence	Jet A1
Engine	
TC-holder	Pratt & Whitney Canada Corp.
Type	PWC PT6A-34
Serial number	RB0235
Operating time since overhaul, hours	783
Propeller	
TC-holder	Hartzell Propeller Inc.
Type	Hartzell HC-B3TN-3D/T10282N
Serial number	BUA26481
Operating time since inspection, hours	503
Hold Items	None

The aircraft had a Certificate of Airworthiness and a valid ARC[8].

1.6.2 Certification

The aircraft model is certified in accordance with the *"British Civil Airworthiness Requirements"* (BCAR) of June 1 1947, *"Information Circular T /4/58"* dated March 3 1948 and special conditions for single-engine turbine-powered aircraft in accordance with the Federal Aviation Administration (FAA) *"Civil Air Regulations"* (CAR) Part 3, dated March 1964.

The aircraft is certified in the "Normal" category which limits the model to normal flight including stall (except dynamic stall). The model is not approved for aerobatics including spins.

[8] ARC – Airworthiness review certificate.

During flight tests in 1964, prior to the certification according to CAR part 3, tests of the aircraft's stall characteristics were performed based on performance and handling requirements. The tests were performed at the aircraft's maximum take-off mass and at the forward and the aft centre of mass positions and with different engine power. In addition to the manufacturer's flight tests, the Canadian Department of Transport conducted its own flight tests. In the flight tests, an earlier version of the PT-6 engine was installed with a maximum power of 550 SHP (Shaft Horse Power).

SHK has reviewed the flight test reports for the aircraft type. The documentation shows that there was no clear buffeting during a stall with wing flaps configuration for take-off or landing (35 or 50 degrees). To meet the certification requirements, a stall warning system with a warning light was therefore installed on the instrument panel.

The documentation also shows that at a mass centre position behind the aft limit of the permitted mass centre position (36 % MAC[9]), there were tendencies for the aircraft to roll without nose-lowering movement. This emerged at a mass of 2,313kg (5,100lb) and an approximate mass centre position of 38 % MAC. The aircraft was flown during this flight test with flap configurations for cruise and climb (0 and 15 degrees) with engine power up to 450 SHP.

1.6.3 The engine

The aircraft was equipped with a model PT6A-34 turbine engine driving a propeller shaft via a reduction gearbox. Two major rotating assemblies compose the central units of the engine. One assembly consists of the compressor turbine and the compressor. The other assembly consists of the power turbine and the power turbine shaft. The engine installed had a maximum power of 680 SHP.

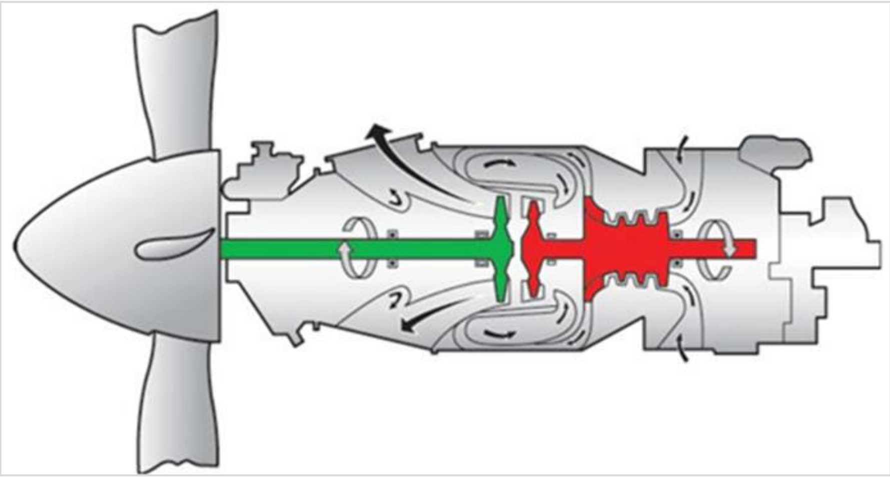


Figure 3. Simplified principle view of the turbine engine, model PT6A. The red part is the compressor turbine and compressor. The green part is the power turbine and the power turbine shaft. Image: Pratt & Whitney Canada Corp.

[9] MAC – Mean Aerodynamic Chord.

1.6.4 The propeller

The propeller that was installed on the aircraft was of the model HC-B3TN-3D and is a three-blade constant speed propeller. Single-acting hydraulics controls the blade angles with feathering and reversing capabilities. The blades are made of aluminium. Propeller rotation is clockwise as viewed in the direction of flight.

Blade-mounted counterweights and feathering springs actuates the blades towards the high blade pitch direction. The oil pressure from the propeller governor is used to move the blades towards low pitch angle.

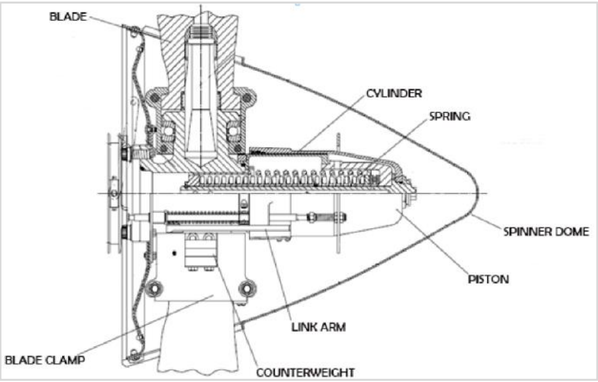


Figure 4. The propeller in a Cut away sketch. Image: Hartzell Propeller Inc.

1.6.5 Flight Controls

The aircraft model is equipped with a conventional flight control system. Ailerons, elevators and rudders are operated with a steering wheel and rudder pedals. Transfer of control movement to the control surfaces is by stainless steel cables and push-pull rods.

Longitudinal trim is provided by elevator trim tabs and yaw is maintained by a rudder trim tab. These are operated using trim wheels on the trim panel.

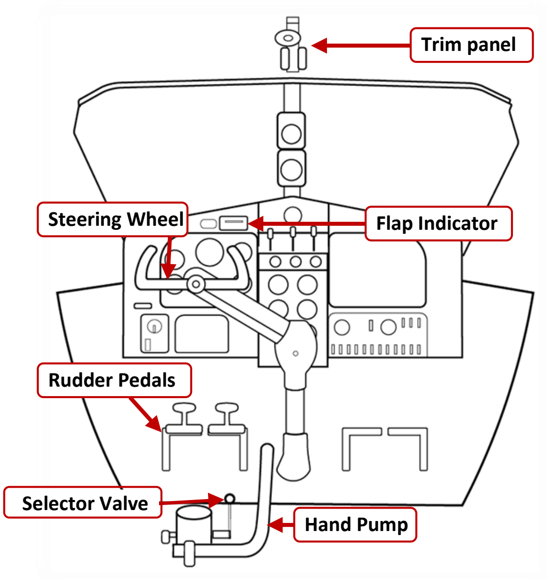


Figure 5. Cockpit layout.

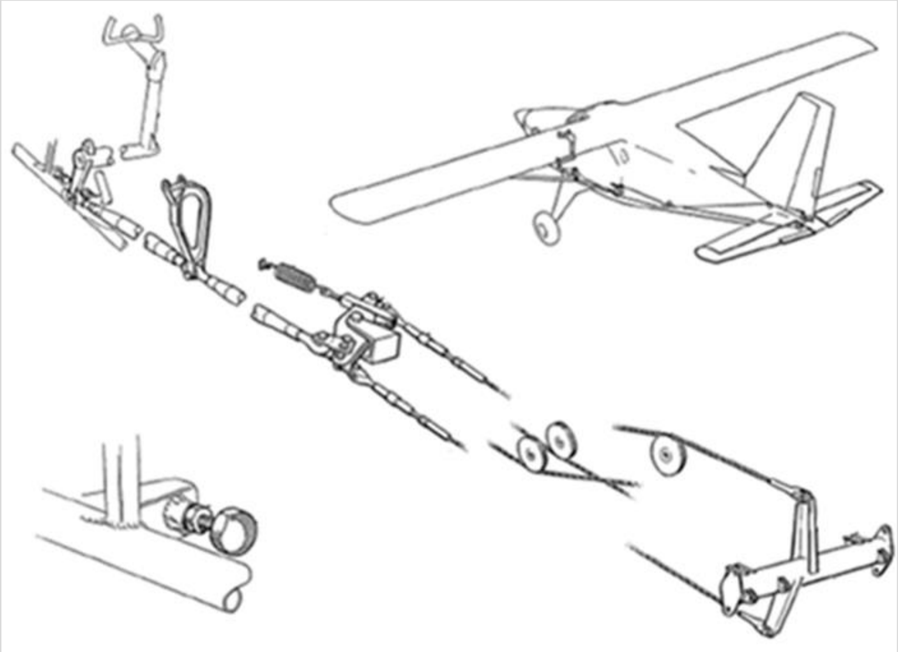


Figure 6. Principle sketch of the elevator control system. Drawing: Viking Air Limited.

The ailerons are differentially rigged to give a greater upward movement than downward. The ailerons droop approximately four degrees for every 15 degrees of flap extension. Maximum droop is 15 degrees with FULL FLAP setting.

Elevator trim system

In order to allow for a stabilised flight in different flight conditions such as different centre of gravity positions, flap positions or air speed, the pilot must keep the elevator in a specific position to meet the current condition. To reduce or eliminate the required stick force, there is a trim system.

Elevator trim is adjusted on the trim panel in the ceiling between the pilot's seats with either of two trim wheels (see Figure 7). A pointer, moving over a graduated scale marked NOSE UP, 0 and NOSE DOWN, indicates the direction and degree of trim applied.

Figure 7. The trim panel in the ceiling between the pilot's seats. The elevator trim is highlighted with a dashed red box. The pointer indicates 0.

Movements initiated at the trim panel is transmitted by the cables over pulleys to the screw jack drum, which is mounted on the fuselage rear bulkhead. Rotation of the cable drum extends or retracts the screw jack. The linkage, the torque tube and the push rods transmit the movement of the screw jack to the respective trim tab.

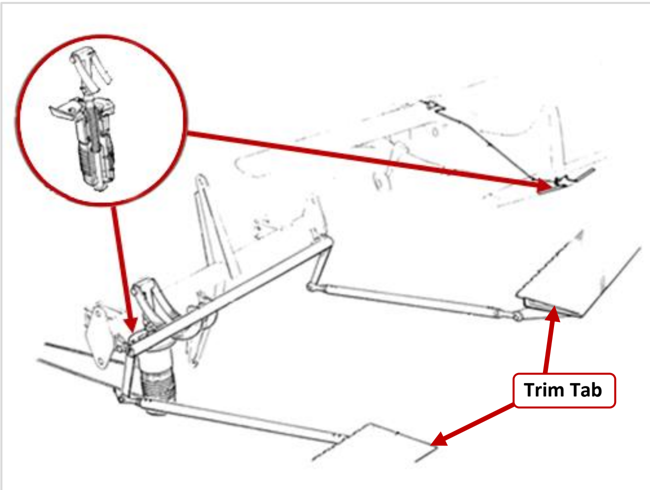


Figure 8. Principle sketch of the elevator trim system. Screw jack drum in detail circled, the arrows points to where the drum is installed in the aircraft. The markings are inserted by SHK. Picture: Viking Air Limited.

Wing Flap System

The wing flaps are of the slotted type and extend from each wing root to the inboard end of the ailerons.

The wing flaps are operated by means of a hydraulic hand pump, with integral selector valve and reservoir, which supplies fluid under pressure to a double-acting hydraulic actuating cylinder. The hand pump, located next to the pilot's seat, supplies fluid through pipes to a ratchet and thermal relief valves on the left cabin wall and then on to the actuating cylinder above the ratchet valve.

The actuating cylinder ram is connected to a lever near the left end of a torque tube, mounted across the cabin roof. A lever at each end of the torque tube transmits movement to the relative wing flap through a push-pull rod.

The wing flaps are retained in any intermediate position by ceasing to operate the hand pump. This action closes the ratchet valve and traps fluid in both the delivery and return lines thereby applying a hydraulic lock to the actuating cylinder. A thermal relief valve is installed below the ratchet valve to by-pass the ratchet valve in order to relieve excess pressure caused by expansion of the fluid during operation in hot climates.

In flight, the combined aerodynamic forces produce a nose-up moment when the wing flaps are extended, and a nose-lowering moment when the wing flaps are retracted.

Wing Flaps position indication

A wing flaps position indicator is located above the left instrument panel. The movement of the wing flaps moves the indicator. The motion is transmitted from the wing flap torque tube via a flexible cable to the wing flap position indicator.

The wing flap position indicator has five marked positions:

- Cruise 0 degrees
- Climb 15 degrees
- Take-off 35 degrees
- Landing 50 degrees
- Full 58 degrees

1.6.6 Fuel system

The aircraft has three fuselage tanks (forward, centre and aft) and two wing tip tanks. The fuselage tanks are located under the cabin floor. The centre tank consists of two compartments, the front compartment supplies the engine with fuel. The fuel is pressurized by electric feed pumps and filtered before delivery to the engine.

1.6.7 *Stall warning*

The stall[10] warning system consists of a movable detecting vane mounted on the leading edge of the left wing. The movement of the detecting vane activates a microswitch when the angle of attack is so high that the air begins to flow upwards from a point below the detecting vane.

When the microswitch is activated, the warning light marked "STALL WARNING", located above the flight instrument panel is illuminated.

According to the Flight Manual the stall speed at maximum take-off mass, take-off wing flaps and zero-degree bank angle is 55 knots with the following configuration: engine idle, propeller feathered and forward CG position.

1.6.8 *Emergency Locator Transmitter*

The aircraft was equipped with an Emergency Locator Transmitter (ELT) of the type Kannad 406 AF-Compact.

The ELT is activated automatically in case of heavy deceleration. It can also be activated manually with a switch on the instrument panel. Upon activation, a self-test is automatically performed that lasts approximately 15 seconds. During the self-test, three signals are sent on the emergency frequency 121.5 MHz and a short test signal on the satellite frequency 406 MHz. After that, another short test signal is sent on the satellite frequency. Thereafter the emergency transmitter continuously transmits alternately between the frequencies (see Figure 9).

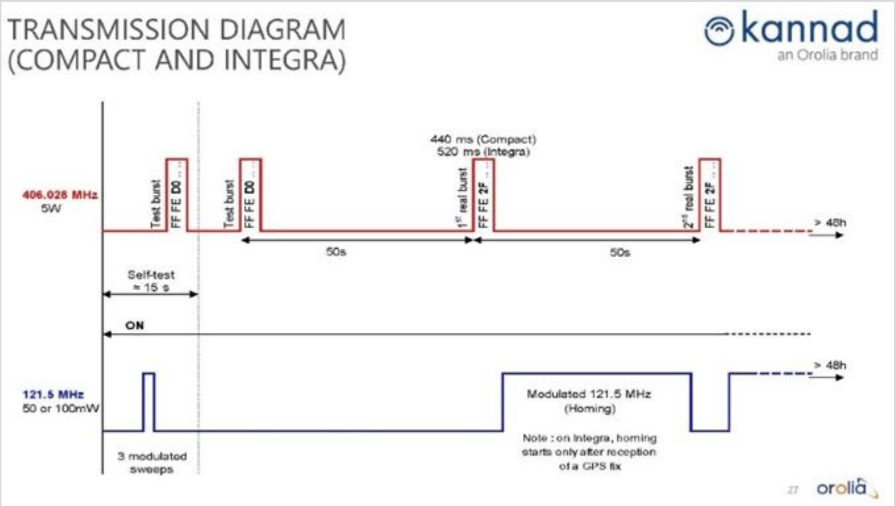


Figure 9. Activation diagram for Kannad 406 ELT.

According to the manufacturer, the purpose of the self-test is to avoid false alarms. The short initial emergency signal alerts the pilot that the ELT has been activated and gives the pilot the opportunity to switch the ELT off, e.g. after a hard landing.

[10] Stall – loss of lift due to that the angle of attack is so great that the air flow separates from the wing, (see section 1.18.6).

1.6.9 Manuals

There is an Aircraft Flight Manual (AFM) for the aircraft. The AFM describes limitations, normal operating procedures, emergency operating procedures and performance information.

Supplement

There were two supplements in the AFM. The supplement replaced the information in the AFM.

The first supplement referred to parachuting and was approved in 1992 by the national authority. The supplement was added to the AFM after the aircraft was fitted with a shutter door. It stated, among other things, that the cabin floor must be fitted with a carpet or similar to prevent jumping equipment from getting stuck in the seat brackets or similar, in addition to the pilot a maximum of ten parachutists may be carried and that parachutists with attached parachutes may be placed sitting on the floor without restraint systems.

The second supplement was added in 2005 after a new engine with more power was installed.

Mass and Balance

In the type certificate it states that the aircraft must have a mass and balance documentation that present the aircraft's basic empty mass and centre of gravity position, a load instruction and the aircraft's mass and balance manual (PSM1-2T-8).

The aircraft's mass and balance manual stated that a mass and balance calculation must be carried out before flight to ensure that the aircraft is within prescribed limitations. The AFM states the aircraft's centre of gravity limitations.

Checklists

To ensure that the aircraft was correctly configured before take-off, the AFM contained a Before Take-Off checklist to be performed by the pilot. The aircraft owner had produced his own checklists, with the aid of the AFM, in a format that could be easily read by the pilot. The checklist provided essentially the same information as the checklist in the AFM.

The checklist prepared by the aircraft owner included the following Before Take-Off actions:

- *TRIMS – SET*
- *FUEL TRANSFER – AS REQ*
- *CABINHEAT – MAX 3 NOTCHES*
- *BOOSTER PUMP – #1 ON (1+2 ON)*
- *IGNITION SWITCH – AUTO*
- *OIL TEMPERATURE – CHECKED*
- *SEATBELTS – LOCKED*
- *CLEARENCE – RECIVED*
- *T/O BRIEFING – GIVEN*
- *FLAPS – T/O*

LINING UP

- *LANDING LIGHT – ON*
- *TRANSPONDER – ALT*

ON RUNWAY

- *PROPELLER KNOB – SET*
- *GYROS – CHECKED*
- *PITOT HEAT – ON AS REQ*

When pilots were trained to fly the aircraft, they were instructed to use the checklist. They were also taught to perform memory items as a supplement to the checklist to ensure that the most critical items from the checklist were performed. The memory items were to be performed just prior to take-off after the before take-off checklist was performed.

The memory items before take-off were:

- TRIMS – adjust elevator and rudder trim
- FLAPS – set take-off wing flaps
- FUEL TRANSFER – check the fuel transfer selector
- CABIN HEAT – control cabin heat
- PROP – pre-set the propeller control RPM

During interviews, it has emerged that some pilots used the checklist on the first flight of the day and after a prolonged stop. For other flights, only memory items were used to replace the critical actions of the checklist.

Emergency Checklist

The aircraft was also equipped with an emergency checklist based on the checklist in the AFM.

1.6.10 *Balance diagram*

The airplane structural datum lies 17,5 inches aft of the wing leading edge and is indicated as horizontal arm 200 inches. To avoid mathematical errors when calculating the CG position, the datum Station 0 is located 200 inches in front of the structural reference datum.

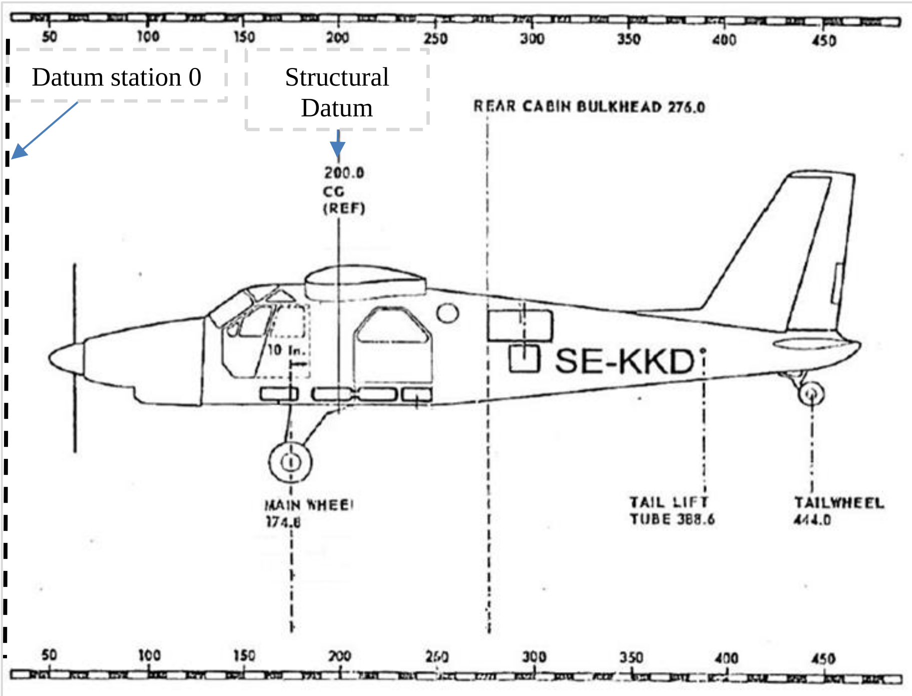


Figure 10. Balance Diagram. Horizontal arms given in inches. Markings are inserted by SHK. Image: Viking Air Limited.

1.6.11 *Weighing and Load instructions*

Weighing

The aircraft's first documented weighing record is from 1986. During the period until the next documented weighing, several changes were made to the aircraft. The engine was replaced with a new model, several hull repairs were carried out and a ballast was installed in the rear of the fuselage. Weighing records from the years 2010, 2013 and 2017 are documented and show that the position of the centre of gravity has moved backwards since the first weighing record. Mass and centre of gravity was similar at all three weighing's. At the 2013 weighing, the latest load instructions were established.

Load instructions

The load instruction was drawn up using the Swedish Transport Agency's then-current template (L1383c) and referred to aircrafts with more than four seats (see Figure 10). The instructions contain a fuel quantity table under point one. The person who creates the instructions must state how much fuel that can be carried, depending on the number of people on board and cargo loaded. Under point two, it must be described how the load must be placed to ensure that the position of the centre of gravity (CG) is within permissible limits.

When examining the load instruction, it has emerged that the fuel quantity table calculation has been based on the density for aviation fuel (Avgas). The density of jet kerosene (Jet A1), which was the type of fuel refuelled before the accident, is about nine percent higher than Avgas fuel. The difference in density varies somewhat depending on fuel type and temperature. The load instruction states that the pilot should place fuel in the aft body tank to avoid the aircraft becoming nose-heavy when the pilot is alone in the aircraft. Furthermore, it is stated that the wing tanks must be filled when flying at maximum take-off mass. No further description how the cargo would be placed is available. The description how the load should be placed has remained the same since 1989 when the first load instruction for the aircraft was drawn up.

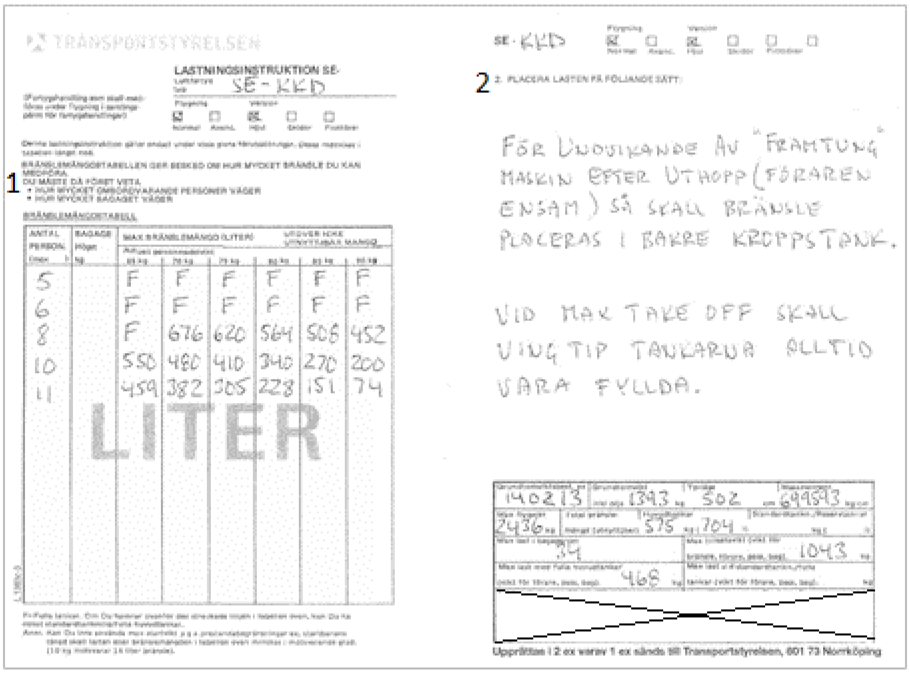


Figure 11. The picture shows the load instruction that applied to SE-KKD.

1.6.12 Cabin layout and parachutist loading

The parachutists were loaded from front to back. Typically, the aircraft was configured with a bench for two parachutists next to the pilot replacing the right pilot's seat. In the rear part of the cabin there was a bench with room for two parachutists. The remaining parachutists were placed on the cabin floor. The floor was covered with a carpet which provided some friction. Figure 12 shows how the aircraft was loaded with eight parachutists in the case when the front bench was mounted next to the pilot.

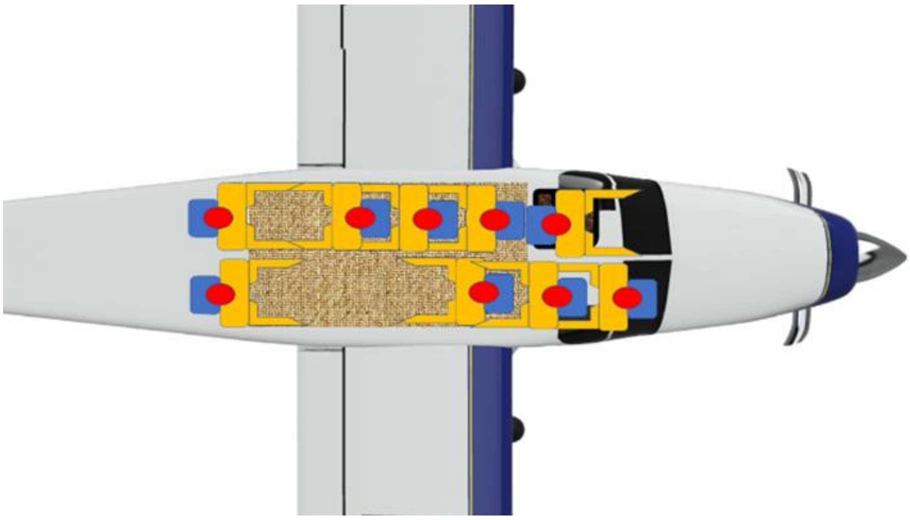


Figure 12. The aircraft loaded with eight parachutists and with the front bench mounted next to the pilot.

However, due to the Covid-19 pandemic, the right pilot seat was installed at the time of the accident. By having done so, the pilot intended to keep his distance from the parachutists. This resulted in that the parachutists who normally would have been placed on the front bench were now placed on the floor further back in the cabin (see Figure 13). Any risk analysis due to the change of loading has not been presented.

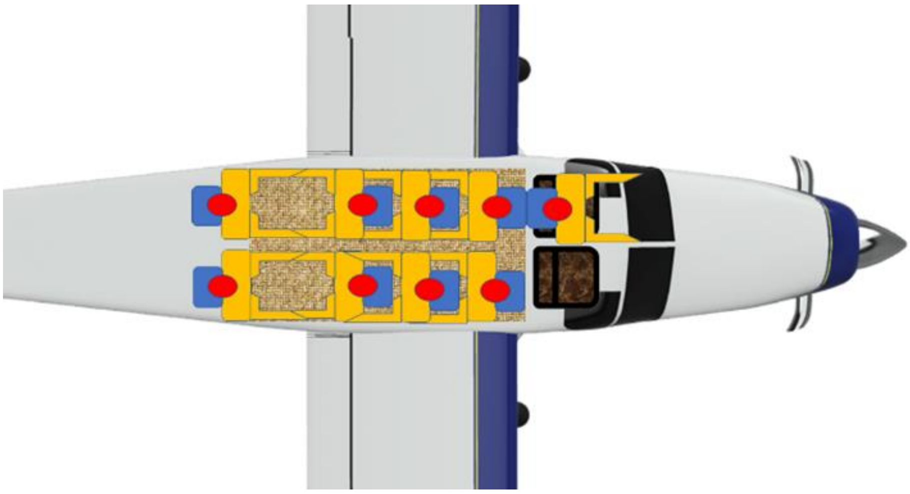


Figure 13. The aircraft loaded with eight parachutists with the right pilot seat installed.

There was no documentation describing in which positions in the cabin the individual parachutists were to be placed.

Örebro skydiving club, which at the time had leased the aircraft, used SkyWin as an administrative computer program to administer the parachuting operations. The program was used in order to produce a load manifest that was to be printed and handed to the pilot. The load manifest included, among other things, the weight of each individual parachutist including equipment as well as the total weight of all the parachutists. SkyWin did not have a balance calculation function and the load manifest did not indicate where the parachutists intended to sit.

1.7 Meteorological information

According to METAR at Örebro Airport 19:20: Wind 230 degrees 4 knots, visibility >10 km, few Towering Cumulus with a base of 4,000 feet and scattered clouds with a base of 8,500 feet, temperature/-dewpoint +23/+14°C, QNH 1021 hPa.

The winds in the altitude layers up to 600 feet, were from the southwest (230 degrees) and at a speed of at 4 to 10 knots.

The accident happened in daylight.

1.8 Aids to navigation

Not applicable.

1.9 Communications

Below is the radio communication that occurred from the time the pilot called the tower before the flight until the impact.

Time	Transmitter	Radiocommunication	Time from first call
19:17:32	SE-KKD	Örebro Tower SE-KKD (first call SE-KKD)	00:00
19:17:37	TWR	SE-KKD, Örebro Tower.	00:05
19:17:40	SE-KKD	Yes, then I have eight skydivers who want to go low lift as high as I get to the cloud base, I don't know exactly how high but if I can get them and they want to jump over the glider line. I stand on the tarmac and I'm ready.	00:08
19:17:59	TWR	KD, how many passengers onboard?	00:27
19:18:02	SE-KKD	There are nine of us on board, eight skydivers and me.	00:30
19:18:06	TWR	KD, line up runway 19, Alfa and backtrack, 220 degrees 4 knots and QNH 1021	00:34
19:18:15	SE-KKD	Lining up runway 19.......and back track... I dont need but... excuse me, I'll get back, here a taxiing aircraft in front of me I'll come back	00:43
19:18:30	TWR	Do so	00:58
19:18:32	S-JZ	Yes, KD we are holding at the side so that you can pass	01:00
19:18:36	SE-KKD	Thank you very much, KD	01:04
19:18:38	SE-KKD	Lining up runway 19, what was the QNH?	01:06
19:18:41	TWR	QNH 1021	01:09
19:18:43	SE-KKD	1021, thanks KD	01:11
19:18:46	TWR	KD, well clouds at 95 I think are the lowest are, but you are cleared up to FL100, transponder 5721 in the TMA	01:14
19:18:58	SE-KKD	27 öh, 5271, transponder and we will take as high as we can to the cloudbase, I'll get back about jumping	01:26
19:19:08	TWR	KD you are cleared upp to FL100 and transponder 5721	01:36
19:19:13	SE-KKD	Cleared to 100, transponder 5271 S-KD	01:41
19:19:18	TWR	KD 5721	01:46
19:19:20	SE-KKD	5721 sorry, KD	01:48
19:19:24	TWR	S5970, you have now left controlled airspaice, if you wich you can leave the frequency.	01:52
19:19:31	SWD5960	Thank you for your help S5971	01:59
19:19:40	TWR	S-KD initiate your climb south, I will call you when you can turn north again	02:08
19:19:45	SE-KKD	Initiate climb south S-KD	02:13
19:19:49	TWR	KD, runway 19 cleared for take-off	02:17
19:19:51	SE-KKD	Runway 19 cleared for take-off KD	02:19
19:20:12	TWR	S5960 the wind is 210 degrees 4 knots	02:40
19:20:18	S5960	Thanks S5960	02:46
19:21:09	Aircraft	Impact	03:37

Table 1. Transcription of the radio communication from the pilot's first call until impact.

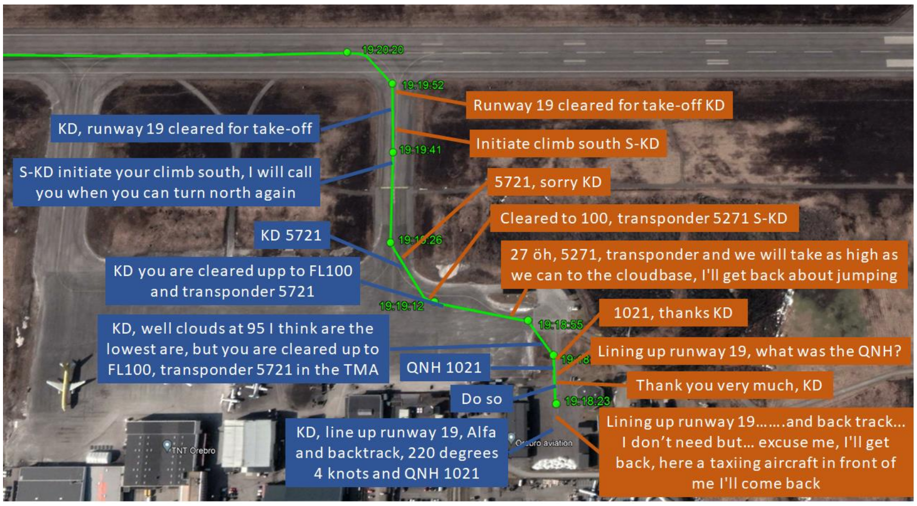


Figure 14. Picture of communication during taxi out to the runway. Blue boxes are transmission from tower and the orange boxes are transmission from the pilot. Picture: Google-Earth with text boxes inserted by SHK.

1.10 Aerodrome information

Örebro Airport (ESOE) is an approved instrument airport according to AIP[11] Sweden. The airport has a paved runway with the designations 01/19. At the time, runway 19 was in use. It is 3,270 metres long and 45 metres wide. The runway was dry.

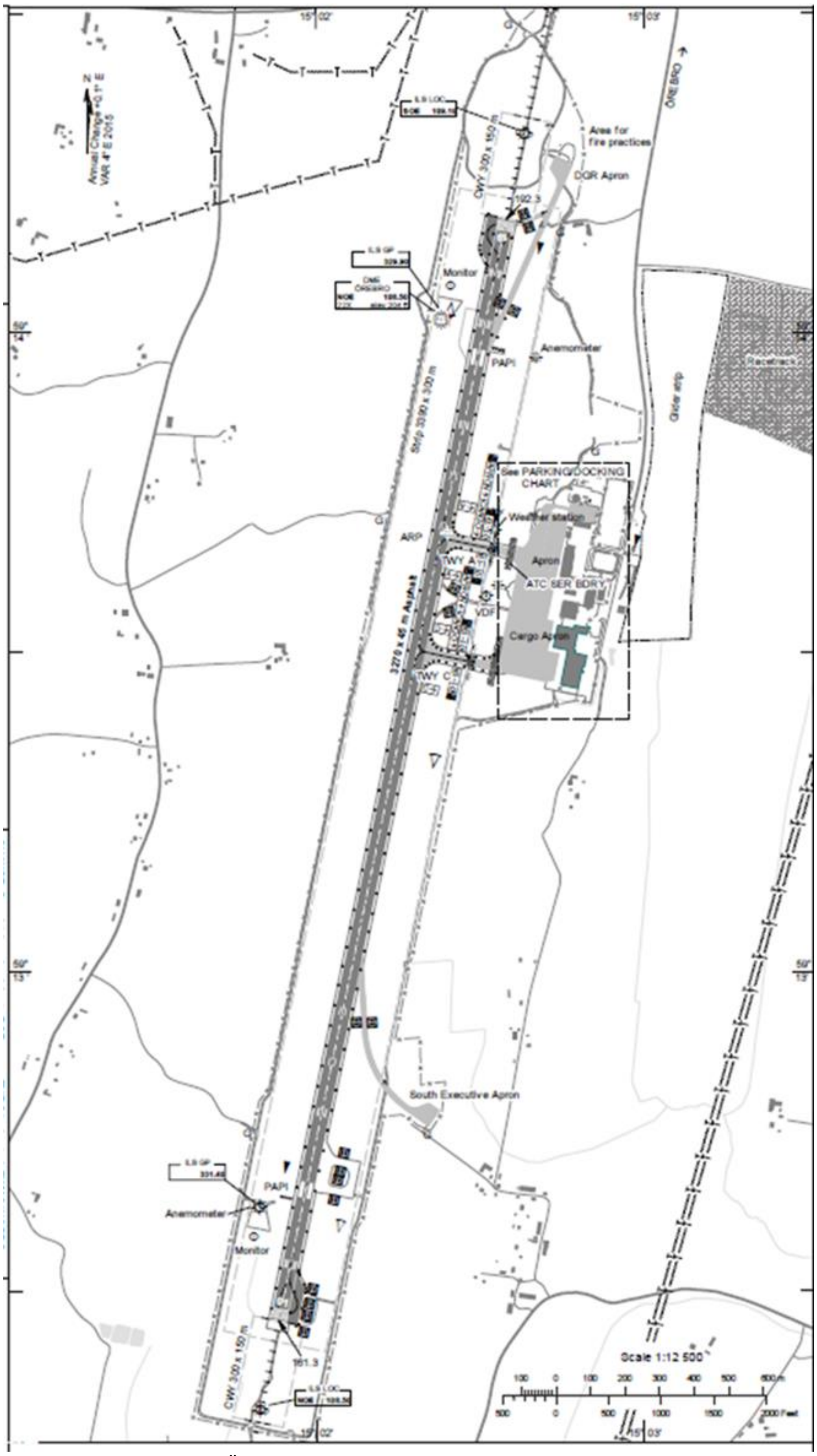


Figure 15. Overview of Örebro Airport, AIP Sweden. Image: © LFV

[11] AIP – Aeronautical Information Publication.

1.11 Flight recorders

There was no permanently installed flight or voice recorder in the aircraft. This was not required for the aircraft type.

SHK has obtained, read out, or attempted to read out, information from other sources or entities, which are presented below.

1.11.1 Recorded radar data from LFV – Air Navigation Services of Sweden

The aircraft's transponder provided the radar system with an identification signal and an altitude indication. The lateral position was calculated by the radar equipment based on the transponder's identification signal, while the altitude information was obtained directly from the aircraft's transponder.

1.11.2 ADS-B registrations from Flightradar24

The aircraft's transponder, equipped with an ADS-B function[12], calculated and recorded data from a built-in GPS receiver and a pressure sensor connected to the aircraft's static system. The data included lateral position indications, altitude information, speed, track, vertical speed and time indications for each registration. The transponder sent the data to two ground stations near Örebro Airport, which forwarded the information to Flightradar24.

1.11.3 Registrations from a GPS receiver

An independent Garmin GPSmap was mounted on the instrument panel in front of the pilot. The unit was damaged by fire and sent to the French aviation accident investigation board (Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, BEA) which assisted SHK in reading out information from the unit.

Registrations from all flights during July 8 could be retrieved from the non-volatile memory. The information consisted of lateral positions, GPS altitude information and time for each registration. All registrations are calculated based on information from the GPS system.

[12] ADS-B – Automatic Dependent Surveillance-Broadcast.

Figure 16 presents the vertical climb profile for all flights during July 8. The profile in purple illustrates the accident flight.

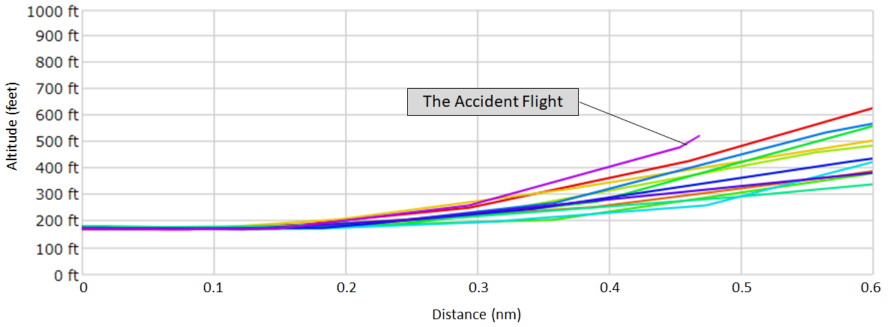


Figure 16. Vertical climb profile from all flights from the same day as the accident. The graph shows the climb profile until the aircraft changed course by 180 degrees to the left.

1.11.4 Compilation of Registrations

All position registrations are presented in Figure 17. Blue dots illustrate radar data, green triangles the ADS-B data and grey stars the GPS data. Altitudes given show the height above the airport reference point.

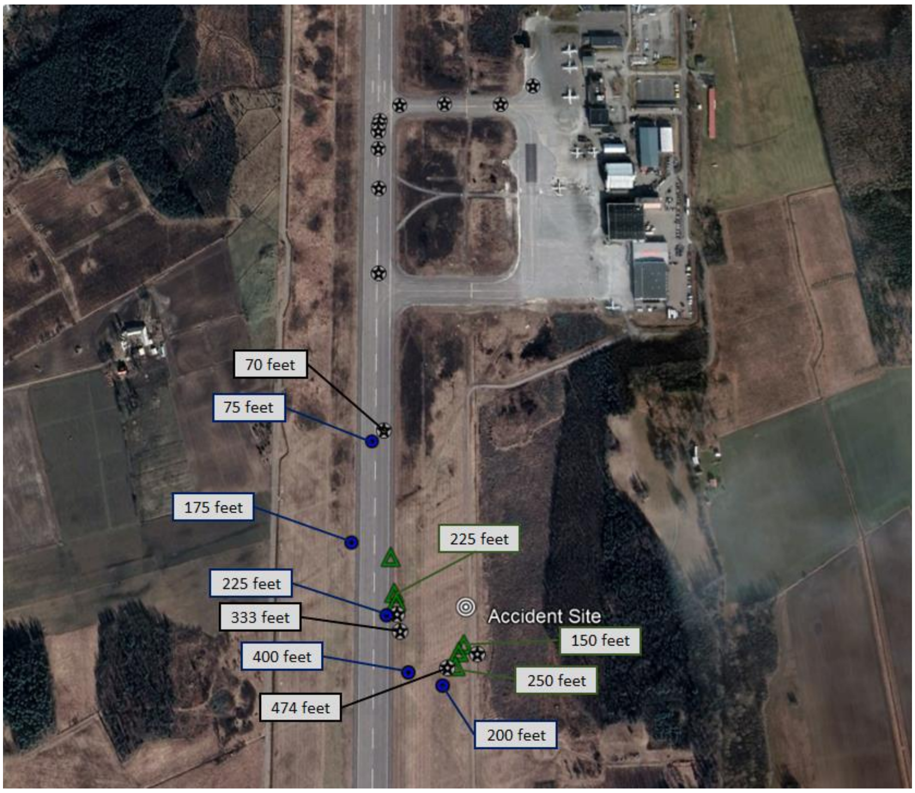


Figure 17. Markings inserted by SHK. Image: Google Earth.

1.11.5 *Sound recordings from the flight*

Sound recordings from the propeller have been obtained from two separate sources (see Figure 18).

A person filmed another object at the same time as the accident occurred. The person was located 1,370 metres south of the accident site.

The tower was equipped with an area microphone for sound recording within the tower.

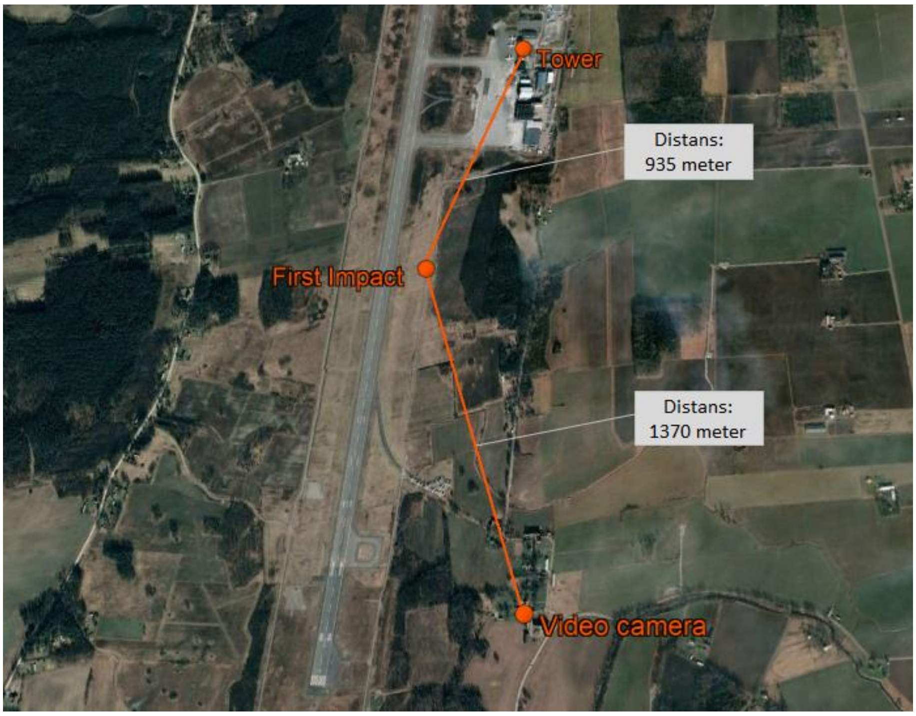


Figure 18. Audio recording positions. Image: Google Earth with markings inserted by SHK.

The sound recordings have been analysed and by using the frequency the propeller speed has been calculated. The sound recording from the tower is presented in a spectrogram where the frequency of the propeller sound can be read out (see Figure 19).

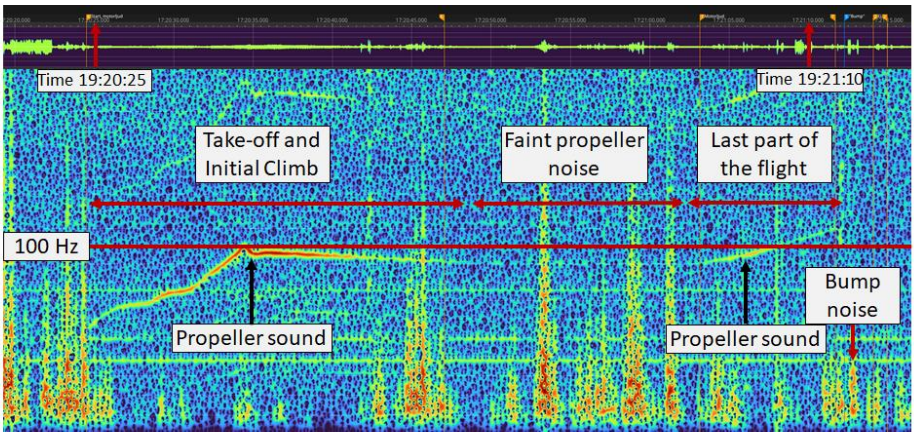


Figure 19. Spectrogram from the recording in the tower. Markings inserted by SHK.

The aircraft was fitted with a constant speed propeller. This means that the propeller speed is kept relatively constant even when the power is changed. However, there are short-term changes of the propeller speed (transients) during rapid changes of the power, which occurred at the end of the power setting during the start. This explains the short-term increase in frequency seen in Figure 19, just before the arrow "Propeller Sound". The increasing frequency in the final part of the flight as the aircraft turns towards the tower is due to the Doppler effect. When the frequency is corrected for the doppler effect and weighted with the frequency measured from the film south of the airport, there is no evidence of any large rpm changes, sudden changes in engine power, or other abnormal noise.

Analysis of the audio recording is presented in Figure 20. The points in the diagram are position indications based on data from Garmin GPS and Flightradar24. The audio recordings at each position are an average of the propeller RPM from the tower and film audio recordings, corrected for the Doppler effect[13].

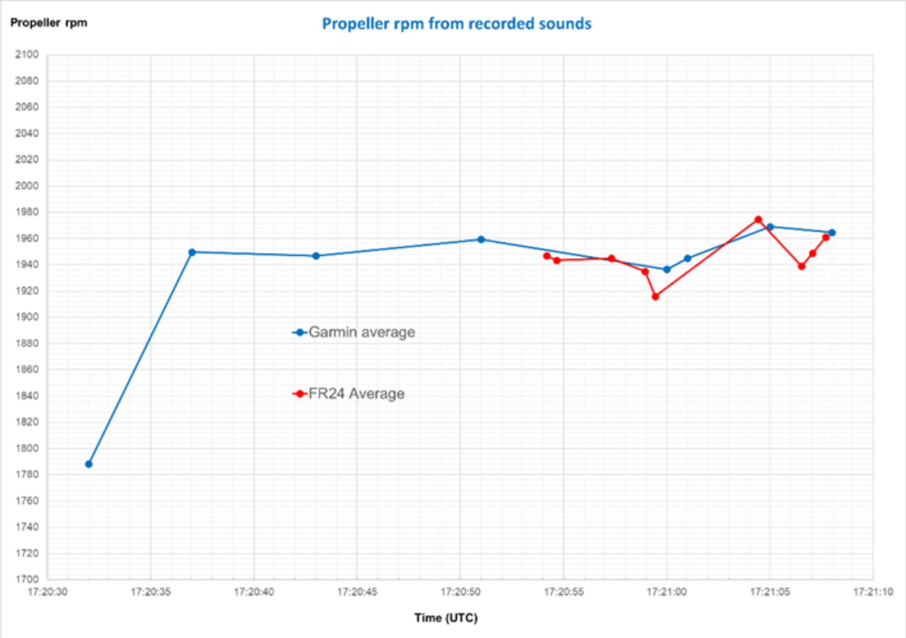


Figure 20. Mean propeller RPM corrected for the Doppler effect.

[13] Doppler – physical phenomenon, which means that the frequency of a signal, such as sound waves, is perceived differently depending on whether the source is approaching or moving away in relation to the observer.

1.11.6 Footage from surveillance cameras at the airport

There were two cameras at the airport that recorded the aircraft during taxi out before take-off. One camera was located at the refuelling facility and pointed south and the other camera was located at the terminal and pointed west. The pictures show that the wing flaps was retracted and the elevator trim was in an abnormal position for take-off.

Figure 21. Image from surveillance footage from a camera located at the refuelling facility. Image: Örebro Airport.

Figure 22. Image from surveillance footage from a camera located at the airport's terminal. Image: Örebro Airport.

1.11.7 Examination of the parachutist's registration equipment

The altimeters and acoustic altimeters and automatic triggers (cypresses) that were found on board have been analysed. No information was available on any of the devices.

1.11.8 Examination of mobile phones

The pilot’s phone has been analysed, but no information relevant to the investigation has been found.

1.11.9 Examination of the Pilot watch

The pilot wore a Garmin D2 AIR watch which has the ability to record flight data. The information contained in the watch could not be retrieved.

1.11.10 Examination of GoPro cameras

Two cameras were found at the accident site. One was in good condition, but contained no information. The other was damaged by the fire and sent to BEA for an attempt to read out information. No information related to the accident was found.

1.12 Accident site and aircraft wreckage

1.12.1 Accident site

The final position of the aircraft was next to a road within the fenced area to the east of the runway, 142 metres from the centre line and 1,540 metres from the end of runway 19.

Figure 23. The impact site marked with a red circle and the aircraft's final position.

1.12.2 Aircraft wreckage

At impact, parts of the aircraft separated, such as the propeller, right wing and left main landing gear along the 48 metres that the aircraft skidded.

Figure 24. The aircraft at the accident site.

The right wing detached from the aircraft at impact and ended up 20 metres in front of the aircraft. Two propeller blades separated from the hub and the propeller hub detached from the engine gearbox.

The cabin had been exposed to fire.

When examining the accident site and the aircraft wreckage, no traces of collision with birds or other objects could be identified.

1.12.3 Elevator Trim Position

The trim panel and elevator trim tab were found in a position as seen in Figure 25 below.

Figure 25. The left picture shows the trim panel where the arrow points to the set position of the elevator trim. The right picture shows the corresponding position on the right elevator trim tab.

1.12.4 Flap Position

During the investigation of the accident site, the wing flap were found to be in the extended position.

Figure 26. The left-wing flap marked with a red circle.

1.13 Medical and pathological information

The forensic examination states that eight of those on board died of injuries from the impact. One of the occupants died from the injuries from the fire and the impact. The injuries did not allow for any possibility of survival.

1.14 Fire

Fire broke out during the impact. The fire was extinguished by the rescue and firefighting service.

1.15 Survival aspects

1.15.1 Rescue operation

The airport rescue service, Nerikes Fire Brigade (municipal rescue service), police and ambulance participated in the rescue operation. JRCC[14] was alerted but the state air rescue service did not need to be activated as the crash site was known.

Alarm from the Air Traffic Controller

After the pilot received clearance for take-off, the air traffic controller registered that the aircraft took off. The air traffic controller did not follow the aircraft's departure visually because other air traffic needed to be monitored on the radar. Moments after the aircraft had started, a short signal sounded in the air traffic control tower. The air traffic controller took no action because the signal did not continue. When the air traffic controller looked out towards the runway, the aircraft with the parachutists could not be seen from the tower nor on the radar. The air traffic controller then called the aircraft three times on the radio with no response. The air traffic controller saw smoke from a place next to the runway and thought it might be dust from a car on the adjacent gravel road.

The aircraft's emergency transmitter was automatically activated at the time of the accident (see section 1.6.8). When the constant distress signal from the ELT was heard in the air traffic control tower, the air traffic controller realized that an accident had occurred. The air traffic controller then alerted the airport's rescue team through a radio call and activated the emergency alarm. The activation starts an alarm signal that sounds at the airport and alert SOS Alarm to call the air traffic control tower.

Alarm from the technician

A technician working on a cargo plane outside a hangar in the southern part of the apron watched as the plane started to take-off. The technician then continued working, but looked up when he perceived an abnormal engine noise and then saw the aircraft dive towards the ground. The aircraft disappeared out of sight and a loud bang was heard. The technician started running towards the scene of the accident and at the same time called 112.

SOS Alarm answered the call from the technician and shortly after that the alert from the airport came. The air traffic control tower and JRCC was called and include in the conversation. SOS Alarm alerted Nerikes Fire Department along with several ambulances and informed the police. Since the accident site was known, the rescue resources could be sent directly to the scene. An ambulance helicopter was alerted and the JRCC also alerted the SAR helicopter. However, the helicopters could be recalled before they arrived.

[14] JRCC – Joint Rescue Coordination Centre.

The rescue operation

When the technician ran towards the crash site, he saw that the aircraft was on fire. The fire increased while the technician ran towards the scene of the accident and when he arrived the fire was intense. No person could be seen outside the aircraft. It was neither possible to try to rescue anyone from the aircraft due to the intense fire. The technician arrived at the aircraft about a minute before the airport rescue team arrived.

When the air traffic controller called the airport's rescue team, they were in a lounge about 250 metres from the fire station. Immediately after the call, the four-man force drove a car to the fire station, put on emergency clothing and drove the fire truck out to the runway. They drove along the runway and turned onto the runway safety area towards the aircraft.

In Figure 27 below, the accident site is marked with a red triangle. A red circle points out where the rescue team was at the time of the alarm. The rescue team's drive from the lounge to the fire station is presented with a dashed line. The route from the fire station to the scene of the accident is presented with a solid line. The dotted line indicates the path that the technician ran to the accident site via. The specified times have been verified.

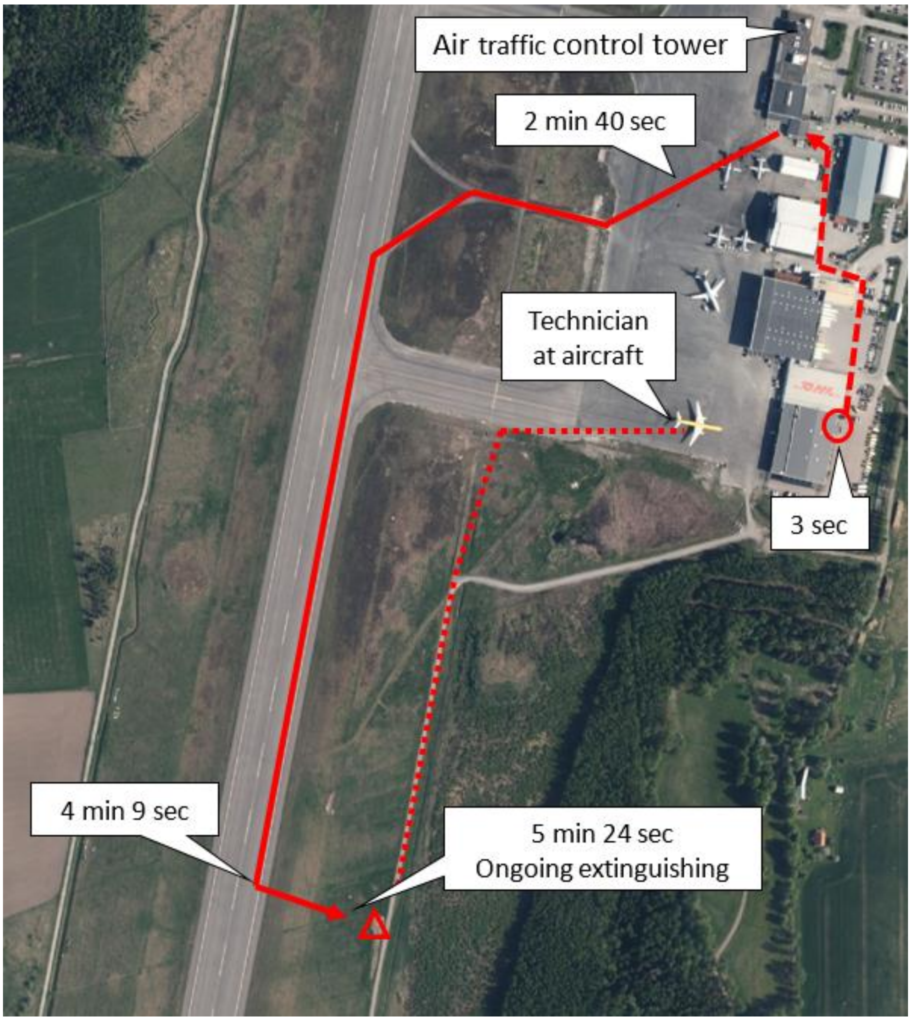


Figure 27. Satellite image of the airport. The times given are the times that could be verified from the time the airport rescue team received the alarm. The markings, lines and text boxes are added by SHK. Image: © Lantmäteriet.

The fire truck stopped 30 metres from the aircraft and the fire truck's water cannon was used to extinguish the fire with foam. Two firefighters also pulled out hoses to extinguish the fires around the aircraft.

Figure 28. The situation after the operation had ended. The white is the extinguishing foam. Image: Police Authority.

When the fire was extinguished, the aircraft was inspected. Two lifeless persons lying half way out of the front part of the aircraft were seen. No other persons could be seen in the aircraft, which was heavily demolished and covered in foam after the fire. As only two persons could be observed, the rescue team checked the vicinity around the aircraft but no persons were found outside the aircraft. Upon further inspection of the aircraft, another lifeless person could be seen inside the aircraft. At this stage, the municipal rescue service and ambulance had arrived at the scene.

The first team from Nerikes fire department and the first ambulances arrived 13 minutes after the alarm. At the same time, several police patrols arrived. The rescue personnel were able to focus directly on life saving efforts as the fire was extinguished. Ambulance paramedics, firefighters and police officers all participated in the work to get the persons out of the aircraft. A task force from the police was on the scene and could assist with tools in order to try and open or cut the wreckage.

The medically responsible ambulance paramedic assessed and prioritized the need for care. One person indicated signs of life and was transported directly to hospital by ambulance. That person later died at the hospital. Another person showed signs of life but was deemed unable to survive a transport to the hospital and was treated on site, but the person's life could not be saved. The other seven people were found deceased as they were lifted out of the aircraft.

The municipal rescue operation ended 20:00 hrs and the police took over management and surveillance of the accident scene.

1.15.2 Alarm and response times

The table below presents the times from impact, the alert and the rescue operation. The times are from audio recordings in the control tower and from witness statement. All times have been verified.

Time	Event Description	Time from Alarm	Time from Impact
19:21:09	Impact		00:00
19:21:13	Second-short audio signal from the aircraft's ELT on the frequency 121.5 MHz heard in the control tower.		00:04
19:21:49 until 19:22:19	The air traffic controller does not see the aircraft on the radar and calls the aircraft three times.		00:40 until 01:10
19:22:28	The aircraft's ELT begins transmitting continuously on 121.5. MHz.		01:19
19:22:36	The air traffic controller starts the alarm.	00:00	01:27
19:22:39	The airport rescue team responds and makes its way to the fire station.	00:03	01:30
19:23:55	The air traffic controller informs the rescue team that there is smoke coming from the southern part of the airport.	01:19	02:46
19:24:21	The air traffic controller informs the rescue team that there is heavy smoke on the east side of the runway, inside the airport area.	01:45	03:12
19:25:16	The rescue team announces that they are going out on the emergency route.	02:40	04:07
19:26:45	Film sequence showing when the airport's fire truck turns towards the accident site.	04:09	05:36
19:28:00	Film sequence showing that extinguishing is ongoing.	05:24	06:51
19:35:40	The first force from Nerikes Fire Department arrives. Ambulance and police arrive shortly afterwards. Care of people from the aircraft begins.	13:04	14:31

Table 2. Time indications from impact until the rescue personnel began the treatment of the occupants.

1.15.3 Position of crew and passengers and the use of seat belts

The pilot was secured in the left pilot seat with a four-point belt.

The parachutists were seated in the cabin behind the pilot. No seat belts or other safety devices for the parachutists were installed in the aircraft.

1.15.4 *Survival Aspects*

All on board had their parachutes on. The conditions did not allow for anyone to rescuing themselves using the parachutes.

The NTSB's General Aviation Crashworthiness Project (1985)

In 1985, the National Transportation Safety Board (NTSB) conducted a crashworthiness project for general aviation. Within the project, a graph was produced that presented the reviewed accidents and the possibility of survival in relation to impact speed and impact angle. The project proved that the accidents examined in the study were generally survivable within the marked area. The area demarcation (in gray) is at an impact speed of 45 knots with an impact angle of 90 degrees, 60 knots with 45 degrees and 75 knots with zero degrees.

According to the graph, the possibilities of survival in the current accident were very small.

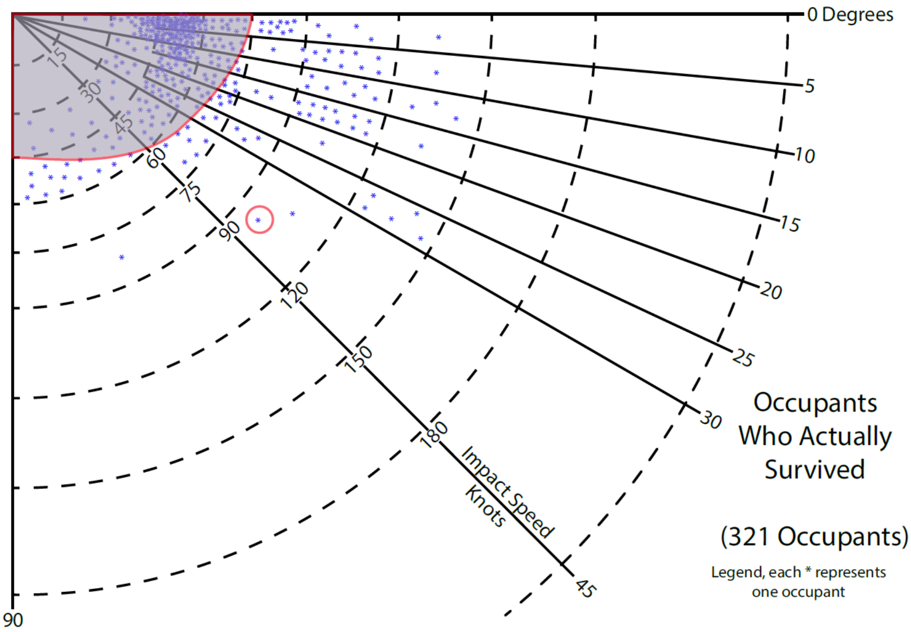


Figure 29. Graph based on data from NTSB. The survivable area is marked in grey within the red line. Each reviewed accident is marked with a blue star. The red ring shows the calculated angle and speed at the actual accident.

1.16 Tests and research

1.16.1 Flight Control System

The flight control system has been examined. No evidence suggesting any malfunctions has been detected.

Elevator trim system

The trim setting used for take-off corresponded to an elevator trim position that is common when landing with only one pilot on board.

The top left image in Figure 30 shows the trim setting on the trim panel after the accident. The top right image shows a similar setting presented on an undamaged trim panel. The bottom left image shows a picture from the crash site and the elevator trim tab position after the accident. The lower image on the right was taken before the accident as the air-craft was on its way out to the runway and it shows the elevator trim tab position before take-off. The elevator trim tab position in the two lower images corresponds to the setting on the trim panel illustrated in the upper part of the image.

Figure 30. The pictures present the elevator trim indication and trim tab position before and after the accident. Lower right image: Private person.

The left image in Figure 31 present an elevator trim setting which, according to other pilots, is normal for take-off with a pilot and parachutists on board. The right image shows the elevator trim tab position before take-off at one of the earlier flights during that day. The trim position on the panel in the figure corresponds with the trim tab position in the figure.

Figure 31 Trim panel setting and elevator trim tab position before take-off with a pilot and parachutists on board. Right picture: Örebro Skydivers Club.

1.16.2 Verification of elevator trim position

With the help of the type certificate holder, SHK has analysed the aircraft's trim rudder position after the accident. The analysis has been carried out based on the position of the trim rudder cable on the cable drum which indicates the position of the elevator trim tabs. Based on the assumption that the rigging was carried out according to specification of the control system and elevator trim system, the position of the elevator trim tab was calculated to have been 16.5 degrees nose up, with an accuracy of ± 0.5 degrees.

Figure 32. Elevator trim cable position and connection on the cable drum.

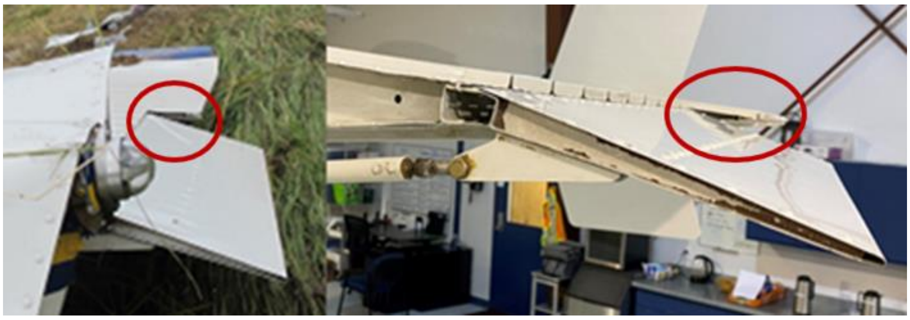


Figure 33. The left part of the picture shows the position of the elevator trim tab after the accident. The right part shows the elevator trim tab position at 16.5 degrees nose up according to the type certificate holder.

1.16.3 *Verification of wing flaps position*

To determine the position of the wing flaps, two different measurements have been performed when examining the wreckage.

Clear trails of soot around the wing and wing flap system were present from the fire. At one of the measurements, the left wing-flap was positioned at the soot edge of the left wing. The flap angle was measured between the wing and the wing flap.

The second measurement was performed on the actuating cylinder for the wing flaps. The piston of the operating cylinder could be positioned at a visible soot edge and measurement was carried out between the attachment points of the operating cylinder. With the help of documents from the type certificate holder, the wing flaps angle has been calculated.

Figure 34. The left picture shows soot trails around the wing and wing flap. The right picture shows the operating cylinder and attachment points. Soot edge circled in red.

Based on the two measurements, the position of the wing flaps was calculated to be 24 ±2 degrees.

1.16.4 *Pilot's seat position*

The seat rail of the pilot seat had six holes to lock the seat in. Pictures from previous flights with the pilot proved that the seat was positioned in the second rear hole. Two and a half centimetres from the rear stop.

Examination of the pilot seat locking mechanism and seat rails has been carried out. During the investigation, nothing has emerged that indicate that the seat locking mechanism or seat rails had impaired functions.

1.16.5 Engine Examination

The examination of the engine was carried out by representatives of the type certificate holder Pratt & Whitney Canada Corp. under the supervision of SHK.

An initial external examination of the engine revealed that the front reduction gearbox had cracked and the exhaust section was damaged. The engine controls and the reversing linkage were damaged. The engine had been exposed to fire in the area around the auxiliary gearbox. Due to these damages, the engine could not be tested in a test bench.

Figure 35. The front gearbox housing was cracked, exposing the internal components. Photo: Pratt & Whitney Canada Corp.


Figure 36. The auxiliary gearbox had been exposed to fire. Photo: Pratt & Whitney Canada Corp.

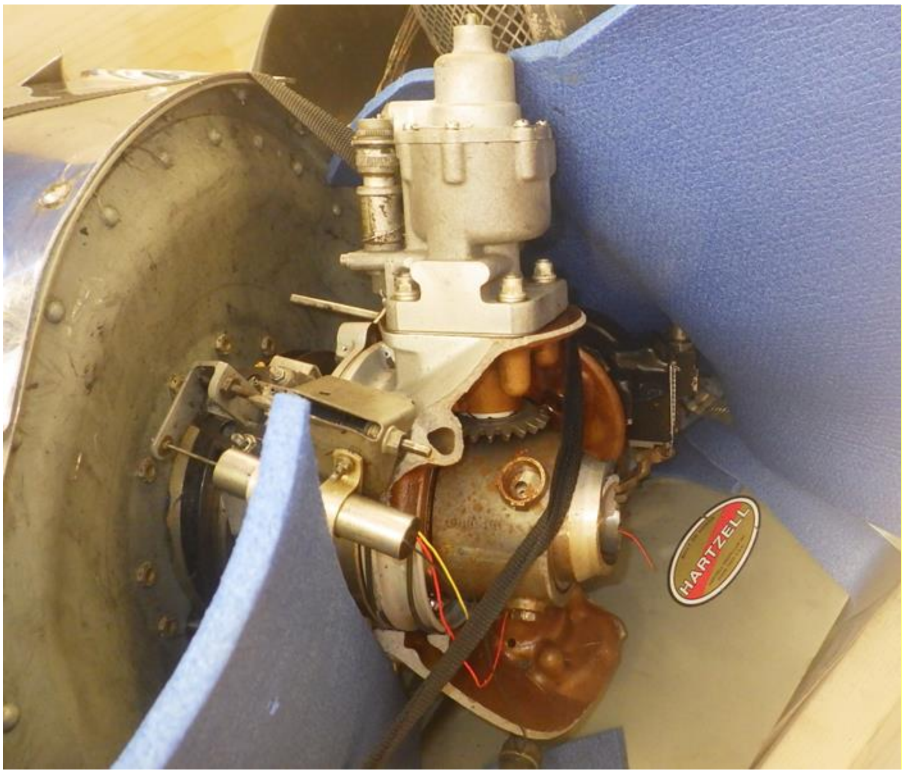


Figure 37. The propeller's overspeed governor and propeller governor remained on the housing from the reduction gearbox which, together with the propeller, separated on impact. Photo: Pratt & Whitney Canada Corp.

When examining the external lines for the compressor bleed air (P3), it was discovered that the locking wire that secures the lines for inlet and outlet to the P3 air filter was missing (see Figure 38). The nut on the inlet pipe to the air filter could not be loosened by hand but did not indicate any torque when disassembling it with a torque wrench. The torque on the nut at the outlet from the air filter was within specifications.

The nuts that secured the inlet and outlet nipples on the filter also lacked its locking wire.

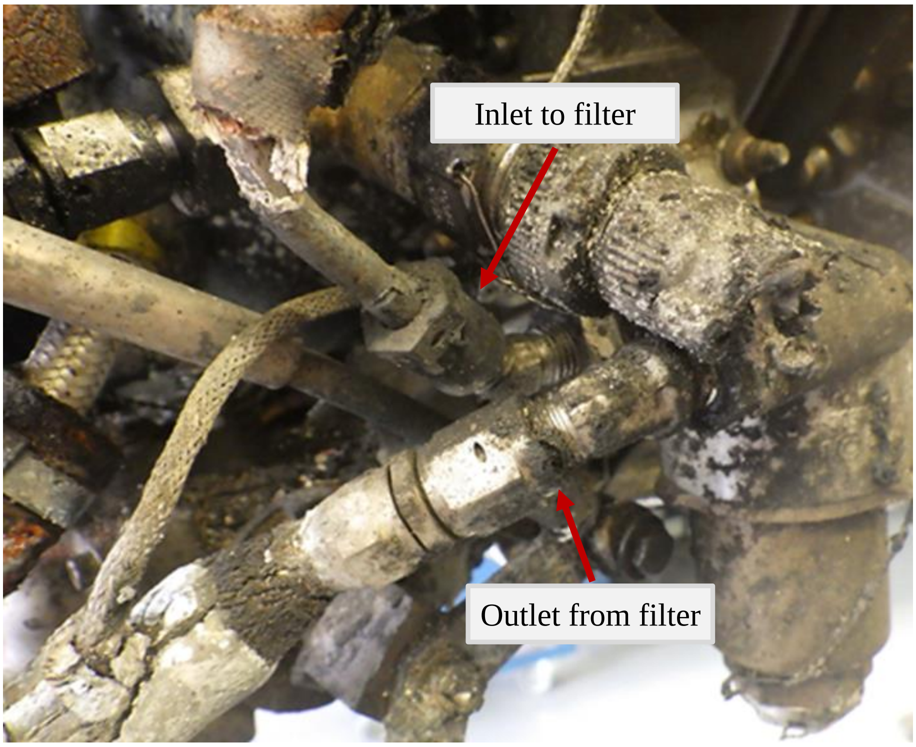


Figure 38. The picture shows which nuts that were not lock wired. The upper nut in the picture lacked the specified torque. Markings inserted by SHK. Photo: Pratt & Whitney Canada Corp.

Further investigation has been carried out to evaluate a possible leakage and possible influence of the compressor bleed air (P3). The test results revealed a small leak. The measured leakage was reviewed by the engine manufacturer who stated that the leakage was negligible and that it did not affect the operation of the engine.

The engine was split at the flange connecting the compressor section to the power turbine for further examination of the compressor turbine, compressor, combustor, power turbine, power turbine shaft, reduction gearbox, auxiliary housing and its components.

The damage to the internal components was characteristic for an engine developing power at the time of impact.

Due to damage to other components on the engine such as the fuel control unit, fuel pump, oil pump, propeller overspeed governor and speed regulator, these could not be tested. The components were inspected externally and then disassembled for an internal inspection.

During the engine examination, nothing was found that was deemed to have negatively affected the engine power or the sequence of events.

1.16.6 Examination of the propeller

Examination of the propeller at Pratt & Whitney Canada Corp. was carried out by a representative from Hartzell Propeller Inc. under the supervision of a representative from SHK.

The propeller was disassembled to assess the operational condition at the time of impact.

Measurements of impact marks on the cylinder surface and piston inner surface were noted and analysed to determine the blade angles. As part of determining the engine power at impact, the damage of the blades was assessed.

The examination showed damage to all three propeller blades (see Figure 39). Two of the propeller blades had been torn off at the attachment to the propeller hub. The propeller blade that still was connected to the propeller hub had slipped in the clamp.

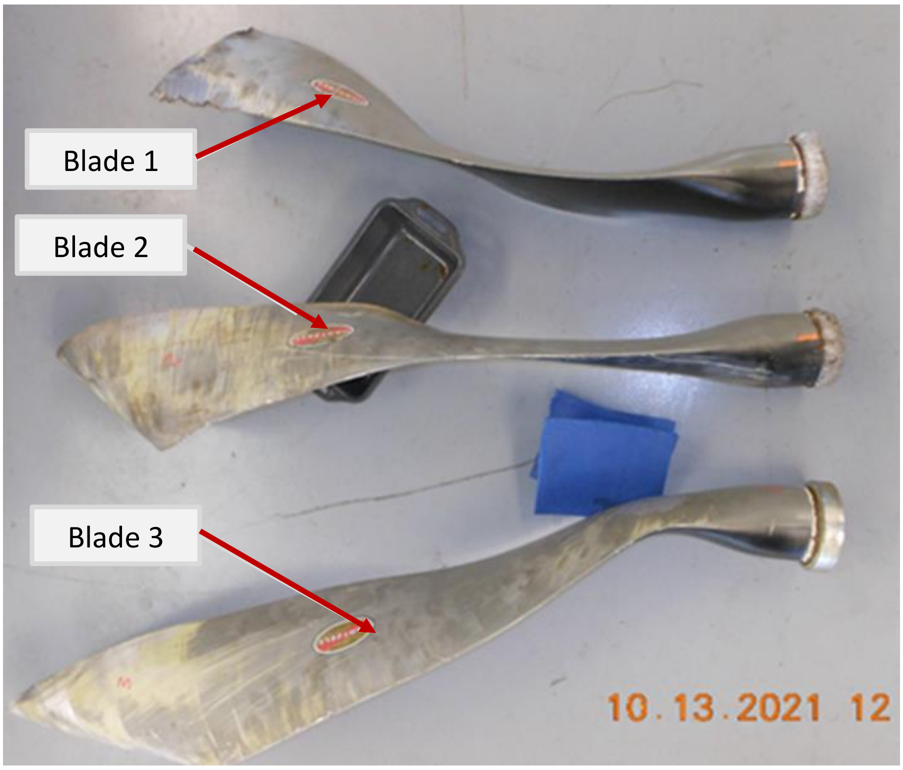


Figure 39. The propeller blades during examination. Markings inserted by SHK. Photo: Hartzell Propeller Inc.

On propeller blade number one three smaller pieces had separated from the blade tip. The pieces that had separated were severely bent, which indicates high power at impact (see Figure 40).

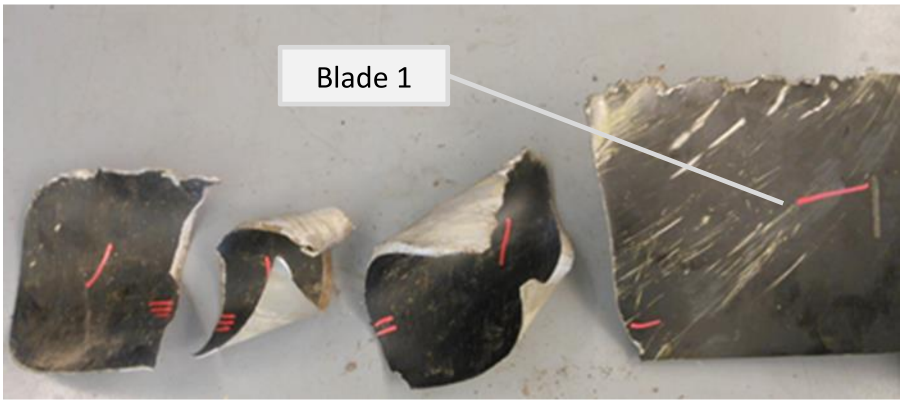


Figure 40. The three separated blade pieces from propeller blade number one. Markings inserted by SHK. Photo: Hartzell Propeller Inc.

When disassembling the propeller hub, it was found that there were impact marks on the inside of the piston (see Figure 41). The impact marks were measured and the measurement for the blade that first hit the ground corresponded to a blade angle of 22.2 degrees. An impact mark from the counterweight on the spinner next to the same blade gave another indication that the propeller was working at a blade angle of 22 to 23 degrees at impact.

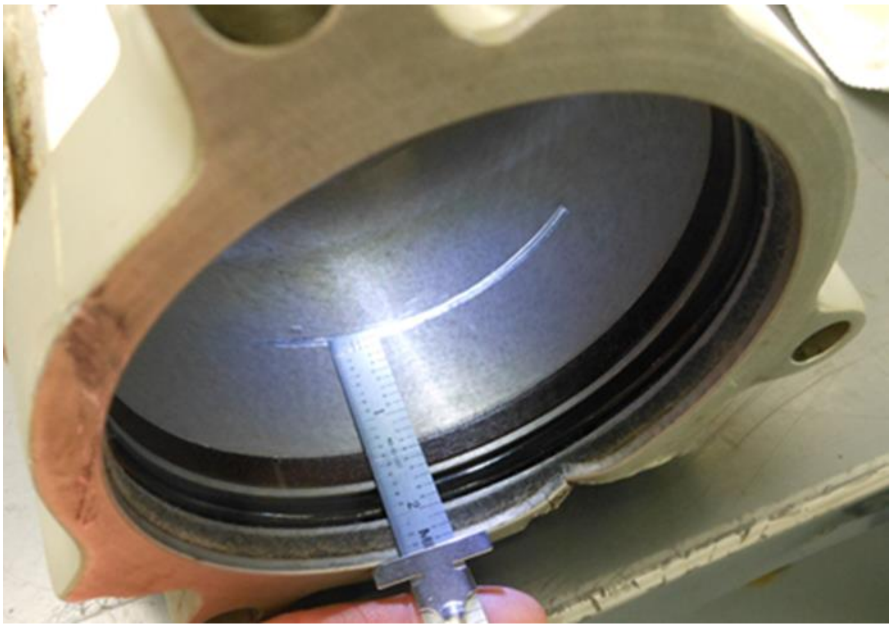


Figure 41. Impact marks in the propeller cylinder head.

No damage or defects were found that would have prevented normal operation before the impact. All damages were in accordance with those that occur in the event of an impact where the engine has high power with positive thrust on the propeller.

1.16.7 Fuel System

The aircraft, engine fuel systems and filters have been investigated to the extent possible. During the investigations, nothing has been discovered that may have affected the engine power negatively.

1.16.8 Fuel Analysis

It was not possible to take fuel samples from the aircrafts fuel tanks. A fuel sample was therefore taken from the refuelling facility that was used when the aircraft was refuelled at Örebro Airport. SHK has commissioned Element Materials Technology AB to carry out an analysis of the fuel, which was of the type Jet A1.

Results of the analysis proved that measured values were within the required limits, except the test "Solid Contaminants" where visible particles were observed. The properties "Water Content" and "Water Tolerance" indicated no signs of contamination.

1.16.9 Examination Warning Lights

SHK has examined seven of the aircraft's warning lights.

The examination included the following lights:

Stall Warning – Illuminates when the aircraft approaches stall.
Beta fail – Illuminates if there is a fault in the propeller reverse system.
Pitch position – Illuminates when reverse is not available.
Chip detect – Illuminates if there are metal chips in the oil system.
Generator warning – Illuminates if the generator does not supply power.
Low fuel pressure left and right – Illuminates at low fuel pressure.

Stall warning light

The stall warning light is located on the instrument panel and illuminates when the angle of attack[15] approaches stall[16].

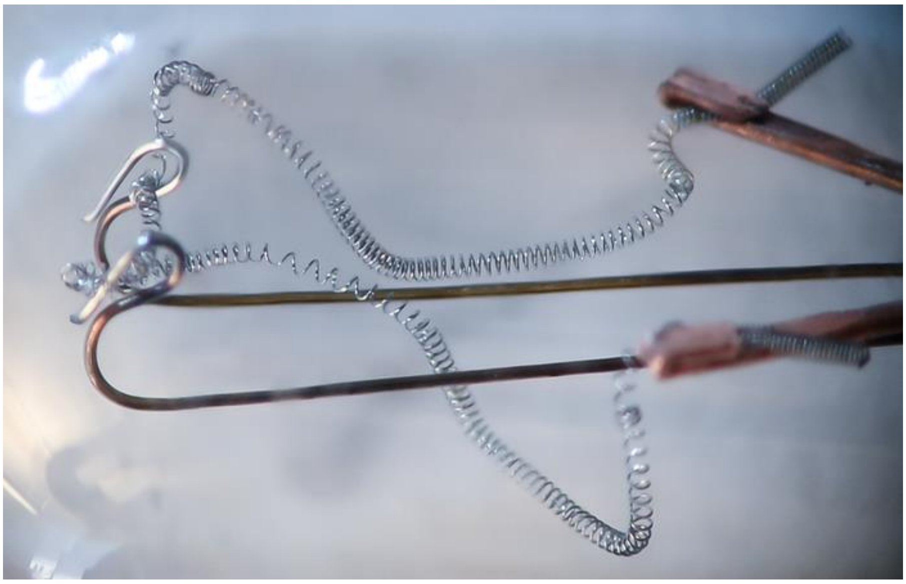


Figure 42. Enlargement of an image of the stall warning light bulb. The picture shows the deformed filament.

[15] Angle of attack "α" – angle between the chord of the wing and the incoming airflow.
[16] Stall – loss of lift due to that the angle of attack is so great that the air flow separates from the wing. (see section 1.18.6).

The filament in the warning light bulb had been deformed without breaking, which indicates that it was hot and illuminated at impact.

Figure 43 present a reference bulb with an intact filament without deformation. This indicates that the particular light had been switched off at impact.


Figure 43. Intact filament without deformation.

Other examined warning lights were not illuminated.

1.16.10 *Mass and Balance Calculation*

No documented calculation of mass and balance for the flight could be found. The pilot had access to the loading instruction. During interviews with pilots who flew the aircraft, all of them were of the opinion that there was no risk of ending up behind the permitted centre of gravity area.

SHK has acquired an Excel spreadsheet for mass and balance calculation that was produced by Skåne's Skydiving Club in the spring of 2021. Calculations in the spreadsheet assumed that the right pilot's seat was removed and instead there was room for parachutists. During the course of the investigation, it has emerged that the spreadsheet was not used by the pilots who flew at the skydiving club.

The weights of the parachutists that were registered in SkyWin (see section 1.6.11) have been compared with the autopsy weights and assumed weights of equipment and clothing (rig weight 9.5 kg and clothing 3 kg). The result shows that the combined mass of all parachutists was 43 kg heavier than registered in SkyWin.

SHK has carried out calculations of mass and balance. The calculations have been based on the parachutists calculated weights and a fuel quantity of 270 kg (centre tank and aft fuel tank full). In order to more accurately determine the moment arm of each individual parachutist, SHK built a full-scale model of the passenger cabin. A weighing with eight parachutists sitting in the model were carried out. This resulted in moment arms for each row for further calculations.

It has not been possible to clarify in which position the individual parachutists were positioned. SHK has therefore carried out mass and balance calculations with several different assumptions regarding the position of the parachutists in the cabin.

In all calculations, the position of the centre of gravity was outside the permitted mass and balance area. According to the calculations, the position of the centre of gravity was somewhere between the front (blue) and the rear (orange) dot, i.e. the aircraft was more tail-heavy than allowed, (see Figure 44).

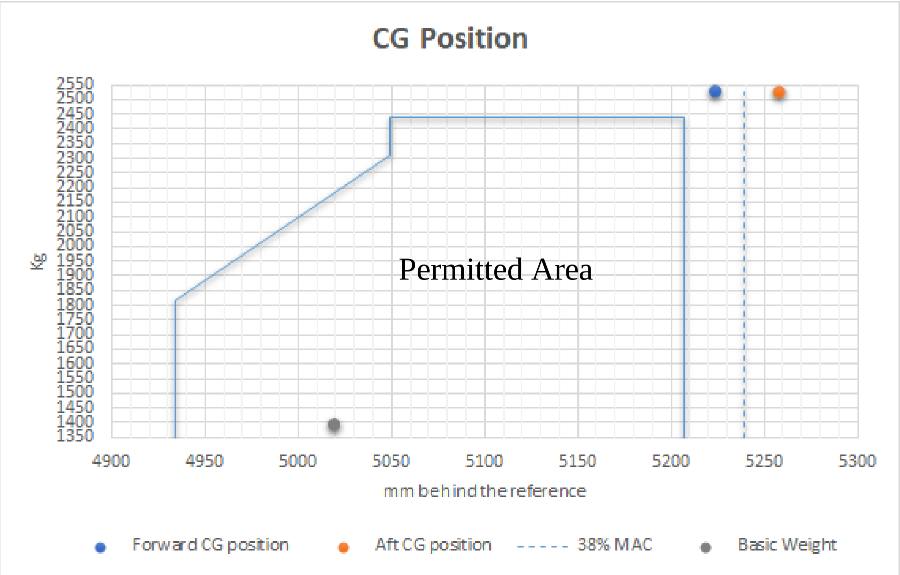


Figure 44. Mass and balance envelope. The vertical axis shows the mass of the aircraft and the horizontal axis shows the centre of gravity position of the aircraft. The 38 % MAC line present the center of gravity position where the aircraft tended to roll without a nose-lowering tendency during the certification.

1.16.11 Reference Flight

SHK has carried out reference flights with an aircraft of the same aircraft model. The aircraft was modified to a higher take-off mass, which meant that the reference flights could be carried out with a take-off mass which, according to SHK´s calculations, was the same as at the time of the accident flight.

The purpose of the reference flights was to understand the flight characteristics and to produce relevant flight data under conditions that was similar to the accident flight. The purpose was also to understand the situation in which the pilot found himself in.

Evaluations on the ground

Pilot's ergonomics in the cockpit

A person of the same length as the pilot was placed in the pilot seat. Full rudder deflections could be performed with the rudder pedals and the steering wheel in all possible pilot seat positions.

The wing flap system

To extend the wing flaps to the take-off position, six and a half full pump strokes were required. To return them to the flaps up position, four full pump strokes[17] were required.

One pump stroke was required to pump from take-off wing flaps to a flap position of 22± two degrees.

The elevator trim system

In order to trim to a full nose up from position "0", four and a quarter revolution was required on the trim wheel. That corresponded to just over eleven retakes.

To trim from 16.5 degrees, nose up to neutral, it took three revolutions on the trim wheel, which is about eight retakes.

Evaluations in the air

Stick forces

Three flights were conducted. The flights were performed at three different centre of gravity locations (CG); the front, middle and aft positions. At each flight, the stick forces were measured. The flights were performed with the elevator trim tab position at 16.5 degrees nose up and with the take-off flap setting (see Table 3).

Flap position	Forward CG	Middle CG	Aft CG
Take-off	19,1daN	23,5daN	27,5daN

Table 3. Stick forces at different centre of gravity (CG) positions.

With two hands on the steering wheel, the forces were demanding but manageable for the pilot. It was also possible to handle the stick forces with one hand, but only for a short period of time.

[17] Pump stroke – The pump is double-acting. A pump stroke is considered a movement in one direction.

1.16.12 Stick force calculations

As stated in section 1.16.10, all of SHK´s mass and balance calculations ended up outside the permitted mass and balance area. During the reference flight, stick forces could therefore not be measured in the centre of gravity positions of the accident flight.

In the graph below, calculations of stick forces are presented based on the results of the reference flight with elevator trim position 16.5 degrees nose up and flap position for take-off (35 degrees). Based on the reference flight, the stick force has been calculated to be between 28.6 and 30.4 daN, (see Figure 45).

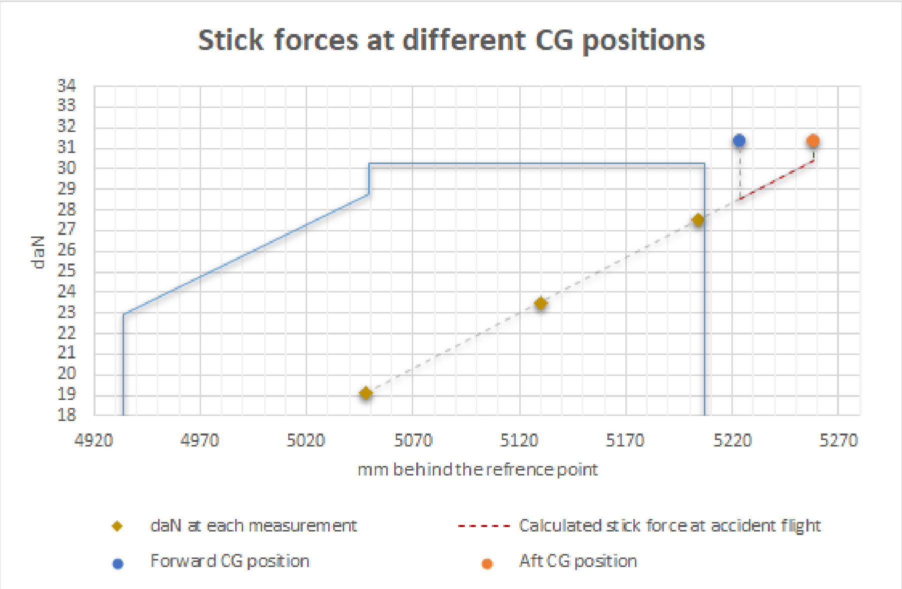


Figure 45. The graph present stick forces (daN) in relation to the centre of gravity position. Yellow markings present the measurement points during the reference flight. The centre of gravity position has according to calculation been somewhere between the front (blue) and the rear (orange) dot. The red dashed line shows stick forces within the calculated balance area at the time of the accident.

An aircraft must be controllable in all flight phases according to the current European design regulations for CS-23[18]. As a reference to the calculated control forces, it can be mentioned that the control forces for controlling the aircraft in pitch should not temporarily exceed 22.2 daN with one hand on the steering wheel and 33.4 daN with two hands on the steering wheel.

1.16.13 Evaluation of stick forces

As part of understanding how the stick forces can be experienced under different circumstances, SHK has constructed a stick force simulator. In the evaluation, the stick forces measured for the accident flight were used. During the evaluation, it was clear that there were several circumstances that determined how the stick forces could be handled in flight.

[18] CS-23 Normal, Utility, Aerobatic, and Commuter Category Aeroplanes.

The force was experienced differently depending on the subject's physique and strength. If the arms were fully extended, the subject managed more force over-time compared to if the arms were bent. When the arms were bent, the muscles got tired and it became more difficult to make minor adjustments. The longer the time passed, the more difficult it became to deal with the situation. With one hand on the steering wheel, it was even more difficult to make minor adjustments. When adjusting, it was also difficult to push the steering wheel forward, while it was easy for the rearward movement to become large.

1.16.14 Calculated flightpath

In section 1.11 registered data where presented from different sources and units. Based on an analysis of this data, SHK has calculated the flight path at the time of the accident, see Figures 46 to 48. The accuracy of the various data differs and possible sources of error have been considered in the calculations.

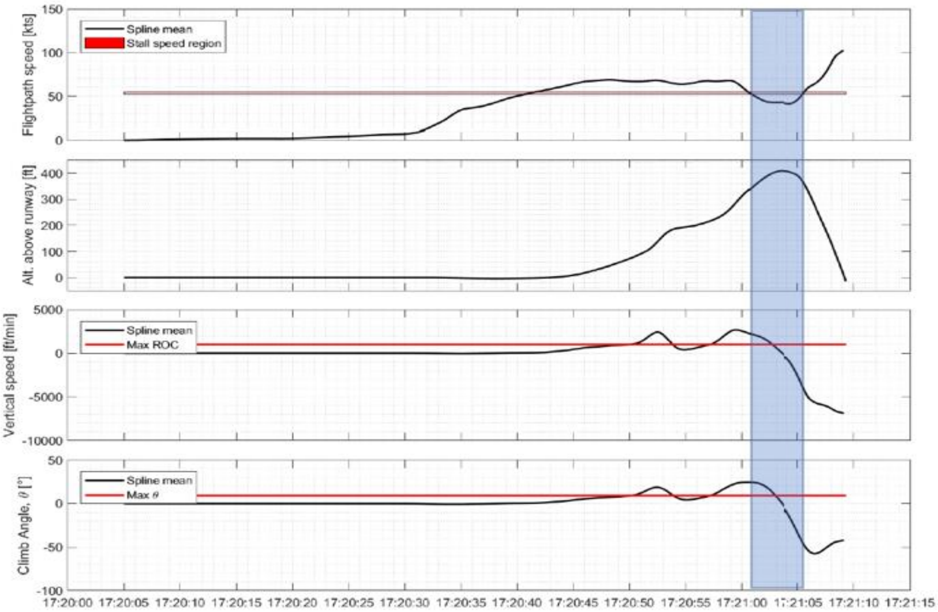


Figure 46. The graph presents calculated speed through the air, altitude (above the airport reference point), vertical speed and angle of climb/descend. The blue marked area points out the time during which the speed has been below the stall speed according to the flight manual.

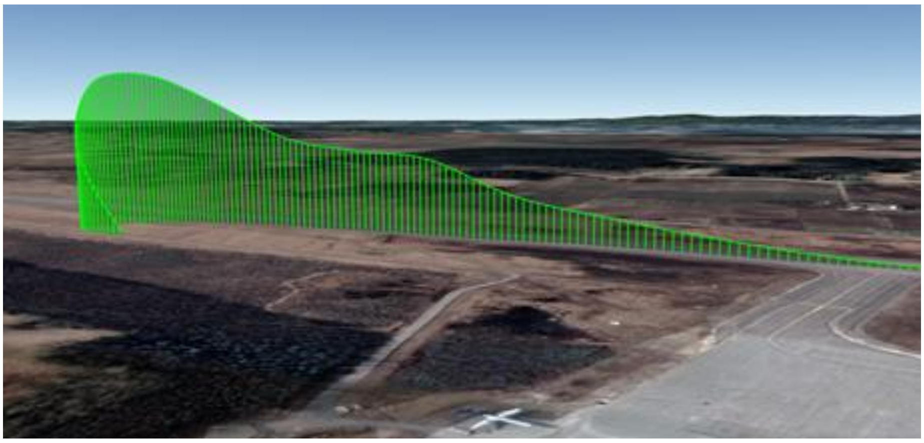


Figure 47. Calculated flight path. Markings inserted by SHK. Image: Google Earth.

Figure 48. Calculated flight path. Markings inserted by SHK. Image: Google Earth.

1.17 Organisational and management information

1.17.1 The operator

The flight was a non-commercial flight operated in accordance with Annex VII (Part-NCO) of Regulation No. 965/2012[19] laying down technical requirements and administrative procedures related to air operations. According to the regulations, the commander is the operator of the aircraft.

1.17.2 Aircraft Owner and Holder

The aircraft was registered in Sweden in 1989 and was operated and owned by Skåne's Skydiving Club until 2016 when Kalle David Flyg AB was created and took over the ownership of the aircraft. Kalle David Flyg AB was owned by Skåne's Skydiving Club. In the company there was a person who was responsible for the flight operations, called manager flight operations.

South Sweden Flight Academy AB was registered as holder from June 18, 2021. At the time of the accident, Örebro Skydiving Club leased the aircraft from Kalle David Flyg AB.

[19] Commission Regulation (EU) No 965/2012 of 5 October 2012 on technical requirements and administrative procedures in connection with aircraft operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council.

1.17.3 Skånes Skydiving Club

The Club is an association that was founded in 1963 and the club's mission is to conduct sports parachuting.

On March 27 of 2021, the club organized a Safety Day for parachutist and pilots. The Swedish parachute association (SFF) had sent out an agenda for these meetings that was to be reviewed before the season started within skydiving clubs. Mass and balance was a mandatory agenda item for all skydiving clubs during the Safety Day. It was not mandatory for parachutists and pilots to attend the meeting. From the parachute club's notes from the meeting, it appears that mass and balance was handled. Furthermore, it appears that in the case of SE-KKD it was primarily considered to be the mass that played a key role in handling of mass and balance. This is because the aircraft, according to the notes, had the advantage of the door being positioned approximately at the aircraft's centre of gravity.

Within the club, there have been meetings with pilots who flew the aircraft. In the spring of 2021, a certain meeting was held in which mass and balance was on the agenda. However, according to interviews, the meeting more focused on internal issues within the parachute club. No decision on how to handle mass and balance was ever made. The parachute club's manager flight operations partially participated in the meeting. The pilot who performed the accident flight did not participate.

1.17.4 Swedish parachute association (SFF)

The Swedish Transport Agency has, with the support of chapter 12 §§ 1 and 8 of the Aviation Act (2010:500) and chapter 12 §§ 1 and 4 of the Aviation Ordinance (2010:770), delegated to the Swedish parachute association (SFF) to issue certificates of competence, student certificates and carry out inspections and supervision of sport skydiving in Sweden. The Swedish Transport Agency has also instructed SFF to perform proactive flight safety work regarding all sport skydiving within the organization.

From the delegation decision and the agreement reached between the Swedish Transport Agency and SFF, it states that the organization's operations must be governed by a handbook system which, among other things, must describe procedures and instructions for the operation.

SFF has established such a handbook system. In chapter 402:03 there are regulations with regards to aircraft and pilots. According to section 3.3.1, pilots of aircraft from which parachute activities are performed must be approved for the mission and trained by the manger flight operations within an aviation company or by the person responsible for the flight operations within the skydiving club. The flight time requirements must also be met. The chief instructor (CI) in the skydiving club reports the approved pilots to SFF, which entails authorization to carry out skydiving throughout Sweden. The jump leader must ensure that the pilot is informed of any local regulations, as well as the regulations summarized in the pilot instructions.

The training mentioned in the handbook (section 3.3.1) is described in more detail in sections 3.3.4 to 3.3.7. It states that the training plan for pilots contains a general part and a specific part. The specific part is divided into a theoretical and a practical section. The specific, theoretical part must contain a review of the current aircraft's handling and limitations. The specific, practical part must include flying and landing with a fully loaded aircraft, flight profile, climb and descend as well as jump flights with experienced parachutists. The general part must, among other things, include review of flight profiles, including spotting[20] and review of emergency procedures, including pilot emergency jump.

After the accident involving parachutists in Umeå on 14 July 2019[21], the Swedish Transport Agency directed the following request to SFF:

As responsible for supervision in aviation, the Swedish Transport Agency requests that the Swedish parachute association checks its procedures and ensures that the skydiving clubs have knowledge of the importance of staying within the applicable weight and balance limitations during the practice of parachuting and that procedures and routines are followed.

In its response to the Swedish Transport Agency, SFF reported a number of corrective actions. One of the actions was a risk analysis, through brainstorming, to identify hazards and analyse risks depending on available safety barriers. The result of the risk analysis was documented in a risk matrix. In the matrix both flight- and parachute operational hazards were included. One of the hazards identified was parachutist being positioned incorrectly with regard to mass and balance. The risk was judged to be unacceptable. As a risk-reducing measure, the matrix stated the following:

"HM/Liftchef is responsible for positioning according to the load sheet, instructions or markings in the cabin. Mass and balance calculation according to POH or the Skydiving Club SOP."

After the measure, the risk was considered acceptable and would be further followed up with "Operational Control" and occurrence reporting.

Another action was to present standard operating procedures (SOP) for flights with parachutists based on the risk analysis in accordance with the commercial flight rules AMC1 SPO.OP.230.

After the accident in Umeå, SFF established material for a safety day, focusing on mass and balance. The information was sent out to the clubs before the start of the season. Mass and balance was a mandatory agenda item for all skydiving clubs during Safety Day 2021.

[20] Spotting – calculation of jump position.
[21] SHK report RL 2020:08.

In the spring of 2021 a training program was developed for pilots. Training materials were produced for new skydiving pilots, transition to a new type of aircraft and refresher training. Implementation began in April 2021. The pilot operating the accident flight had not undergone the implemented refresher training.

1.17.5 Örebro Airport Rescue Service, function and requirement

Örebro Airport is EU-certified and covered by the European Commission's Regulation (EU) No. 139/2014[22] on requirements and administrative procedures for airports. As a supplement to the overall requirements in the EU regulation, EASA has produced Guidance Material (GM) and Acceptable Means of Compliance (AMC).

It follows from the EU regulation that the airport operator must have a Safety Management System (SMS). Within the framework of such a system, safety functions must be continuously reviewed to ensure its function. There must be a rescue service at the airport and a plan for how the rescue service should be performed.

AMC5 ADR.OPS.B.010(a)(2) states that the response time for rescue and firefighting services shall not exceed three minutes with an objective of not exceeding two minutes from the time of the first call to the emergency rescue and firefighting services. Every point on every operational runway must be reachable within the response time, if visibility and surface conditions are optimal.

Regarding emergency services in AMC1 ADR.OPS.B.005(c) it states that various identified accidents should be practiced, that all parts of a rescue operation should be practiced, that a full-scale exercise should be carried out every two years and that the exercises should be evaluated. Furthermore, it is stated that after evaluation, the parts of a rescue service that does not meet the desired requirements should be practiced separately and re-evaluated.

SHK has had access to Örebro Airport's SMS and evaluated the parts that concern the airport rescue service.

Örebro Airport applies the Basic Airport concept, which means that an employee can have several skills and work in an integrated manner with different tasks. For the rescue personnel, this means that they are on standby for rescue services at the same time as performing other tasks.

What is stated in the AMC regarding deployment time was found in the SMS. There was no analysis or description how the response time would be kept within the framework of the Basic Airport concept. There

[22] Commission Regulation (EU) No 139/2014 of 12 February 2014 on requirements and administrative procedures for airports pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council.

was also no description of how the response time would be practiced. The only documentation that existed regarding the exercise of response was a driving time test to the southern end of the runway that was carried out on June 27 2018. The documentation revealed the following:

"From fire station, with vehicles indoors to threshold south: 1.42 minutes (102 seconds). Carried out by responsible Manager for fire and rescue".

It is not clear to SHK how the test was performed.

1.18 Additional Information

1.18.1 Flight Rules

Flight operations in connection with parachute operations with aircraft other than complex motor-driven aircraft may be conducted in accordance with Annex VII (Part-NCO) to Commission Regulation (EU) No 965/2012[23] provided that it is carried out by an organization whose purpose is to promote aeronautical or recreational aviation , the aircraft is owned by the organization or leased without crew, that the flight does not generate profits that are distributed outside the organization, and that flights with members from other organization's constitute only a marginal part of the organization's business.

Operation conducted under Part-NCO do not require special permits or approvals.

As a supplement to the overall requirements in the EU regulation, EASA has produced Guidance Material (GM) and Acceptable Means of Compliance (AMC).

NCO.GEN.105 states that the commander is responsible for all operational procedures and checklists being followed according to point 1b of Annex IV to Commission Regulation (EU) No 2018/1139.

AMC.GEN.105(c) specifies as an acceptable way of meeting the requirements that the commander should use the latest manufacturer's checklist. It also states that if checks conducted prior to take-off are suspended at any point, the pilot-in-command should re-start them from a safe point prior to the interruption.

NCO.GEN.105 further states that the commander must be responsible for ensuring that the aircraft's mass and centre of gravity location is such that the flight can be carried out within the limits specified in the aircraft's documentation.

[23] Commission Regulation (EU) No 965/2012 of 5 October 2012 on technical requirements and administrative procedures in connection with aircraft operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council.

Specialized aviation activities, e.g. parachute operations, must be performed in accordance with a checklist. This is stated in NCO.SPEC.105. It is the commander who must establish the checklist based on a risk assessment, where the complexity of the operation is assessed and inherent threats and risks as well as risk-reducing measures are determined. The checklist, which includes duties for commanders, crew members and task specialists, must be readily available on each flight and must be regularly reviewed and updated as necessary.

NCO.POL.100 states that during all operational phases an aircraft's mass and centre of gravity must meet all limitations specified in the flight manual or equivalent document.

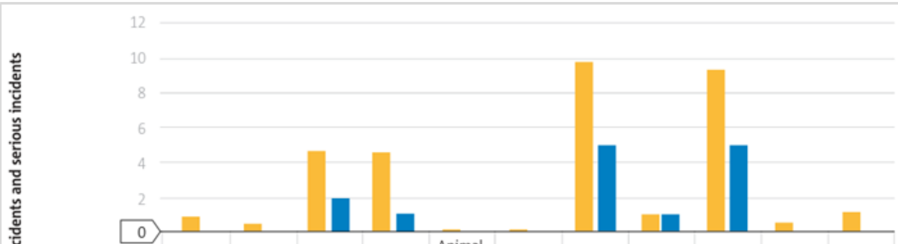
In Part-NCO, Chapter E, Section 4 (NCO.SPEC.PAR) there are also special operating regulations for flying with parachutists. Among other things, there are regulations regarding checklists and placement of parachutists.

1.18.2 *EASA's safety work in skydiving activities*

Annual safety review

One area added to EASA's annual safety review issued in 2022 is parachute operations. According to the EU regulations, the operation constitutes specialised operations (SPO) and the statistics are divided into commercial specialised operations (SPO) and non-commercial specialised operations (within the framework of Part-NCO). In Sweden, the majority of parachute operations are conducted under the regulations for non-commercial operations.

EASA analysis by type of operation in special operations (SPO) prove that most accidents and serious incidents on average occurred in parachute operations and towing during the period 2011–2020.



	Aerial advertising	Aerial observation	Agri-cultural	Air show/ race	Animal herding/ Mustering	Calibra-tion	Parachute drop	Photo-graphy	Towing	Other	Unknown/ blank
Average 2011-2020	0.9	0.5	4.7	4.6	0.1	0.1	9.8	1	9.3	0.5	1.1
2021	0	0	2	1	0	0	5	1	5	0	0

Figure 49. Statistics by type of operation in commercial special operations.

EASA's analysis of non-commercially operated small aircraft operations is presented in Figure 50 below. The graph presents the number of accidents and incidents for each identified risk area (blue bar) as well as the calculated risk for each risk area (yellow bar).

Although the statistics present non-commercial activities, EASA has chosen to combine statistics with SPO in regards to the risk area parachute operation. However, most of the events occurred during non-commercial activities.

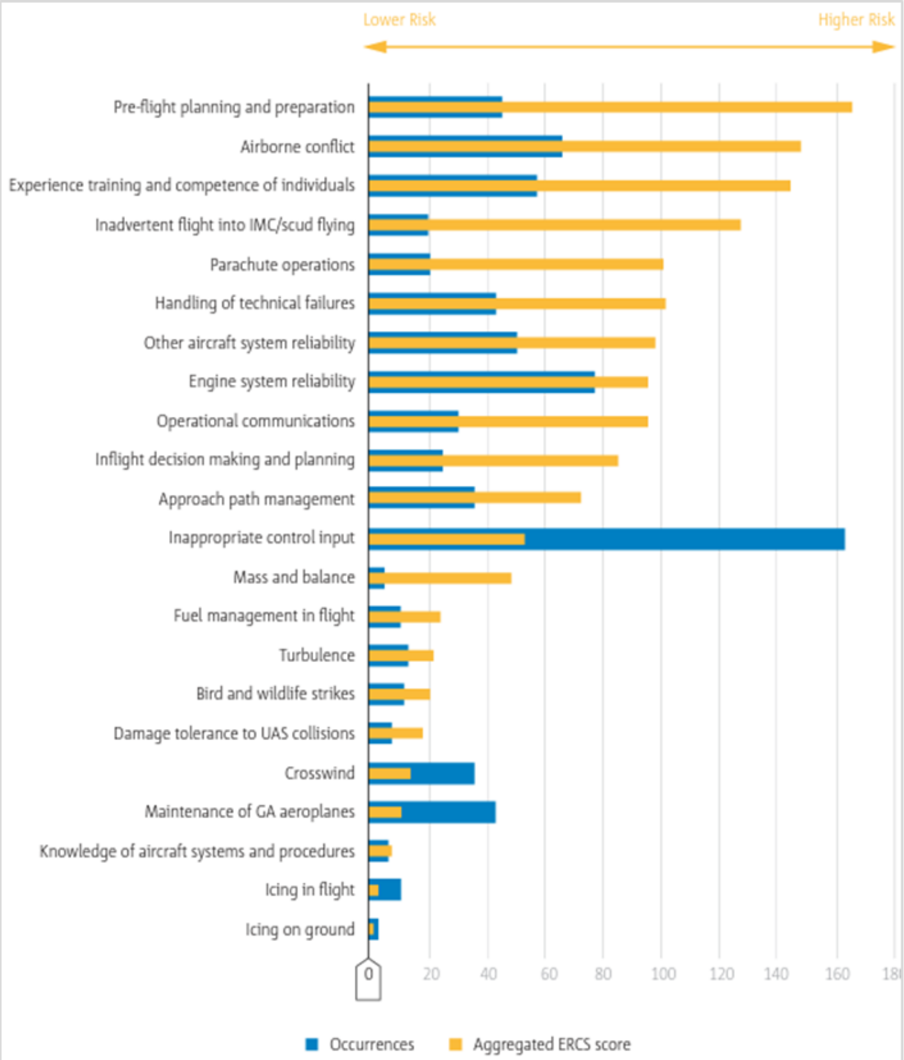


Figure 50. Level of risk and number of accidents and serious incidents involving non-commercially operated small aircraft. The blue bar presents the number of events and the yellow bar present the risk.

The statistics also revealed that aircraft upset has the highest risk in parachute operations.

European Plan for Aviation Safety (EPAS)

The EPAS constitutes the Regional Aviation Safety Plan (RASP) for EASA Member States. EPAS includes strategic priorities, main risks affecting the European aviation system and necessary measures to mitigate these risks to further improve aviation safety.

Accidents between 2010 and 2019 in Europe involving small non-commercially operated aircraft with a maximum take-off mass below 5,700 kg resulted in between 91 and 132 deaths per year. Fatal accidents during parachute operations significantly contributed to the high death toll.

EASA considers safety promotion to be the backbone in the mitigation against accidents in general aviation. As part of increasing flight safety, a safety promotion task has been created (SPT.0121).

A special workshop was organized on 25 February 2021 as part of SPT.0121. At the same time, a dedicated safety promotion section for skydiving was launched on EASA's general aviation website. The workshop was about improving the safety of skydiving. Some measures that was suggested were the creation of a European coordinated Parachute Federation and the dissemination of an indicative operational manual for Parachute Clubs.

1.18.3 National regulations for skydiving, LFS 2008:22

The Swedish Aviation Administration's[24] regulations (LFS 2008:22) on parachuting contain certain provisions on flight duty on board aircraft when parachuting, aeronautical equipment and flight crew, as well as specific regulations concerning safety. These regulations, which are from the period prior to the European regulatory framework entering into force, contain some deviations in comparison to this. As the possibility of having specific national rules is limited, some of the regulations are not applicable. According to the Swedish Transport Agency, work is underway to review the national regulatory framework.

1.18.4 The Swedish Transport Agency's oversight of parachute operation

The Swedish Transport Agency has supervisory responsibility for the delegation to SFF (cf. section 1.17.4), individual pilots who fly skydivers on the condition that it is a non-commercial flight according to the rules in Annex VII (Part-NCO) and for aircraft used in the operation.

The Swedish Transport Agency has stated that oversight regarding non-commercial operations with non-complex aircraft (NCO) is primarily exercised through safety promotion, i.e. information and training aimed at operators. This has been carried out mainly through the activities conducted within the framework of the General Aviation Safety Council.

After the accident in Umeå in 2019, the Swedish Transport Agency has had extensive contacts with SFF and participated in several seminars and meetings that SFF conducted with its members. The latest oversight before the accident in Örebro by the delegation to SFF was carried out in December 2019.

During the period after the accident in Umeå in 2019 until the current accident, no oversight of pilots operating aircraft in non-commercial skydiving activities was carried out.

[24] In 2009, the Swedish Aviation Administration's were transferred to the Swedish Transport Agency.

After the accident, an oversight was performed on a pilot operating in a non-commercial skydiving operation. A number of remarks were documented and classified as "observations". These concerned, among other things, mass and balance as well as the lack of risk assessment and checklist according to current regulations for non-commercial specialized flight operations. During the inspection, reference was made to a risk assessment produced by SFF. However, no such assessment was presented.

The owner or operator is responsible for ensuring that an aircraft is airworthy and meets current requirements. Renewal of airworthiness for EASA aircraft is handled by airworthiness organizations approved by the Swedish Transport Agency. Before new airworthiness documents are issued, the organization must verify that the aircraft is airworthy and meets current requirements. The Swedish Transport Agency perform oversights of the organizations and carries out product inspections of aircraft to verify that the process is working. Product control includes inspections of Swedish aircraft. The Swedish Transport Agency has not prioritized airworthiness inspections on aircraft that has been involved in skydiving. From 2014 until the accident in Örebro, the Swedish Transport Agency carried out five airworthiness inspections of Swedish aircraft used in skydiving operations.

The most recent physical inspection of SE-KKD was carried out on 24 July 2004 by the Swedish Civil Aviation Authority.

1.18.5 The Swedish Transport Agency's oversight of Örebro Airport

The Swedish Transport Agency is the authority that carries out oversight at airports.

During the part of the oversight regarding emergency services, the Swedish Transport Agency ask, among other questions, whether there is a contingency plan and whether the plan is tested according to the requirement. Questions are also asked about the response time. The Swedish Transport Agency has not reported any deviations regarding the requirement for response time at airports where oversights have been carried out.

The last oversight at Örebro Airport was carried out on 27 May 2020. The report from the inspection contained 17 deviations that were to be remedied and two observations. Regarding fire and rescue services, there was a discrepancy regarding the lack of certain documentation. The deviation was commented as corrected. One of the observations was that the staff at the airport themselves had identified that the last full-scale fire and rescue drill was overdue. The last drill was held in 2014.

The Swedish Transport Agency assessed that the operation was up to current regulations. This was under the condition that the deviations were corrected, the root causes of the deviations were investigated and that corrective actions were introduced to prevent repetition.

1.18.6 Stall

To counteract the force of gravity, the aircraft must produce a lift equal to the mass of the aircraft. When this is the case, the load is 1 G.

The amount of lift force depends mainly on five factors:

- The angle of attack” α”
- Airspeed
- Wing profile
- Wing area
- Air density

The angle of attack "α" is the angle between the chord of the wing and the relative wind.

If airspeed is reduced, the angle of attack (α) must be increased to maintain lift. If the angle of attack exceeds a certain value, the airflow over the wing will separate and the increase of lift in relation to increase of angle of attack will decrease. If the angle of attack is increased further, the lift force can decrease drastically.

On the left side in Figure 51 four wing profiles are presented in the air stream with four different angles of attack. To the right, in the same figure, the lift force coefficient *(C_L)* is presented as a function of the angle of attack. At 1 the airflow is still adjacent, at 2 the airflow has begun to separate, at 3 the critical angle of attack has been reached and the lift is at its maximum value and at 4 the lift coefficient has decreased significantly.

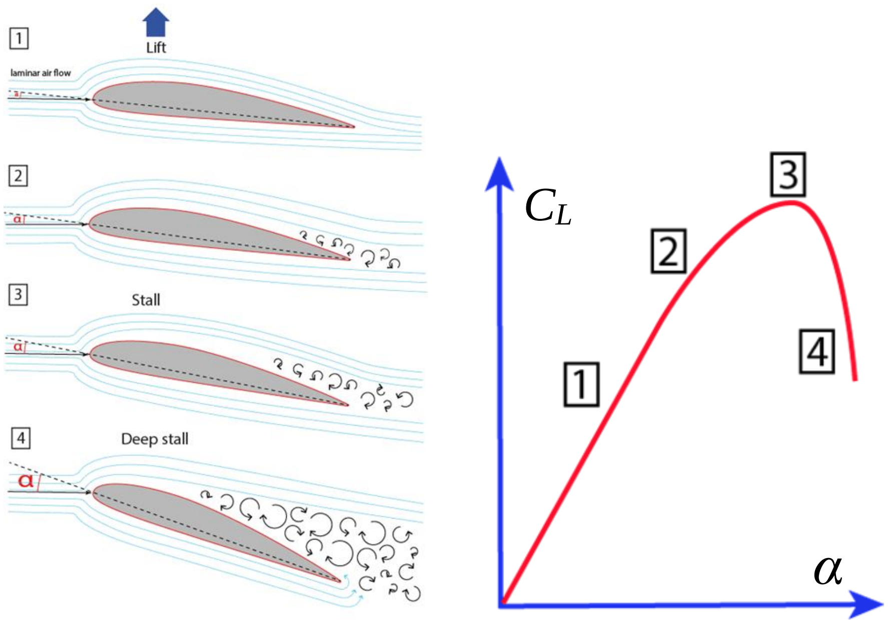


Figure 51. On the left, four wing profiles with different angles of attack and the chord (marked with a dashed line). On the right, the lift coefficient (C_L) as a function of the angle of attack.

Stall

A stall is an aerodynamic condition that occurs when laminar airflow over the aircraft's wing is disrupted, resulting in a loss of lift. Specifically, a stall occurs when the angle between the chord of the wing and the relative wind exceeds the wing's critical angle of attack (see Figure 51).

A stall can in principle occur at any speed if the critical angle of attack is exceeded.

G-stall (accelerated stall)

A G-stall can occur in any flight phase. Generally, G-stall is caused by the pilot making rapid elevator changes which increase the G-load in such a way that the critical angle of attack is exceeded.

Asymmetric stall

If an airplane is flying at a yaw angle though the air, one wing will stall before the other. The stalled wing will then lose lift at the same time as it is slowed down by the drag created by the separation of the flow. The aircraft will then experience a sudden yaw and roll that may lead to a spin unless the pilot counteracts the yaw and reduces the angle of attack.

1.18.7 Upset Recovery

There are a variety of factors that can lead to an aircraft upset when the aircraft exceeds normal operational limits. Some of the factors may be weather, system or pilot induced. This can cause the pilot to lose control of the aircraft.

To regain control in a high pitch attitude and low speed situation, there are various techniques. One technique is to bank the aircraft to lower the pitch attitude and avoid stall.

1.18.8 Flight with high take-off mass

When flying with a high take-off mass, the aircraft's performance deteriorates. Take-off and landing distances become longer, climbing ability decreases and stall speed increases. In addition, greater rudder forces occur and the aircraft becomes more difficult to manoeuvre.

1.18.9 Flight with the centre of gravity far aft

With the centre of gravity aft of the rear limit (tail-heavy condition), the aircraft becomes less stable in pitch and yaw. Less downforce is required on the stabilizer to raise the nose. As a result, pitch inputs result in greater effect and the stick forces are reduced. This is especially noticeable at take-off where the rotation rate can be greater than expected.

The stability characteristics also increased the risk of overcompensation due to elevator sensitivity.

The reduced longitudinal stability can lead to significantly adverse stall characteristics and the signs of an approaching stall less clear. The initial stall easily develops into a fully developed stall and the possibility to recover from stall becomes more difficult with a risk of a secondary stall occurring and thus a greater altitude loss.

1.18.10 Human Decision Making

There are several models used to describe human decision-making. Different models may also have different ways of describing why one option is chosen over another. Thoughtful decision-making is used in situations where there is time to explore various options. When there is time, various outcomes can be analysed in view of various actions.

In contrast to thoughtful decision-making, there are situations where a decision must be made quickly and where the outcome is not always as evident. This type of decision-making is usually categorised as being one in which the decisions made are not the most optimal. One model that describes this sort of process is naturalistic decision-making (NDM). This model highlights the natural ability to make a decision quickly. Human beings are able to rapidly analyse potential solutions sequentially, i.e. one after another, with the first solution that is relevant and feasible being chosen. Accordingly, this is not a decision-making process in which several different potential solutions are compared to one another.

1.18.11 Surprising and Sudden Events

There are obvious difficulties in predicting how an individual will act in a sudden and unexpected situation. From a theoretical perspective, the term 'Startle Effect' can be used. This phenomenon has been defined as a combination of a cognitive and an emotional response to a sudden stimulus, i.e. both as an autonomous reaction (not directly voluntary) and an emotional reaction (e.g. fear). The difference between, for example, beginners and experts can generally be described as the extent of their experience and practice. Situations that have been rehearsed, or that the individual has tangible experience of, can more frequently be said to have prepared them for such sudden and surprising occurrences. However, even experienced pilots may act in an unexpected way precisely because the response to a sudden and surprising stimulus is not directly voluntary and has an emotional component. What often characterises this sort of response is that the action is immediate and aims to resolve the present emergency situation rather than the situation as a whole. In hindsight, such actions may be perceived as irrational and it may be difficult to find a clear logic behind the decision-making.

There is no universal approach that can prepare an individual for all possible eventualities. Nonetheless, the basic premise should be to prepare and train for identifiable and uncommon situations so that a practised pattern of behaviour can replace the basic autonomous reactions to the greatest possible extent. However, this provides no guarantee that such a pattern of behaviour will actually be used.

1.18.12 Similar Events

SHK has identified a previous incident that has certain similarities with the one that has been investigated:

Report AAIB UK, NO 1/82, on the accident with Pilatus PC-6/B2-H2 Turbo Porter G-BHCR at Peterborough (Sibson) Aerodrome, on 15 February 1981.

The aircraft was making a parachuting flight in fine weather and was being flown by a pilot who held a Private Pilot's Licence. Almost immediately after becoming airborne the pilot found he had to use both hands on the control column to counter a strong nose-up out of trim force. The aircraft gained about 250 feet in a semi-stalled condition, then yawed to the left and lost height until it struck the ground, suffering serious damage but not catching fire. Three of the nine parachutists on board received serious injuries and the other occupants received minor injuries.

The accident was the result of loss of control of the aircraft following a take-off with an incorrect horizontal stabiliser trim setting. Contributory factors were the incorrect loading of the aircraft, the difficulty of retrimming the horizontal stabiliser rapidly and an inadequate standard of aircraft operation.

Following the investigation, the UK Civil Aviation Authority was recommended to regularly monitor the operational standard of civilian parachute organisations. The agency also recommended substantially increasing the flight time requirements for pilots involved in flying with parachutists. Both in relation to flying experience and knowledge of the aircraft they fly.

1.18.13 Actions taken

The Swedish Transport Agency

The Swedish Transport Agency has reprioritized and added personnel resources to the operation in order to be able to carry out oversight inspections to all parachute clubs in Sweden. This work is ongoing and has been stated as a high priority within the authority. The Swedish Transport Agency intends to carry out visits to all parachute clubs before the season starts in the spring of 2023.

Within the Swedish Transport Agency section of continued airworthiness, all owners and users of aircraft that are used when flying with parachutists have been asked to disclose documents for approved supplements as well as approved mass and balance documents that the pilot must use.

In addition, documentation is also requested for modifications and installations in the aircraft, as well as documentation that weighing is carried out in accordance with associated basic specification.

The Swedish Transport Agency also prioritises funds within the framework of the General Aviation Safety Council for continued training of both pilots and parachutists.

EASA

During December 2021, a Sunny Swift[25] was published by EASA dealing with operational manuals for parachute clubs.

EASA has performed a Safety Issue Assessment (SIA) related to the parachute operations. It concludes that the safety risk needs to be mitigated. Therefore, a Best Intervention Strategy (BIS) of parachute operations process was initiated. The BIS process will develop further on proposed SIA actions. This process may result in mitigation actions related to the rulemaking, safety promotion or any other suitable means.

EASA intends to launch a campaign in 2023 that will highlight the most common causes of accidents in skydiving operations. The campaign aims to spread knowledge and experience about operational procedures that contribute to mitigate high risks.

SFF

During May to October 2021, SFF has performed oversight visits to 12 out of 16 active skydiving clubs. Skåne Skydiving Club had not been visited before the accident. In November 2021, the chief instructor at SFF conducted a conference with the chief instructors from the skydiving clubs with the intent of sharing information, discussions and further training. The agenda for the conference included, among other things, a repetition of mass and balance and pilot training from the previous conference. During March 2022, SFF sent out documents for the safety day "Safety Day" to the skydiving clubs. SFF is also evaluating a tool for mass and balance calculation that some clubs have developed.

Skåne Skydiving Club

After the accident, the skydiving club has developed a system for calculating mass and balance. The load sheet that the pilot receives present both the total mass and the centre of gravity for the aircraft. The calculations also consider the movements that occur when the parachutists jump from the aircraft and they are presented in the load sheet. The lift manager is responsible for ensuring that the parachutists are positioned according to the load sheet.

[25] Sunny Swift – Comic strip used to promote important safety topics to pilots across Europe produced by EASA.

Kalle David Flyg AB

The company has developed an operational manual for parachute operations. The manual describes, among other things, standard operational procedures when flying parachutists and operational limitations.

Örebro Airport

After the accident, Örebro Airport started a working group in the spring of 2022. One measure that has been introduced is that the fire truck must be manned within 30 seconds. Exercises have been carried out where the runway ends have been reached within the regulated response time.

1.19 Special methods of investigations

None.

2. ANALYSIS

2.1 Initial starting points

Through analyses of recorded data and information from witnesses the flight path has, for the most part, been determined. Furthermore, a probable course of events has been established based on the facts obtained and investigative measures taken.

No technical fault with the aircraft that may have affected the accident has been identified.

After the accident, the investigation examinations showed that the elevator trim was set in an abnormal position for take-off and that the aircraft's mass and balance were outside the approved area. The analysis has therefore focused on the operational conditions and circumstances of the accident.

There has also been reason to in more depth and detail analyse the composition of the organizations involved and the impact on flight operations within parachute operations, the structure and function of the regulatory system, the ability to identify risks in the operation and the rescue effort.

2.2 Pre-flight conditions

The intention was to drop eight parachutists from an altitude of 1,500 metres. The parachutist bench to the right of the pilot had been replaced with a pilot's seat to distance the parachutists from the pilot. The pilot received a load sheet before take-off that included the parachutist weights, but not where the parachutists intended to sit in the aircraft.

During the day of the accident, the pilot had performed six flights from Örebro Airport, alternating with another pilot. The flight prior to the accident flight was conducted by the other pilot and it was followed by a ground stop.

The weather conditions were good and are not considered to have influenced the accident.

2.3 Course of events

The pilot taxied from the general aviation apron at the flying club via taxiway A for take-off runway 19. During taxiing, several continuous radio transmissions were made between the air traffic control and the pilot. There was also a situation with an oncoming aircraft on the taxiway that required the pilot's attention.

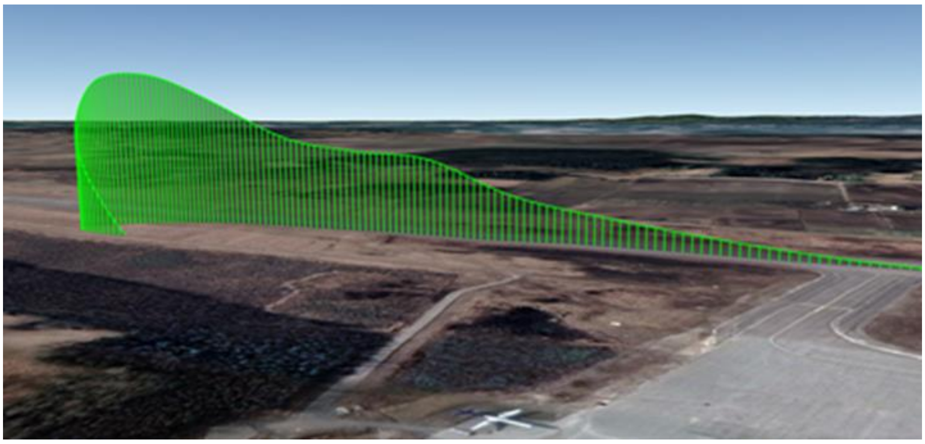


Figure 52. Calculated flight path.

Due to the position of the elevator trim, the nose pitched up more than usual as the aircraft rotated and as the speed increased. The pilot then needed to counteract this by pushing the steering wheel forward. At the same time, the stick forces were higher than normal due to the fact that the trim was set in an abnormal position for take-off. The aircraft was also less stable due to the mass and balance being outside the approved envelope. In that situation, the pilot was likely surprised and needed to quickly identify what was causing the aircraft to behave differently.

When airborne it is not obvious to abort the take-off even though the pilot identified a problem. If the pilot was in control of the aircraft, he may have chosen not to change anything until a safe altitude had been reached. Most likely, the pilot realised relatively quickly that the aircraft was not trimmed correctly. He may have chosen the first identifiable and relevant solution to him, which was to continue the flight. However, it cannot be ruled out that the pilot continued the flight because the situation that arose required the pilot's full attention. It may also have been that the stick forces were so high that he did not want to let go of the steering wheel, in order to with one hand, change the trim position or retard the throttle to abort the take-off and land straight ahead.

During the climb phase, the aircraft drifted slightly to the left compared to the flights that the pilot had performed earlier that day. This indicates that sufficient compensation for drift was not performed. During the same period, flight data and calculated flight path indicate variations in vertical speed. The variations indicate that the aircraft was difficult to handle in pitch, which was probably due to the prevailing centre of gravity position and large stick forces. The pilot was likely both mentally and physically stressed in that situation. There is a relatively long distance between the registrations in the flight data during the climb phase. It may therefore be possible that the climb profile has been even more variable and that the aircraft has been even more difficult to handle than what can be seen on the calculated flight path.

During the investigation, nothing is evident to suggest that anything other than take-off wing flaps was used for take-off. According to the flight manual, wing flaps should be retracted after passing 300 feet above the ground. It was also the normal procedure for the pilots flying the aircraft. After the accident and impact, the wing flaps were slightly retracted and not in their take-off position. It has not been determined whether the pilot chose to retract the wing flaps during the climb phase to reduce stick forces or whether he began retracting them as part of the normal procedure. To retract the wing flaps, the pilot had to release one hand from the steering wheel. SHK's tests have proved that it is difficult to make fine corrections, keep the steering wheel in a certain position and simultaneously perform other tasks with only one hand on the steering wheel with the stick forces that prevailed. During this phase the climb angle increased rapidly which probably coincides with a high nose attitude.

At 400 feet above the ground, the aircraft yawed sharply to the left (see Figure 53).

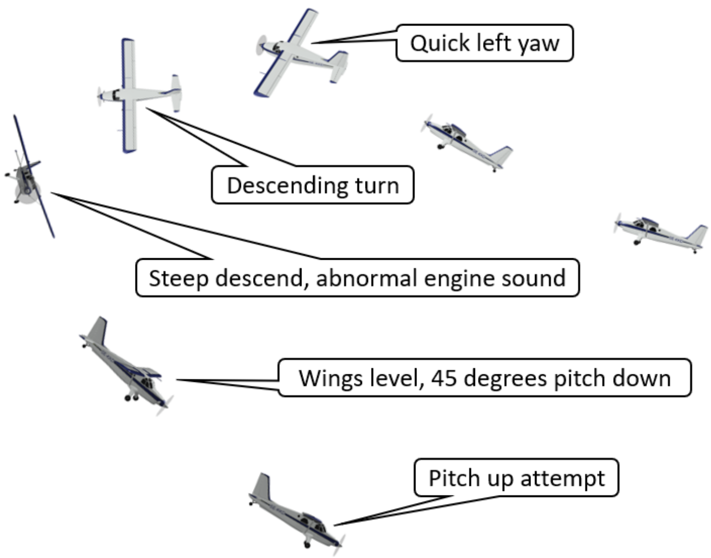


Figure 53. Compilation of the flight path based on statements from several witnesses.

It has not been possible to determine what caused the yaw. It may have been a deliberate action by the pilot but it may also have been due to the pilot losing control over the aircraft.

SHK bases the further course of events on two alternative scenarios.

Scenario 1 Deliberate action

The pilot was trained in aerobatics. Therefore, he probably had good knowledge of how to handle the aircraft in unusual attitudes. To get out of the resulting attitude, the pilot may have chosen to bank the aircraft to the left to try to reduce the pitch attitude and avoid stall (a so-called Upset Recovery).

Scenario 2 Loss of control

Another scenario is that the aircraft stalled and banked to the left. The stall was probably asymmetrical due to high engine power in combination with insufficient rudder being used. The aircraft type's flight characteristics outside the certified mass and balance area, may also have contributed to the yaw. The type flight tests, at the centre of mass being far back, indicate that there is a lack of clear warnings in the form of buffeting before a stall and an approaching to stall may have been difficult for the pilot to detect. The stall warning system that was in the aircraft was visual only with a relatively small light on the instrument panel. In the situation that the pilot found himself in, attention may well have been directed elsewhere, which may have resulted in that the visual warning was not noticed. It is associated with risks to only have a stall warning light without an associated aural warning.

Attempt to resume control

Because the aircraft's centre of mass position was behind the certified approved area, the pilot could not be prepared for how the aircraft would behave after the yaw, regardless of the scenario. An aggravating circumstance in this phase of the flight was the position of the elevator trim which meant that the stick forces in the control stick were different. Stick forces vary with speed and become higher as speed increases. According to the estimated flight path and witness statements, the aircraft continued in a descending turn into a steep dive. During the dive, the aircraft rolled out and continued wings level in the opposite direction to the take-off direction. This indicates that the pilot was trying to regain control of the aircraft. The calculated flight path shows that when the aircraft was at wings level it started to level off prior to impact. It is also consistent with the witness statements. It is not possible to determine whether it was the pilot's actions or the position of the elevator rudder that caused the aircraft to level off. The fact that the stall warning light was on at impact indicates that the aircraft was in an accelerated stall before impact. The low altitude was not sufficient to regain control of the aircraft.

At impact, the engine had high power with positive power on the propeller. The flight lasted 46 seconds after the aircraft started rolling on the runway for take-off.

2.4 Could the pilot's state of health have influenced the course of events?

Nothing has emerged from the medical examinations to indicate that the pilot's mental or physical condition was impaired before or during the flight.

The flight path during the climb out phase shows that the pilot maneuvered the aircraft. If the pilot had not maneuvered the aircraft, the aircraft would have pitched up even more and also earlier in the climb phase due to the trim setting and then stalled. The variations in climb rate also indicate that the pilot maneuvered the aircraft during the climb phase.

After the yaw to the left, the aircraft was in a descending turn, probably at high power. If no control inputs were made by the pilot after the turn, the aircraft would likely have continued in a diving turn or gone into a spin. The fact that the aircraft rolled wings level and continued straight on the wings until impact indicates that the pilot tried to regain control of the aircraft.

Overall, there is nothing to suggest that the pilot's state of health affected the course of events in a way that contributed to the accident.

2.5 Why was the elevator trim in an abnormal position for take-off?

In parachute operations, the aircraft usually takes off fully loaded and lands without a load, resulting in that the aircraft is close to the aft centre of gravity limit on take-off and close to the forward limit upon landing. Large elevator trim change is therefore required during ground stop to assure the next take-off to be a stable flight without large stick forces.

There was a checklist in the aircraft that should be used by the pilots before a flight to ensure that the aircraft was properly configured for take-off. Two of the items on the checklist were to verify and set the elevator trim position and to extend wing flaps to the take-off position. As a checklist supplement, the pilots were taught to perform memory actions to ensure that the most critical actions from the checklist were done. Those actions were to be performed just prior to the take-off.

Interviews with pilots who flew the aircraft revealed that these procedures had changed over time and that the checklist was only used on the first flight of the day and during longer ground stops. Otherwise, only memory actions were used.

On a film sequence from one of the airport's surveillance cameras, the aircraft can be followed during taxiing out to the runway. The film sequence shows that the elevator trim was in an abnormal position for take-off and that the wing flaps were in a retracted position just before the aircraft entered the runway.

After the accident, wing flaps were in an extended position while the elevator trim position was still in an abnormal position for take-off. The wing flaps had thus been extended either in connection with the aircraft entering the runway or when the aircraft was on the runway. However, the position of the elevator trim had not been correctly set prior to take-off. Wing flaps and elevator trim were included in both the pre-take-off checklist and in the memory actions.

It has not been possible to determine how the pilot normally handled checklists and memory actions. There was a documented remark in the pilot's previous proficiency check encouraging him to use the checklist to avoid forgetting important items. This could indicate that the pilot sometimes used only memory actions prior to take-off. It is likely that the pilot on this flight only used memory actions before take-off. Partly because the checklist where wing flaps and elevator trim should be configured for take-off would have been carried out just before entering the runway. Partly because of the identified routine change which meant that the pilots who flew the aircraft under certain conditions only used memory actions.

The time from when the pilot taxied from the aero club until he took off from the runway was just under two minutes. During this time, continuous radio calls were made between the traffic controller and the pilot. There was also a situation with another taxiing aircraft on the taxiway which occupied the pilot's attention while there may have been other disturbances in the aircraft. On several occasions, the pilot answered the air traffic control's instructions incorrectly during taxiing, which could indicate that the pilot's workload was high.

The checklist is a tool to help the pilot remember to carry out mandatory actions at different flight phases. The pilot must read and carry out the items on the checklist. The memory actions were a supplement to the checklist that would help the pilot remember the most critical actions.

Being interrupted or disturbed when only memory actions are used is different from being interrupted while using a checklist. In the event of a disturbance when only memory actions are used, the pilot must remember not only what the memory actions are, but also when the disturbance occurred in order to continue where one was in the flow. When an interruption occurs, using a checklist before take-off, the pilot only needs to identify how far he has gotten in the checklist and re-start reading from a safe point prior to the interruption. There are always risks when being distracted regardless of whether you use checklists or memory actions, but if only memory actions are used it is more likely to forget an item. The normal functioning of the human memory can be impaired under stressful situations.

In all, the circumstances suggest that the pilot was disturbed in his routines and, likely using only memory actions, caused him to forget to reset the elevator trim to the take-off position.

2.6 Why was the accident flight performed outside the approved centre of gravity limits?

SHK's calculations have determined that the mass and centre of gravity were outside the approved limits at the time of the accident flight.

In order for a pilot to perform a calculation of mass and centre of gravity location, certain information such as the basic empty weight of the aircraft and its centre of gravity location must be available. In addition, there must be correct moment arms and correct data on the mass of the aircraft's payload. Payload in this case includes fuel, the pilot and the parachutists.

The current mass and centre of mass position of the aircraft

In order to obtain the basic empty weight and centre of gravity position of the aircraft, weighing has been carried out and documented in weighing protocols. When comparing the different weighing's, it can be stated that the mass of the aircraft has increased and that the centre of gravity has ended up further back. The are several reasons for the change, but what has affected the centre of gravity the most is the installation of a ballast in the rear of the aircraft (see Figure 54).

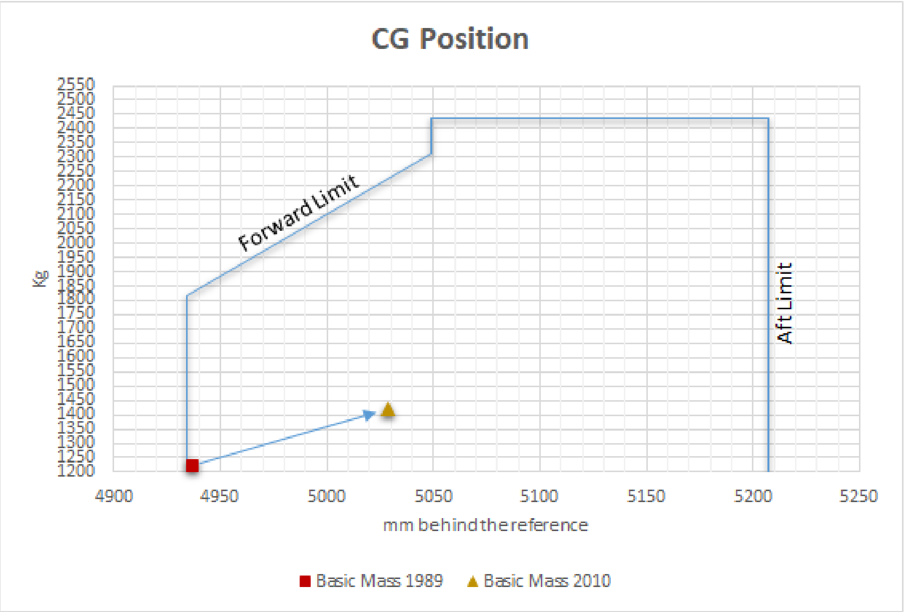


Figure 54. The change of the centre of gravity after installation of ballast. Direction of change illustrated by arrow.

Arm (moment arm) for the parachutists

Neither the type certificate holder's manuals nor the flight manual's parachuting supplement provided the Arm for parachutist's positions in the aircraft. The pilot therefore had no ability to perform a mass and balance calculation with the help of any documentation, and had to rely solely on the load instructions available for the aircraft.

Load instruction

In 1989, the first load instruction was drawn up. The instruction contained a fuel quantity table and an instruction for where the load should be placed.

The fuel quantity table would give the pilot information about how much fuel could be carried depending on the number of persons on board. The table was calculated with the density of AVGAS instead of the density of Jet A1 fuel, which was the fuel to be used. The density of AVGAS is lower than the density of Jet A1 fuel. This meant that the pilot thought he could refuel more than he could, which may partly explain the excess weight that was present.

When the load instruction was drawn up in 1989, the centre of mass position was close to the forward limit (see Figure 54 above). To avoid the aircraft becoming nose-heavy with only one pilot on board, fuel was specified to be placed in the aft fuselage tank. It was however not clear how much fuel that was needed in the aft fuselage tank. The load instruction did not include a balance diagram, which is the common practice for this type of instruction. During the investigation, it has emerged that the pilots always flew with the aft fuselage tank full and that the aircraft was otherwise loaded from the front bench and rearwards. SHK can establish through calculations that the routine that existed for loading worked in most cases in order to stay within the permitted aft limit for centre of gravity. However, this only applied when the right pilot's seat was removed and the front skydiver's bench was installed.

After installation of the ballast in the aircraft, the position of the centre of gravity was moved further aft and the load instruction to carry fuel in the aft fuselage tank was thus no longer relevant. This was not noticed and the load instruction in regards to the location of the load was passed on to the subsequent load instruction without any change.

With the installation of the ballast, the basic conditions for the calculation of centre of gravity changed and the margin to the aft centre of gravity limit was reduced. In the image below, the margin to the aft limit is illustrated in each year with an orange and black arrow. (see Figure 55).

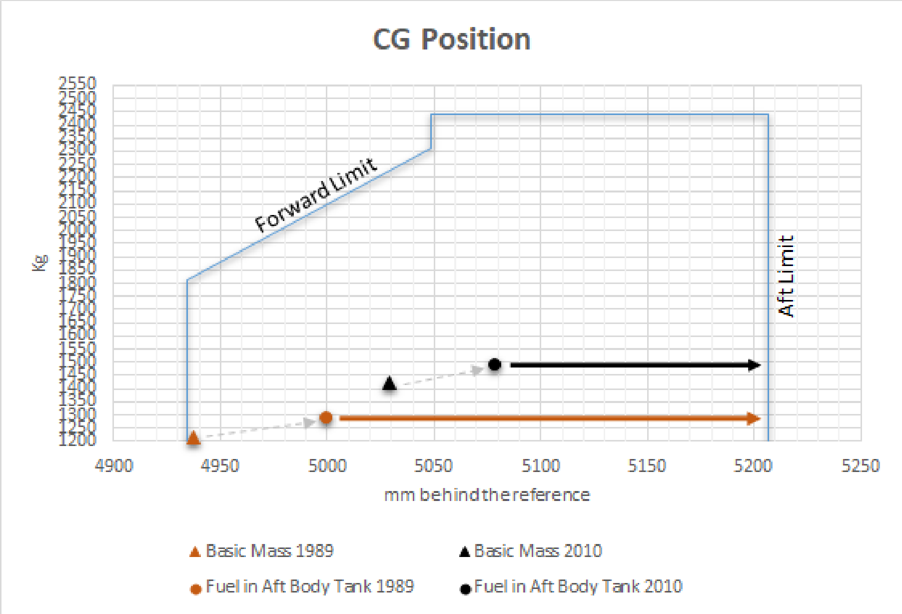


Figure 55. The change of the centre of gravity after installation of ballast and with fuel in the aft body tank. The orange and the black dot illustrate the starting position for the respective years before the load of parachutists.

There was thus no way to see or calculate the current centre of gravity using the load instruction. Despite this, in most cases the flights could probably still be performed within centre of gravity limits because two parachutists were placed on the normally installed forward bench, and that the aircraft was loaded from front to back. However, a latent risk had been created with an incorrect instruction in a document that should help the pilot load the aircraft correctly.

To distance the pilots from the parachutists during the Covid-19 pandemic, the pilots flying the aircraft had replaced the parachutists' bench to the right of the pilot with a pilot's seat. This meant that two parachutists who would normally be placed on the front bench now had to sit further back in the cabin, which even further shifted the position of the centre of gravity to the aft (see Figure 56).

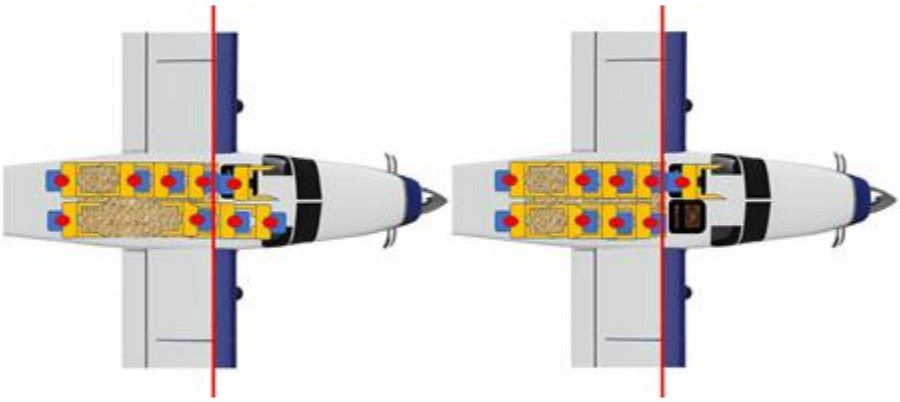


Figure 56. The left picture present how the aircraft was originally loaded and the right present how the aircraft was loaded with the right pilot seat installed. The red line shows the centre of gravity according to the load instruction at standard empty weight.

A combination of ballast being installed and the parachutists being placed further back in the aircraft resulted in that the risk of getting behind the approved aft limit for the centre of gravity increased.

The load sheet that the pilot received from the parachute club before the flight indicated the weight of each parachutist but not where the parachutist intended to sit. Therefore, the pilot could not know how the balance was affected by the parachutist. How the balance is affected is largely determined by the weight of the parachutist and in which position (moment arm) the parachutist is sitting.

The balance changes a lot depending on whether the heavier parachutists sit in front or in the back of the cabin. To prevent the centre of gravity from getting outside the approved limits, there must either be a procedure that handles the balance of the parachutists, or the load sheet must contain the information required for the pilot to perform a mass and balance calculation.

In summary, it can be stated that the pilots who flew the aircraft did not have the sufficient information to perform a correct mass and balance calculation with the information they had access to. It is the responsibility of the commander to perform a calculation and not to conduct the flight if the documentation is substandard. So why did the pilots accept to fly without a more in-depth analyses and a calculation mass and balance?

It can probably be due to several reasons. The operation of flying parachutists was conducted in a context where several organizations influenced the operation in different ways. These organizational factors will be handled upon in more detail later in the analysis (see section 2.10). Furthermore, there was a common opinion among the pilots that there was no risk of ending up behind the approved centre of gravity limit with SE-KKD. This view has been verified by all the pilots that SHK have interviewed and that flew the particular aircraft. This view is also supported by the loading instructions, which only mention the risk of the aircraft becoming nose-heavy. The fact that the aircraft has been operated in parachute operations in the same club for a long time may also have affected the pilots. Experience and opinions have been inherited and the original 1989 configuration has been allowed to prevail in the approach to the centre of gravity position, regardless of the modifications that have been made to the aircraft. The lack of a balance diagram that visually showed where the centre of gravity position was located has probably also contributed to an incorrect perception.

2.7 Stick forces

SHK has demonstrated through reference flights and calculations that the stick forces during the accident flight may have between 28.6 daN and 30.4 daN with the same configuration. According to the current European certification standard (CS-23), the stick forces in the accident flight were close to the allowable limit, for temporary application, with two hands on the steering wheel and above the allowable limit for one hand on the steering wheel. When the aircraft was certified, this standard did not exist, but the current certification requirements can be used as a reference to understand which forces can be considered as manageable.

The simulations in the stick force simulator (see section 1.16.13) proved that several circumstances affected the pilot's ability to handle the resulting stick forces, including the position of the pilot's seat and whether the pilot had one or two hands on the steering wheel. The overall conclusion is that the forces that the pilot had to deal with were physically demanding, especially with one hand on the steering wheel.

2.8 Drifting into failure

A pilot is sometimes interrupted in his work reading the checklist before take-off and there is a risk that something on the checklist will not be carried out. When the system of memory actions was introduced to complement the checklist, it is likely that it was seen as a safety-enhancing measure as it became an extra check to ensure that the critical actions were carried out. In this case, however, the memory actions system may have contributed to a procedural drift toward not using the checklist.

A procedural drift occurs over time where the change takes place in small steps. Often, a procedural drift is initiated by streamlining in order to save time or money or to manage routines that are not perceived as working in the every day to day business. The change is usually not perceived as a threat because it happens slowly. The process of procedural drift is also not controlled, which means that there is a lack of knowledge about when safety barriers have been crossed and when latent conditions have been created in the system. The fact that the routine change has not caused any immediate negative effects is taken as proof that it is working.

In the current operation, there was no requirement for a manual system or documentation for operational routines. The result of this is that a pilot cannot easily familiarize himself with the operational procedures that originally were created. This can lead to greater variations in how the aircraft is operated and also contribute to procedural drift.

It is not unusual in parachute operations to fly "back to back", which means that you do not switch off the engine after landing, but load the aircraft and start again. The parachutists want to make as many jumps as possible, which means that there may be an expectation on the pilots to be fast between landing and take-off. The parachutists want to reach the exit altitude as quickly as possible, which means that there may be an expectation on the pilots to do fast turnarounds. There is also an economic aspect to the lift taking as short a time as possible, since the aircraft are costly to operate.

In the investigation, there are circumstances that suggest that a procedural drift has occurred regarding the use of checklists and memory actions, but it is difficult to know with precision when and how it may have occurred. As an example, procedure drift may have started with the use of only memory actions during "back to back" flights at some point. The same pilot landed and took off, which meant that the pilot knew how the aircraft was configured. It probably proved time-efficient, and since the memory actions contained all the critical actions from the checklist, it was easier to just use the memory actions. After that, the method was perhaps used sporadically when the workload required it. Over time, it may have become more and more common to use only the memory actions because it was perceived to work and no adverse effects were seen.

2.9 Regulations

In order to be a commander in parachute operations, no special rating is required, even though flying with parachutists is generally significantly more complex than a normal private flight and often takes place at a high pace. In order to proactively identify and manage complex risks in such an operation, a well-developed risk assessment is required.

According to the Part-NCO, the pilot shall conduct a risk assessment to identify existing risks and take compensatory measures before each flight. No risk analysis has been presented for the current flight. After the accident, the Swedish Transport Agency carried out an oversight on a pilot in another skydiving club. That pilot was also unable to present a risk analysis. The inspection also revealed that the pilot expected the SFF to produce a risk analysis for the flight operations in connection with parachute operations. There are therefore reasons to doubt that risk analysis are carried out regularly before each flight, which in turn may indicate that pilots do not have sufficient knowledge of the regulations in this regard.

Pilots who fly in skydiving operations often have a private pilot license and varying experience. There is reason to question whether it is reasonable to expect that every pilot conducting parachute operations have sufficient tools in order to perform a risk analysis that identifies and manages the hazards that may exist.

The statistical outcome from EASA revealed that flying in parachute operations is associated with high risks and there are several incidents and accidents every year with many fatalities. The biggest risk is aircraft upset, a factor that also proved to be central in this accident.

During the investigation, flight operational deficiencies have been identified. It has also been difficult to clarify who participated in information meetings and what information was shared. A special rating for pilots who fly parachutists could raise awareness and knowledge and thus reduce the inherent risks in the operation. Also, by introducing a requirement for refresher training to maintain the rating, knowledge would be strengthened and the opportunities to take part of the risks identified would increase. Furthermore, it would also ensure that all who fly parachutists have taken part in the information produced from various organizations. Another advantage would be that the national supervisory authority, through oversights, can ensure that such training meets the requirements.

Previous accident investigations[26] have recommended that training should be introduced for flying parachutists. The investigations have to some extent come to the same conclusion, which clearly indicate the need for the introduction of formal training.

SHK therefore recommends that EASA consider to introduce formal training that leads to an additional rating with recurrent requirement for pilots operating in parachute operations.

2.10 The organization's composition and impact

In Sweden, skydiving is performed in parachute clubs. The parachute operation itself is regulated in SFF's regulations, Swedish Regulations for Parachute Operations (SBF). Flight operations are regulated in Commission Regulation (EU) No. 965/2012 of 5 October 2012 on technical requirements and administrative procedures in connection with flight operations. In most clubs, the operational flight activities take place under the regulations for non-commercial flight activities (Annex VII of the regulation, Part-NCO) and the individual pilot is the operator and has responsibility for the flight.

In the SBF it is stated that pilots of aircraft, from which parachute jumps are carried out, must be approved for the mission and trained by the manager flight operations within a company or by the person responsible for the flight operations within the parachute club. A flight operational manager or responsible person within a parachute club thus gains a strong position and a high influence on how flight operations are carried out and thus also on flight safety.

Although the responsibility for the flight rests with the pilot, SFF and the respective parachute club have a great influence on the culture, the standardization of routines in skydiving and the flight operations.

[26] SHK Final Report RL 2020:08 and Finish olycksutredningscentralens Final Report L2014-02.

SHK states that the existing organizational order and the distribution of roles create an uncertainty which can lead to the pilot relying on the routines that the parachute club imparted meets the requirements set out in the regulations for non-commercial flight operations (Part-NCO). It can also be difficult for an individual pilot to question working methods and routines when other pilots have already accepted them.

A formal training that leads to a rating in parachute operations would strengthen the pilots' flight operational knowledge and understanding of the regulations. The pilot's position towards the various organizations would be strengthened and thus also the ability to relate to the organizations.

2.11 Oversight of parachute operations

To ensure compliance with the regulations regarding parachute operations, the Swedish Transport Agency has oversight responsibility.

Oversight is an important tool for drawing attention to deficiencies and should be conducted in such a way and to such an extent that it has an effect on compliance with the regulatory framework and thus has a safety-enhancing effect. During the investigation, it has emerged that the Swedish Transport Agency has exercised oversight mainly through safety promotion and that oversight of non-commercial aviation activities has had a lower priority compared to oversight of commercial aviation activities.

After the aircraft accident in Umeå in 2019, SHK recommended the Swedish Transport Agency to take appropriate measures to ensure that correct and reliable mass and balance calculations are made before every flight. The issue of mass and balance calculations has been processed through SFF, who in turn has produced information material, training material and routines that would be implemented and applied at the local parachute clubs, which the Swedish Transport Agency also required. The material and routines have been distributed to the parachute clubs, but there has been no follow-up to ensure that the pilots who flew the aircraft received the information and completed the mandatory training within the SFF. There has also not been any oversight of the non-commercial flight operations prior to the accident in Örebro.

Overall, the SHK is of the opinion that the oversight activities carried out has not been sufficient to identify deficiencies in the non-commercial flight operations (Part-NCO) within parachute operations.

Due to the corrective actions taken by the Swedish Transport Agency (see section 1.18.13), SHK refrains from making any recommendations to the Swedish Transport Agency.

It cannot be ruled out that the deficiencies identified in terms of oversight also occur in other member states. EASA is therefore recommended to take measures to ensure that the oversight of non-commercial specialized aviation activities within parachute operations is conducted in such a way and to such an extent that it has an effect on compliance with the regulatory framework and thus has a safety-enhancing effect.

2.12 The rescue operation

The air traffic controller acted without delay both when the aircraft disappeared from the radar and when the aircraft's emergency transmitter (ELT) began transmitting continuously. If the take-off of the aircraft had been followed visually from the air traffic control tower, the air traffic controller would have been able to act earlier. However, at the time of the incident, there was other traffic in the airspace that required the attention of the air traffic controller. In this regard, the air traffic controller has followed the applicable regulations by ensuring the airport's air traffic control and control service. All in all, it is considered that the air traffic controller could not have acted quicker in the prevailing situation. Nor have any deviations been identified in the procedures at SOS Alarm or JRCC.

The airport's rescue team acknowledged the alert three seconds after it came. It then took just over four minutes for the rescue team to reach the part of the runway where they turned off towards the aircraft. According to the regulations for the airport, the time from alert to the start of extinguishing on any part of the runway must not exceed three minutes. The operation must also be planned so that a response time of two minutes can be achieved. Driving time from the fire station was about a minute and a half. The long distance to the fire station resulted in that the prescribed response time could not be met. With a faster manning of the fire truck, a response time of less than three minutes could probably have been achieved. No problems or delays have been identified for other rescue resources involved.

A faster response could have reduced the impact of the fire, but it is not considered to have increased the possibility of survival. The aircraft caught fire upon impact. The damage to the fuselage indicates that it was mainly the cabin that was exposed to the fire.

In order to reduce the response time, the rescue force must be able to man the fire truck in a shorter time. Örebro Airport has taken corrective actions to shorten the response time and practiced the corrective actions in real time exercises. SHK therefore refrains from making any recommendation about this to Örebro Airport.

However, it cannot be ruled out that similar deficiencies also exist at other airports with the Basic Airport concept or equivalent. The Swedish Transport Agency's assessment after oversight at Örebro Airport before the accident and several other similar airports has been that the airports meet the requirements for the response time. SHK is of the opinion that the response time in the current case had such a large deviation in relation to the regulations that the Swedish Transport Agency's basis for assessment can be questioned. Since the response time is something that should reasonably be practiced the assessment should be based on results from real time exercises. The Swedish Transport Agency is therefore recommended to carry out a control of the response time at all mentioned types of airports.

2.13 Analysis Summary

In flight operations, there is an agreed safety standard that consists of the authorities regulations, the aircraft's certified limitations and the operations regulations. An accepted safety standard creates a safety margin against the risk of accidents.

Flying parachutists is a complex activity where several different factors affect safety. The investigation has identified several latent threats. The threats have emerged during a long period of time. It is only after the accident that it becomes evident what latent threats existed and the risks they possessed.

Latent threats can be seen as borrowing from the safety margin in relation to the agreed standard. Without realizing it, people start to borrow from safety in order to achieve other system goals because of it.

It is evident that there was a strong opinion that the aircraft could not be loaded so that it became tail-heavy (outside the permitted mass and balance area). This view has been communicated in various ways and has also been supported in the load instruction. Despite the fact that the loading instruction was substandard, no one has questioned it, neither the authorities that reviewed the loading instruction, the organizations that were responsible for the continued airworthiness of the aircraft, instructors that trained the pilots, examiners that performed proficiency checks on the pilots or the pilots themselves. A latent threat has thus been created which meant a smaller margin of safety.

Another loan from safety margin has been the handling of checklists and memory actions in a non-effective way. If the pilot only used the method of memory actions, even relatively small disturbances may have been enough to cause the elevator trim not to be set for take-off.

One circumstance that increased the likelihood of an accident occurring was the Covid-19 pandemic. Removing the bench for parachutists next to the pilot changed the loading of the aircraft. No risk assessment was performed due to the load change.

In summary, there have been several safety procedural drifts in the operation which have resulted in a reduced safety margin. Each individual hazard may not alone entail any immediate risk of an accident, but when they all coincided at the same time, the conditions for the accident were created.

In retrospect, appropriate risk assessments could probably have identified these latent hazards and prevented safety drifts from occurring. However, it can be questioned whether the pilots who carry out flights in connection with skydiving have sufficient tools and resources through their training to carry out such a risk assessment.

Much work and effort has been carried out by many parties after the accident in Umeå with parachutists on board. Among other things SFF has prepared information materials, training material and routines. What these have in common, however, is that no follow-up has taken place to ensure that everyone has received the mandatory information and training.

As a result of this, SHK is of the strong opinion that formal training that leads to a special rating is to be introduced for pilots who carry out flights in parachute operations. This would result in that each pilot receives the support necessary to ensure compliance with the regulations. Furthermore, a refresher course would also enable knowledge and risk awareness to be spread to the pilots. This would also ensure that information and training is followed up and documented. In this way, latent hazards can more easily be noticed in time.

3. CONCLUSIONS

3.1 Findings

a) The pilot was qualified to perform the flight.
b) The aircraft had a Certificate of Airworthiness and valid ARC.
c) A risk assessment was not performed due to the load change when the right pilot's seat was installed.
d) The pilot had performed six flights during that day alternating with another pilot.
e) There was no system for calculating mass and balance before the flight.
f) Mass and centre of gravity were outside the allowed limits.
g) An appropriate loading instruction was missing.
h) There was a strong opinion that the aircraft could not be loaded outside the aft envelope.
i) Pilots sometimes replaced the checklist with memory actions due to procedure drift.
j) Elevator trim was in an abnormal position for take-off.
k) The stick forces have been found to be high and difficult to handle.
l) The stall warning was only presented visually with a light.
m) The aircraft entered an upset flight condition.
n) The low altitude was not sufficient to regain control of the aircraft.
o) The conditions did not make it possible to use a parachute for rescue.
p) The aircraft was in a stall at impact.
q) After impact, a fire broke out.
r) The wing flap was slightly retracted in relation to the take-off flap position after the accident.
s) The injuries to the occupants did not allow any possibility of survival.
t) There is no indication that the pilot's state of health has influenced the course of events in a way that contributed to the accident.
u) No technical fault has been identified on the aircraft which may have affected the accident.
v) There has been no follow-up that mandatory information and training from SFF had been received by the pilots.
w) During the period after the accident in Umeå in 2019 until the current accident, no operational oversight of pilots operating aircraft in non-commercial skydiving activities was carried out.
x) The prescribed response time for an airport's rescue service was exceeded.

3.2 Causes/Contributing Factors

Control of the aircraft was likely lost in connection with the wing flaps being retracted in a situation where the stick forces were high due to an abnormal elevator trim position, while the aircraft was unstable due to being tail-heavy and abnormally trimmed. The low altitude was not sufficient to regain control of the aircraft.

The cause of the accident was that several safety slips occurred in the operation, which resulted in that the safety margin was too small for a safe flight.

4. SAFETY RECOMMENDATIONS

EASA is recommended to:

- Consider introducing formal training leading to a rating for pilots in parachute operations where the rating is maintained through refresher training (see Section 2.9 and 2.10). *(SHK 2023:03 R1)*

- Take measures to ensure that the oversight of non-commercial specialized aviation activities within parachute operations is conducted in such a way and to such an extent that it has an effect on compliance with the regulatory framework and thus has a safety-enhancing effect (see Section 2.11). *(SHK 2023:03 R2)*

The Swedish Transport Agency is recommended to:

- Within the framework regarding oversight of airports with the Basic Airport concept or equivalent, verify whether the airports have taken adequate measures to ensure that the response time of the airport's rescue services complies with regulations (see Section 2.12). *(SHK 2023:03 R3)*

- With support of SFF, take measures to ensure that appropriate risk assessment is carried out by pilots according to checklist and applied during flights in relation to parachute operations (see Section 2.9 and 2.10). *(SHK 2023:03 R4)*

The Swedish parachute association (SFF) is recommended to:

- In conjunction with the parachute clubs, take measures to ensure that mandatory information and training is received by all pilots (see Section 2.9 and 2.13*). (RL 2023:03 R5)*

The Swedish Accident Investigation Authority respectfully requests to receive, **by 11 May 2023 at the latest,** information regarding measures taken in response to the safety recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Jenny Ferm Mats Trense