Statens haverikommission
Swedish Accident Investigation Authority

Final report RL 2021:03e

Accident at Stockholm/Skavsta Airport, Södermanland County, on 6 April 2020 involving the aeroplane SE-MKV of the model TB 9, operated by Skies Airline Training AB.

File no. L-27/20

30 March 2021

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

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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 is carried out in accordance with Annex 13 of the Chicago Convention.

The investigation

SHK was informed on 6 April 2020 that an accident involving an aeroplane with the registration SE-MKV had occurred at Stockholm/Skavsta Airport, Södermanland County, the same day at 16:01 hrs.

The accident has been investigated by SHK, represented by Helene Arango Magnusson, Chairperson until 16 October 2020, subsequently John Ahlberk, Johan Nikolaou, Investigator in Charge, Mats Trense, Operations Investigator, Tony Arvidsson, Technical Investigator and Alexander Hurtig, Investigator Behavioural Science.

Richard Trobrillant from the EASA (Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile) has participated as an accredited representative on behalf of France.

Courtney Liedler from the NTSB (National Transportation Safety Board) has participated as an accredited representative on behalf of the USA.

Manuel Fernandez Fdez from CIAIAC (Comisión de Investigación de Accidentes e Incidentes de Aviación Civil) has participated as an accredited representative on behalf of Spain.

János Eszes from the TSB (Transportation Safety Bureau) has participated as an accredited representative on behalf of Hungary.

Ourania Chatzialekou has participated as an adviser on behalf of EASA (the European Union Aviation Safety Agency).

Magnus Axelsson and Hans Hermansson have participated as advisers on behalf of the Swedish Transport Agency.

The following organisations have been notified: EASA, the European Commission and the Swedish Transport Agency.

Investigation material

- Interviews have been conducted with the instructor, the student, two air traffic controllers, the management of the flight school and two witnesses.
- Fuel from the fuel tank at the airport has been examined and analysed.
- The fuel in the aeroplane's tanks has been examined and analysed.
- The relevant systems on the aeroplane have been examined.
- The training materials from the flight school have been reviewed.
- Recordings of the radio communication with air traffic control have been reviewed.
- Radar data from LFV has been obtained and analysed.
- Pictures from the accident site have been documented using drones.
- Reference flights have been conducted using an aeroplane of the same type.

A fact finding presentation meeting with the interested parties was held 14 November 2020. At the meeting SHK presented the facts discovered during the investigation, available at that time.

Statens haverikommission
Swedish Accident Investigation Authority

Final report RL 2021:03

Aircraft:	
Registration, type	SE-MKV, TB Series
Model	TB 9
Class, Airworthiness	Normal, Certificate of Airworthiness and valid Airworthiness Review Certificate (ARC)[1]
Serial number	1535
Operator	Skies Airline Training AB
Time of occurrence	2020-04-06 at 16:01 in daylight Note: All times are given in Swedish daylight saving time (UTC[2] + 2 hours)
Location	Stockholm/Skavsta Airport, Södermanland County, (position 5847N 01654E, 43 metres above mean sea level)
Type of flight	Schooling
Weather	According to Metar: wind 170 degrees 13 knots, CAVOK[3], temperature/dew point +12/+01°C, QNH[4] 1024 hPa
Persons on board:	2
Crew members including cabin crew	2
Passengers	0
Injuries to persons	Minor
Damage to aircraft	Destroyed
Other damage	Some ground damage
The instructor:	
Age, licence	31 years, CPL[5](A) FI[6](A)[7]R[8]
Total flying hours	393 hours, of which 142 hours on type
Flying hours previous 90 days	36 hours, all on type
Number of landings previous 90 days	57
The student:	
Age, licence	33 years, undergoing training towards CPL(A)
Total flying hours	55 hours, all on type
Flying hours previous 90 days	50 hours
Number of landings previous 90 days	41

[1] ARC – Airworthiness Review Certificate.
[2] UTC – Coordinated Universal Time.
[3] CAVOK – Ceiling and Visibility OK (international abbreviation that replaces data concerning ceiling, visibility and weather under good weather conditions).
[4] QNH – altimeter set so that the altitude above mean sea level is obtained when on the ground.
[5] CPL – Commercial Pilot Licence.
[6] FI – Flight Instructor.
[7] A – Aeroplane.
[8] R – Restricted (authorisation is restricted to leading flight training under the supervision of an FI for the same category of aircraft).

Summary

The intention was to perform a training flight under visual flight rules (VFR). Runway 16, which was being used, was accessed by the instructor to be the most critical runway at Stockholm/Skavsta Airport if an engine failure were to occur as there were obstructions in the direction of take-off.

During the take-off phase and up to an altitude of 500 feet, everything was normal. Just after this, the engine began to lose power before finally failing. The instructor took control of the aeroplane, called *'returning'* on the tower frequency and attempted to return to the runway in the opposite direction. During the turn at low speed, the left wing contacted the ground. The aeroplane then hit the ground with its belly and right wing. The aeroplane then rotated in the roll axis before coming to a halt with the left wing folded in under the fuselage and with the empennage broken off. The engine was torn off and ended up separate from the fuselage.

The instructor and the student were able to get themselves out of the aeroplane uninjured. One witness was on site immediately in order to help after the accident.

The accident was caused by the engine failing in a situation in which there were limited opportunities to land safely. The lack of sufficient knowledge and experience of the difficulties involved in performing a 180 degree turn at low altitude back to the runway following an engine failure led to an uncontrolled impact.

A contributory cause has been that the flight school has not identified through its safety management system the risks that can arise in the event of an engine failure at low altitude.

An underlying cause has been that the EASA's regulations for engine failure after take-off do not describe how this training should be conducted.

Safety recommendations

EASA is recommended to:

- Evaluate and decide whether and which high-risk manoeuvres shall be included in training and be described in a guidance document. One such high-risk manoeuvre could be the operation that involves how to assess when a turn back to the field is safe. See sections 2.4.1 and 2.5.1. *(RL 2021:03 R1)*
- Develop and distribute through the competent authorities a safety bulletin in order to increase knowledge of "*the impossible turn*". *(RL 2021:03 R2)*

The Swedish Transport Agency is recommended to:

- In its role as competent authority, to review the training organisation's safety management systems in terms of the handling and training of emergency procedures at low altitude after take-off. *(RL 2021:03 R3)*

The Transportation Safety Bureau of Hungary is recommended to:

- Revise the training requirement, and confirm that the training organisations are complying with AMC1 FCL.930.FI. *(RL 2021:03 R4)*

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Preconditions

The instructor, who was in the final stage of supervision as an instructor, was to perform a training flight with a student who was undergoing an integrated flight training programme in order to obtain a commercial pilot licence CPL(A).

The intention was to perform a training flight under visual flight rules (VFR). Runway 16, which was in use, was assessed by the instructor to be the most critical runway at Stockholm/Skavsta Airport if an engine failure were to occur. This is because there were obstructions in the take-off direction.

Prior to the flight, technicians had rectified a remark that meant it was not possible to shut down the engine using the mixture.

Earlier that day, the aeroplane had been used for three training flights. Before the training flight immediately preceding the flight during which the accident occurred, the aeroplane was fuelled up and then flown for 40 minutes. Consequently, the aeroplane had not been refuelled prior to the flight in question as the fuel exceeded the minimum fuel requirement.

Engine run-up and inspection was performed in accordance with the aeroplane’s checklist without remark. The fuel selector was set to the left tank, which was also the one that was full.

The crew chose to take-off abeam taxiway F, which meant that the available runway length was around 1,800 metres of the 2,043 metre-long runway.

1.1.2 Sequence of events

According to the pilots, everything was normal during the take-off phase and up to an altitude of 500 feet. After this, the engine began to lose power before finally failing. The instructor, who was sitting on the right, took control of the aeroplane and checked the engine controls. He called ‘*returning*’ on the tower frequency and intended to return to the runway in the opposite direction (runway 34) by turning to the left.

The stall warning[9] sounded on several occasions. During the turn, the instructor felt that the aeroplane was on collision course with the fuel storage tanks on the apron, which is why he turned further to the left in order to avoid a collision.

[9] Stall – a flight state where the angle of attack is so high that the airflow separates from the wing, which results in a drastic reduction in lift.

During the turn, at low speed, the left wing contacted the ground. The aeroplane then hit the ground with its belly and right wing. The aeroplane then rotated in the roll axis before coming to a halt with the left wing folded in under the fuselage and with the empennage broken off. The engine was torn off and ended up separate from the fuselage.

The instructor and the student were able to get themselves out of the aeroplane uninjured. A witness was on site quickly in order to provide assistance, and the fire and rescue service was on site within 90 seconds after the accident. Because fuel was leaking from the aeroplane, the fire and rescue service put extinguishing agent on the area surrounding the aeroplane. A pallet was placed under the fuselage in order to stop a fuel leak.

The accident occurred at position 5847N 01654E, 43 metres above mean sea level.

1.1.3 Additional information

Interviews with air traffic control in the tower

An air traffic controller and assistant who were monitoring the flight have described how their perception was that the aeroplane was climbing slowly and that mist formed behind the aeroplane during the initial phase. When crossing runway 08/26, it was thought that the aeroplane was no longer climbing before it then began descending. It then appeared that the aeroplane began a right turn and thus came to the west side of the runway. When the aeroplane had descended and passed the runway threshold, a left turn began at an altitude that was perceived to be about the same as the height of the tower. During this turn, the perception was that the aeroplane lost height at low speed and collided with the ground. Figures 1 and 2 show a pictorial description of how the sequence of events was perceived by the air traffic controller from the position in the tower.

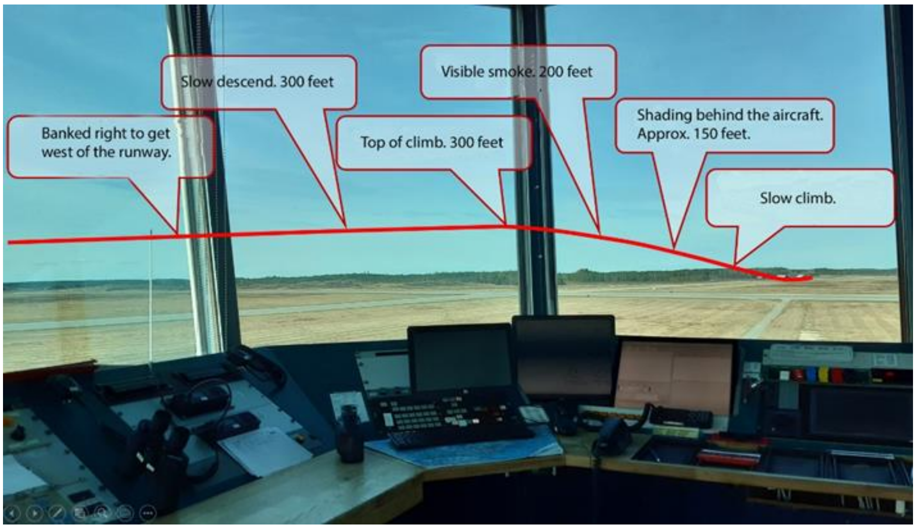

Figure 1. The air traffic controller’s description of the sequence of events (part 1): Photo: ATC Controller, Skavsta tower.

Figure 2. The air traffic controller's description of the sequence of events (part 2). Photo: ATC Controller, Skavsta tower.

The air traffic control assistant perceived a sort of mist following the aeroplane that resembled the appearance of a fuel leak.

Interview with a witness on the ground

A witness who was standing on the apron, to the south of the tower, noticed the aeroplane in the air after the engine had failed. The witness saw the aeroplane first descend and turn a little to the right before then climbing and losing speed. The aeroplane lost altitude rapidly, turned left and collided with the ground, initially with the left wing, before spinning round. The engine was thrown over the fuselage and ended up beyond the aeroplane.

The witness quickly went over to the accident site in order to assist the crew. The two crew members got out of the aeroplane themselves without visible injuries. The fire and rescue service arrived at the site shortly afterwards.

Interview with the instructor

Information from the interview has mainly been described in section 1.1.2. In addition to this, the following has emerged from the interview with the instructor.

The instructor has stated that the procedure for engine failure after take-off at low altitude is reviewed before each flight. According to this procedure, landing following engine failure shall take place straight ahead or shall deviate no more than 30 degrees from the take-off direction. Although this is reviewed before take-off, the instructor stated that this was not an option for the runway in question as there were obstructions in the direction of take-off. The instructor was convinced that the outcome of the accident would not have been survivable if the procedure had been followed.

1.2 Injuries to persons

Ambulance personnel offered the instructor and the student medical examinations, which were declined. Both felt neck pain on the day after the accident and were sent by the flight school to hospital for examination.

	Crew members	Passengers	Total on board	Others
Fatal	-	-	0	-
Serious	-	-	0	-
Minor	2	-	2	Not applicable
None	-	-	-	Not applicable
Total	2	0	2	-

1.3 Damage to aircraft

Destroyed.

1.4 Other damage

1.4.1 Environmental impact

Around 20 litres of fuel leaked out onto the ground.

1.5 Personnel information

1.5.1 Qualifications and duty time of the pilots

The instructor

The instructor, 31 years old, had a CPL(A), FI(A)R with a valid class rating and medical certificate. During take-off and until the engine failed, The instructor monitored the flight, after which he took control.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	1	3	36	393
Actual type	1	3	36	142
Flight time as FI	1	3	36	118

Number of landings actual type previous 90 days: 57.

Skill test for SEP (land) conducted on 25 March 2019 on type.

Competence assessment for the first issue of the FI authorization was conducted on 24 May 2019.

English language proficiency level 6.

The student

The student, 33 years old, was training towards a CPL with medical certificate. During take-off and until the engine failed, the student was in control of the aircraft, after which the instructor took control.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	0	2	14	55
Actual type	0	2	14	50

Number of landings actual type previous 90 days: 41.

English language proficiency level 6.

1.6 Aircraft information

The aircraft of the model TB 9 is a four-seater, low-wing, single-engine aeroplane. It is just over 7 metres long and has a wingspan of just under 10 metres.

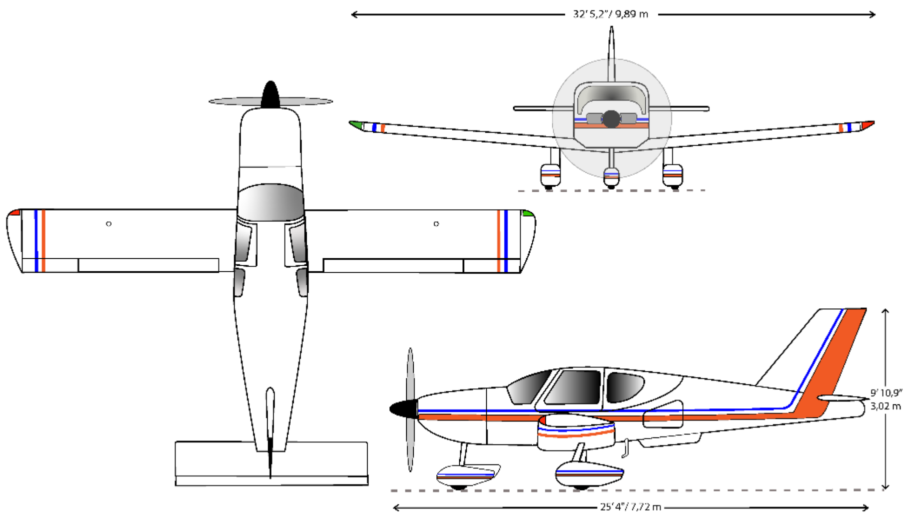

Figure 3. Three-view drawing of the aeroplane model.

1.6.1 Aeroplane

TC-holder	DAHER AEROSPACE
Model	TB 9
Serial number	1535
Year of manufacture	1993
Gross mass (kg)	Max. take-off mass 1,060 kg, current 958 kg
Centre of gravity	At the front within limits.
Total flying time, hours	4,042
Flying time since latest inspection, hours	2
Type of fuel uplifted before the occurrence	100LL
Engine	
TC-holder	LYCOMING ENGINES
Type	O-320-D2A
Serial number	L-17607-39A
Operating time since over-haul, hours	370
Operating time since last oversight, hours	2
Propeller	
TC-holder	SENSENICH PROPELLER MANUF.
Type	74DM6S8-0-54
Serial number	A54740
Total operating time, hours	370
Operating time since inspec-tion, hours	2
Deferred remarks	None

The aircraft had a Certificate of Airworthiness and a valid ARC.

1.6.2 Description of parts or systems related to the occurrence

Engine

The aeroplane is powered by a four-cylinder, horizontally opposed, direct-drive LYCOMING 0-320-D2A engine, rated at 160 BHP at 2700 RPM. It is provided with a starter, a 24 volt/70 amp alternator, an all-weather shielded ignition harness, two magnetos, a vacuum pump drive, a fuel pump and an manifold air filter.

The engine mount is made of steel tubing, rigidly attached on firewall.

Engine inlet air penetrates through an air intake located on the left side of the lower cowl and goes directly through a filter, before being admitted in the air duct under the carburetor. The air duct comprises an alternate air intake with mechanical closing, the purpose of which is to supply the carburetor with heated air when the airplane is involuntary in icing conditions.

Fuel system

The fuel system (Figure 4) consists of two vented, integrated fuel tanks (one in each wing), a fuel selector valve, a filter, an auxiliary fuel pump as well as an engine-driven fuel pump and a carburetor.

Engine-driven fuel pump suction draws fuel from L.H. or R.H. tank through the three-position selector valve and a filter. Then, the fuel goes through the auxiliary fuel pump (electric) and supplies the engine fuel pump. The engine pump supplies fuel under pressure to the carburetor.

The selector valve is controlled through a knob labeled *'FUEL SELECTOR'*. The selector valve knob has following positions labelled: *'CLOSED', 'LEFT'* and *'RIGHT'*.

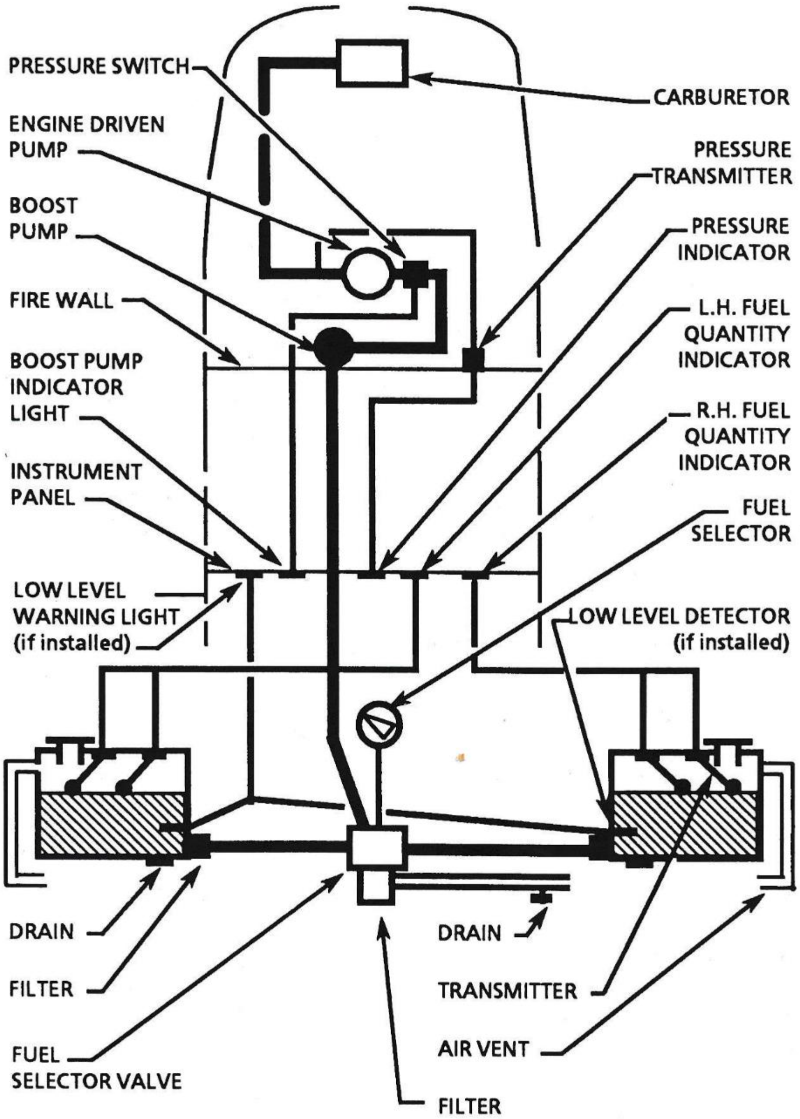

Figure 4. The fuel system for the aeroplane type. Image: Socata TB9 Aircraft Flight Manual.

1.7 Meteorological information

According to SMHI's analysis: Wind, south to south-west, 12 to 15 knots, visibility more than 10 km, cloudless, temperature/dew point +12/+01°C, QNH 1024 hPa.

Upper winds and temperature:

- 500 feet: 160 degrees 20 knots, 8°C.
- 1000 feet: 170 degrees 25 knots, 8°C.

The accident occurred in daylight.

1.8 Aids to navigation

None.

1.9 Communications

Relevant radio communications between the pilot in the aeroplane and the ATC at Skavsta tower have been recorded and are presented in Table 1. A relevant telephone conversation is shown in Table 2.

At the same time as the flight in question, there was another single-engine aeroplane in the circuit and this was asked to cancel its approach.

Time (Z)	Skavsta tower	Internal speech	SE-MKV
13:59:01	S-KV, wind 170 degrees 14 knots runway 16 cleared for take-off		
13:59:06			Runway 16 cleared for take-off S-KV
14:00:00		Oh, what he va….	
14:00:02		Yes, what xx does he...aaah	
14:00:06		Does he have fuel, ehhh, is he leak….	
14:00:11			S-KV returning
	S-KV Roger, S-HT abort and increase speed, keep turning east		
14:00:22		I think he that he has, hel………	
14:00:26	All runways available		
14:00:28		I'm pressing imme-diately (alarm goes off)	
14:00:46			
14:00:52		One getting out of the plane now	

Table 1. Transcribed radio communications from the occurrence.

Time (Z)	Air traffic control	Instructor SE-MKV
14:02:00	Skavsta tower, this is XXX	
14:02:04		Hi XXX, it's XXX I'm the pilot in command for this airplane. But it was falling down, I could not control it
14:02:30	No, I can see that, there was something coming out of it to so I don't know	
14:02:34		is it?
14:02:35	Fuel or something	
14:02:37		I don't know to be honest, it was everything fine with the checks. So there's the thing I just checked it now…..

Table 2. Transcribed telephone conversation from the occurrence.

1.10 Aerodrome information

Stockholm/Skavsta Airport is an approved instrument aerodrome in accordance with AIP[10] Sweden. The airport has two intersecting paved runways with the designations 08/26 and 16/34. Runway 16 was being used at the time, which is 2,043 metres long and 40 metres wide. The runway was dry at the time.

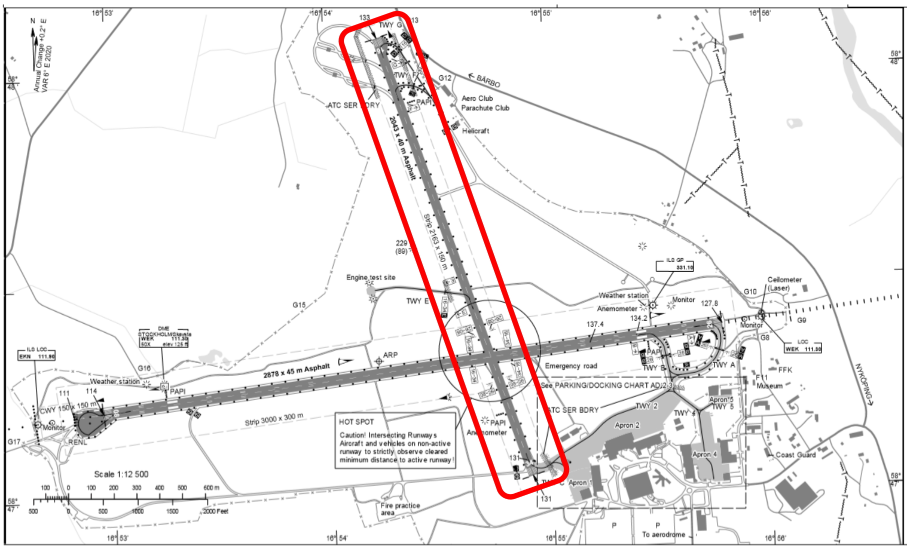

Figure 5. Image showing an overview of Stockholm/Skavsta Airport, with markings for the runway in use. Image: AIP Sweden with red markings by SHK.

After the end of the runway, there was a 167 metre-long strip to a perpendicular road and then a further 30 metres of free space that ends in a fence. After the fence, there was an area with tall vegetation and then a wooded area with young trees. Figure 6 shows an image of the runway threshold taken from a drone at an altitude of 37 metres (120 feet).

Figure 6. Image taken from a drone showing the characteristics after the end of the runway, with a marking indicating the accident site.

The airport's reference point is located 43 metres (142 feet) above mean sea level.

At the time, the airport had fire category 7.

[10] AIP – Aeronautical Information Publication.

1.11 Flight recorders

Flight recorders were not required for the aeroplane type and nor were there any installed.

1.11.1 Radar data

SHK has obtained radar data from the Swedish Air Navigation Services Provider (LFV). The images below that show the aeroplane's flight path have been produced with the aid of the data from LFV.

The heights in Figure 7 follow the yellow line and may deviate by plus/minus 50 feet. The deviations are because a radar height is rounded to the nearest hundred, which means that the actual profile may vary within the scope of the red lines. Radar data for lower heights has not been recorded. All heights are adjusted from QNH to the elevation of the runway threshold and show the height above the ground.

The speed markings under the profile lines refer to an approximate calculated indicated speed. When calculating speed, SHK has taken into account the reported wind at the time of take-off.

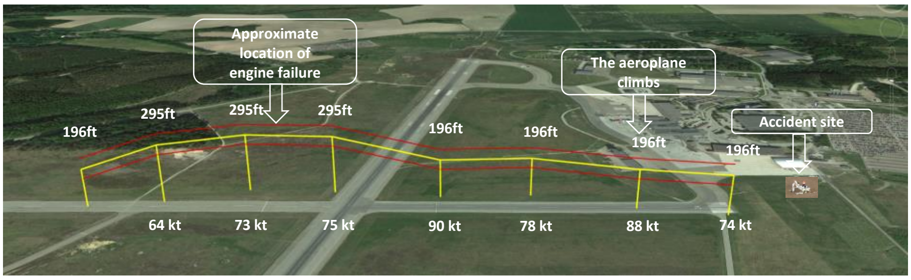

Figure 7. Radar data from LFV (yellow line) shows the route, approximate speed and height with a margin of ±50 feet (red line). Image: Google Earth with inserted route and text by SHK.

Figure 8. The route according to radar data from LFV (yellow line). Image: Google Earth with inserted route and text by SHK.

1.12 Accident site and aircraft wreckage

1.12.1 Accident site

The final position was 87 metres from the runway centre line and 133 metres from the end of the runway. The distance from the end of the runway to the wooded area was 380 metres.

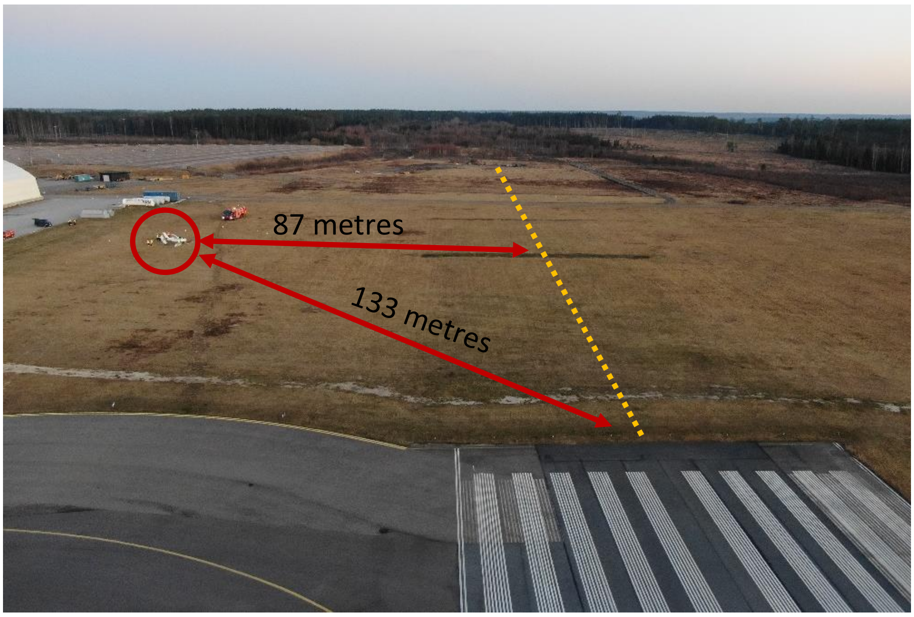

Figure 9. The aeroplane at the accident site in relation to the end of runway 16.

Figure 10. The angle between the take-off heading runway 16 and the impact heading at the time of the accident.

1.12.2 Aircraft wreckage

The aeroplane's left wing was broken off at the wing root and ended up under the fuselage. The right wing had major damage on its leading edge. Upon impact, the engine was torn off where the engine mounting attaches to the firewall, continuing in the direction of travel and ending up beyond the aeroplane. The stabiliser and its attachments had been partially torn loose from the structure. The cabin was basically intact.

Inside the cabin, panels from the luggage compartment had come loose. The left shoulder strap and its upper attachment had been torn off, together with surrounding structures.

Figure 11. Aeroplane wreckage at the accident site.

1.12.3 Technical examination of the aircraft

The initial technical examination at the accident site was conducted on 6–7 April 2020. At the time of the examination, it was established that the controls for the electric fuel pump, the navigation lights, the landing and taxi lights were in the off position. The electrical master and the alternator were in the *'ON'* position. The key for the magnetos was in the *'BOTH'* position. The fuel selector was in the left tank position and the flap for the right wing was partly extended. It was possible to turn the propeller without abnormal resistance. Before the aeroplane was recovered and transported to SHK's examination facility for further technical examinations, the remaining fuel in the aeroplane was drained and measured. There were 36 litres in the right wing tank and 64 litres in the left wing tank.

No faults that may have had a negative impact on the output of the engine were detected during the examinations.

During the subsequent examinations of wing tanks, fuel system, ignition system, engine, carburettor and fuel filter, it was possible to establish that the majority of the spark plugs had a coating of black soot. Small blue paint marks could be seen on the outer wall of the carburettor's float chamber, the paint was the same shade as the float. Aside from this, no faults or discrepancies have been identified that are deemed to have had a potential negative impact on the output of the engine.

1.13 Medical and pathological information

There is nothing to indicate that the mental and physical condition of the pilots was impaired before or during the flight.

1.14 Fire

No fire broke out.

1.15 Survival aspects

1.15.1 Rescue operation

When the air traffic controller pressed the alarm button, the fire and rescue service and SOS Alarm were activated. The airport's fire and rescue service had arrived at the accident site within 90 seconds of the alarm being activated. By that time, the crew had got out of the aeroplane themselves, apparently physically unharmed. Fire and rescue service personnel took care of the crew and offered them transport to hospital in an ambulance for examination, but the crew declined this offer.

As fuel had leaked out of the tanks, foam fire suppressant was laid out in order to reduce the risk of fire.

The ELT[11] of the type Kannad 406 AF-Compact was activated during the occurrence.

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

The student was sitting in the left pilot seat and the instructor in the right. Both were fastened in with three-point seat belts. The upper attachment of the student's shoulder strap detached from the structure during the impact.

None of those on board suffered any serious injuries.

[11] ELT – Emergency Locator Transmitter.

1.15.3 The NTSB's General Aviation Crashworthiness Project (1985)

The American safety investigation authority NTSB conducted a general aviation crashworthiness project in 1985 that resulted in ten conclusions. One of these conclusions was that the use of shoulder belts is the most effective method for reducing fatal and serious injuries in the event of aviation accidents within general aviation.

The project showed that the accidents reviewed in the study were generally survivable within the area demarcated by a line through an impact speed of 45 knots at an impact angle of 90 degrees, 60 knots at 45 degrees and 75 knots at zero degrees.

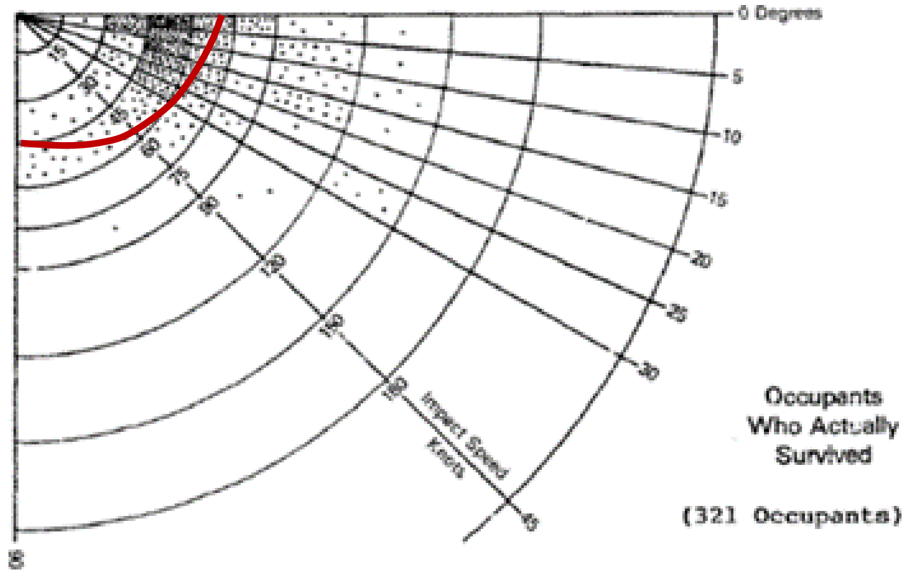

Figure 12. Graph showing the survivable area for general aviation marked with a red line. Impact angle and impact speed. Image NTSB.

1.16 Tests and research

1.16.1 Examination of the fuel

SHK has commissioned Element Materials Technology AB to conduct an analysis of the fuel from the aeroplane's wing tanks. The fuel was of the type 100LL.

The results of the analysis show a good purity and low water content for the right wing tank. The results for the left wing tank indicate the presence of solid contaminants in the fuel.

The measured values for distillation of the sample for the left fuel tank are within the limits required under the applicable specification[12]. However, the sample from the right fuel tank does not comply with the requirements for maximum distillation temperature at the ten per cent recovery point. The fact that the distillation profile differs between the samples may be due to the fuel having been exposed to air for a period and the more volatile fractions having evaporated.

[12] ASTM D910 – Standard Specification for Aviation Gasolines.

One problem that can be experienced as a result of this is that cold starts can become more difficult. This is especially the case for carburetted engines. Because the fuel has a low volatility, the engine can also run unevenly before it has warmed up. However, this is not something that can cause engine failure and fuel was being taken from the left fuel tank at the time of the occurrence.

1.16.2 Examination of the carburettor

The carburettor has been examined on behalf of SHK by Marvel-Schebler Carburetors, LLC in the USA, under the supervision of the Federal Aviation Administration.

Before the tests were conducted, bolts to the float chamber and the piston of the accelerator pump were replaced as the original bolts had been damaged in the accident, see Figure 13.

Testing and examination was conducted on 2 September 2020. The tests resulted in no remarks.

The evaluation did not include idling because the final confirmation for this setting can only be done when the engine is running.

Figure 13. Damaged piston of accelerator pump (left) and part of the carburettor (right).

1.16.3 Examination of the broken off nipple on the electric fuel pump

SHK has commissioned Element Materials Technology AB to conduct an examination of the part of the electric fuel pump where a nipple has been broken off. The aim of the examination has been to establish whether the nipple has been broken off by a force on a single occasion or if there has been defects or cracks in the soldered joint that have gradually led to the nipple coming off.

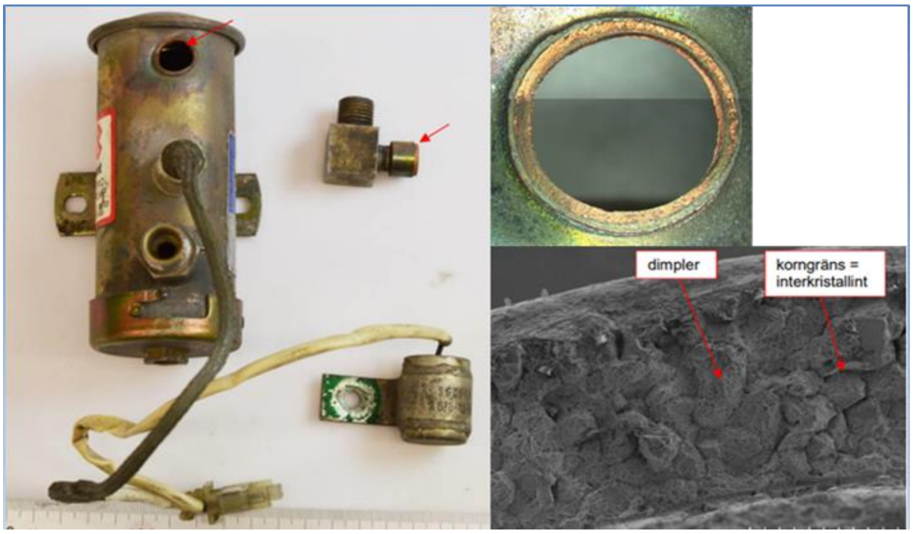

Figure 14. Picture on the right: Fuel pump and detached nipple. The arrows show the fracture surfaces in the soldered joint. Picture top right: Fracture surface on the pump. Picture bottom right: SEM[13] image of the fracture surface on the nipple. The fracture surface is intercrystalline and shows small craters (dimples).

The examination showed that the break is a hard stress rupture from an oblique tensile load. Accordingly, it is most likely that the nipple has been broken off on a single occasion. There may have been small fatigue cracks, but these have not led to the fracture. The fracture surface as a whole, with high deformation and small craters (dimples), is not consistent with fatigue. The soldered joint is made of copper with relatively high levels of sulphur impurities.

1.16.4 Examination of the strength of the seat belt attachment

The bracket of the left pilot's shoulder strap had been broken off the doorpost behind the pilot. The bracket was mounted on a fibreglass structure that consisted of a laminate that was thinner than one millimetre. The design of the bracket results in the laminate being subjected to combined tractive, bending and shearing forces.

According to the certification specifications FAR[14]- 23.785 and 23.561, which were applicable to the certification of the aeroplane, the restraint straps have to cope with a forward load of at least 9 G x 86 kg = 774 kP. Because it was a three-point safety belt, the load was distributed to three attachments, i.e. 258 kP per attachment.

[13] SEM – Scanning Electron Microscope.
[14] FAR – Federal Aviation Regulations.

In the event of a forward load, the bracket is subjected to an equally large downward force because the bracket only transfers the force to the reel for the inertia-reel belt, which is attached to the floor. This means that the bracket is subjected to a load of over 350 kP.

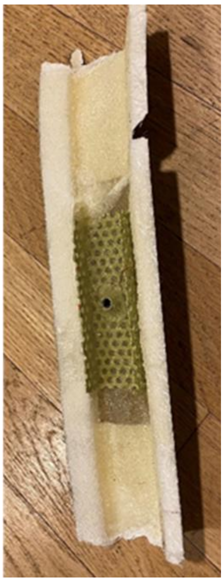

Figure 15. The seat belt attachment on the left side.

1.16.5 *Reference flight*

SHK has conducted a reference flight using an aircraft of the same type.

The purpose of the reference flight was to understand the flight characteristics of the aircraft type and the situation in which the crew was at the time of the accident. Another aim was to obtain relevant flight data under conditions that were as consistent as possible with those that prevailed at the time of the accident. The reference flight was recorded using Nano 3, ForeFlight and GoPro.

The reference flight took place at and in the vicinity of Malmö Airport.

The following manoeuvres were performed:

- Normal take-offs and landings.
- Take-off with simulated engine failure at various heights (100, 200, 300 and 400 feet above the ground) and then glide flight to landing.
- 180 degree turns with the engine at idle from an altitude of 4,000 feet with banking of 30 degrees and 45 degrees.

Take off with simulated engine failure

The profile below describes a flight with similar altitudes as in the accident, adjusted in position to Stockholm/Skavsta Airport.

Figure 16. GPS data for glide flight from a simulated engine failure at 300 feet above the runway.

180 degree turns at 4,000 feet

The aim of the flight was to understand how much altitude was lost and what turn radius the manoeuvre with the aeroplane resulted in following a 180 degree turn, which would resemble the crashed aeroplane's turn back to the runway. For safety reasons, the flight was performed at an altitude of 4,000 feet, which means that the altitude loss and turn radius were probably somewhat larger than those of the accident flight. At the same time, the engine was not shut off completely, which means that there may have been some propulsion from the propeller.

The entry speed for the turn was either stall speed or 5 knots above stall speed with flaps in take-off position.

The minimum altitude loss and turn radius for each bank angle are presented in Table 3.

Bank	Turn in degrees	Flap position	Altitude loss (feet)	Turn radius (m)	Time (sec.)
30	180	1	230	512	23
30	143	1	177	441	17
45	180	1	210	263	13
45	141	1	135	243	10

Table 3. Minimum altitude loss and turn radius for each bank angle and for entry speed stall + 5 knots.

In a turn with a 45 degree bank angle, the aeroplane was felt to be stable, with increasing speed in the turn and no clear tendencies to enter spin.

1.16.6 Combined data

As described in previous sections, information about the occurrence has been provided by a witness in the tower and a witness on the ground. During the interviews, flights with a drone were performed as a reference for the witnesses to relate their memory recollections. Radar data concerning the flight in question are available. Figures 17 and 18 show the witnesses' experiences of the flight and the recorded radar data.

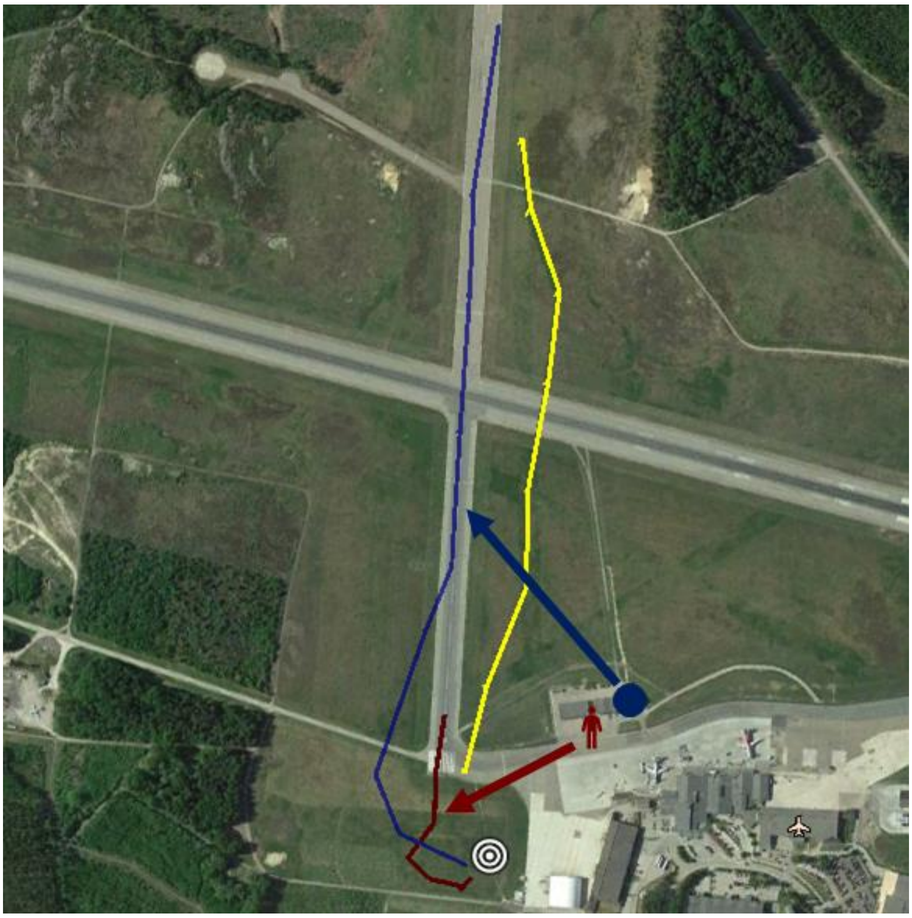

Figure 17. Radar data in yellow, information from the witness in the tower in blue and information from the witness on the ground in dark red. Image: Google Earth with markings added by SHK.

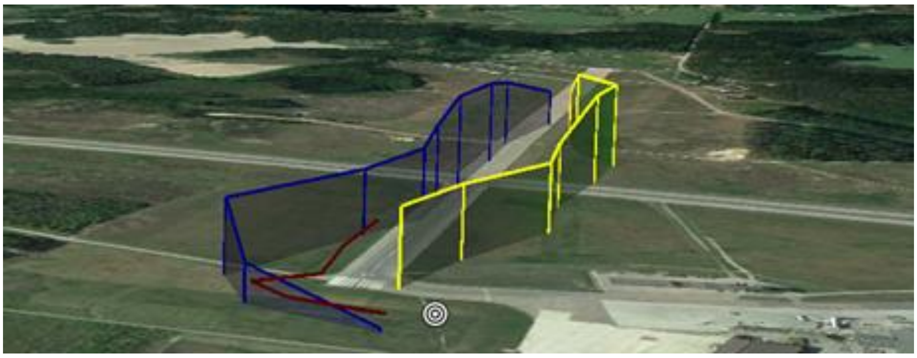

Figure 18. Radar data in yellow, information from the witness in the tower in blue and information from the witness on the ground in dark red Image: Google Earth with markings added by SHK.

1.17 Organisational and management information

1.17.1 General

Skies Airline Training AB (the flight school) was an approved training organisation with a valid training certificate, SE.ATO.0002.

The flight school was formed in 2012 and had its principle base of business at Stockholm/Skavsta Airport.

The flight school had authorisation to operate the training activities that were being conducted during the flight. The flight was part of an integrated ATPL training programme.

1.17.2 The flight school's management system

The management system was described in the flight school's operations manual (OM), safety management system manual (SMM) and a number of training handbooks.

The OM described the organisation's management system, standard operating procedures and the procedures that were being implemented by the organisation in order to ensure compliance with applicable national and international rules and regulations.

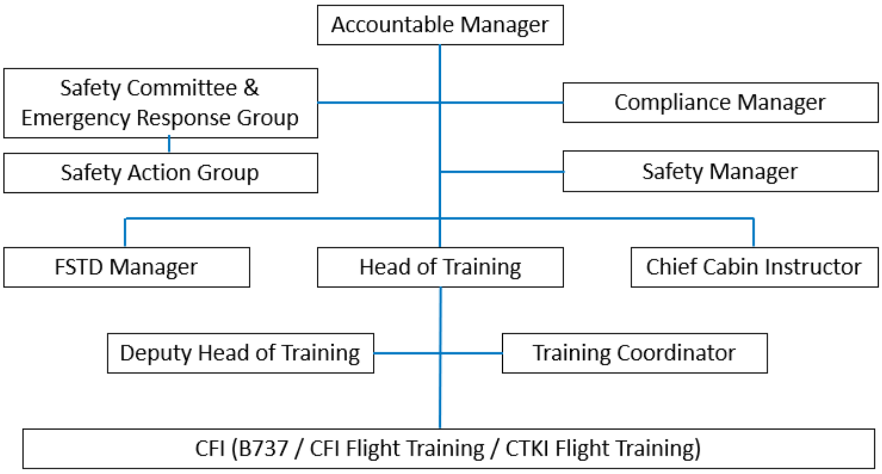

Figure 19. The flight school's function and management system structure.

The purpose of the safety management system manual was to support and continually improve safety at the flight school.

The safety management system's organisation consisted of the Accountable Manager (AM), Safety Manager (SM), Safety Review Board, Safety Action Group and Emergency Response Group.

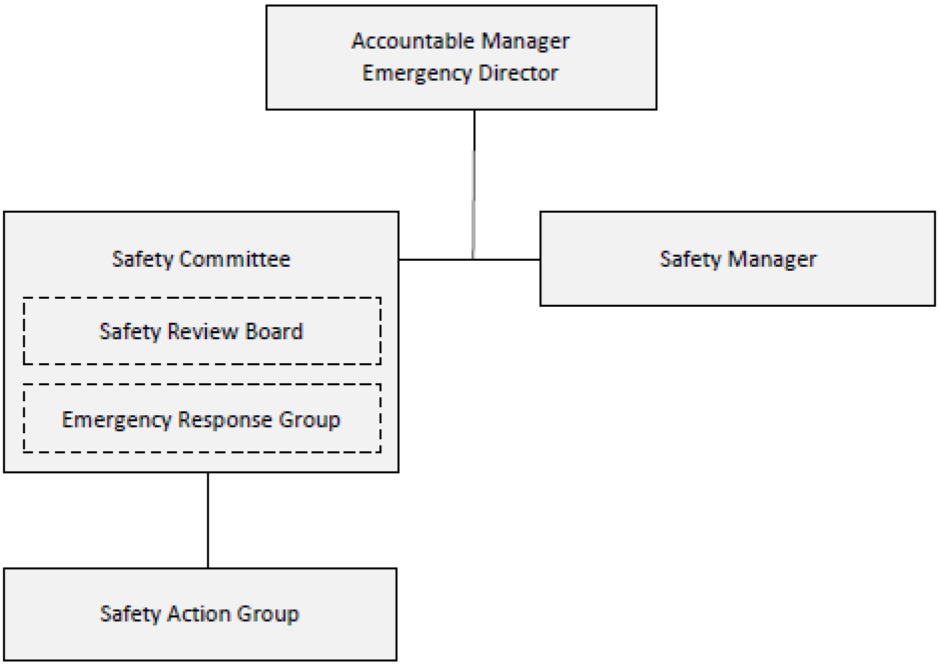

Figure 20. Organisation and structure of the safety management system.

Quarterly meetings of the Safety Committee were the highest level of flight safety management at the flight school. The Safety Review Board (SRB) and Emergency Response Group took part in these meetings. Obligatory participants were the Accountable Manager, the Head of Training, the Compliance Manager and the Safety Manager.

The SRB was responsible for ensuring that the safety management system was audited in order to ensure themselves of continual improvement. At each meeting, the SRB dealt with reports received, newly detected risks, review of the risk log, approval of a new version of the risk log, review of MOC[15], notified safety information and the safety management system's compliance with directive and due dates.

A risk management process was described in the SMM. This consisted of risk identification, risk assessment and risk reduction. The overarching goal for the risk management was to ensure a level of risk in accordance with ALARP[16]. A risk matrix was used in order to define the risk based on severity and probability.

The school used a risk management log in order to document hazards and risks. Each identified risk was described in the log, following which existing procedures and barriers in respect of the risk were identified. Each risk was subject to a risk assessment before a risk mitigation measure was performed. A new risk assessment was then performed, after

[15] MOC – Management Of Change.
[16] ALARP – As Low as Reasonably Practicable.

which the final risk level was established. The risk log was updated when a new risk was identified, a risk assessment was conducted for a risk or a new risk mitigation measure was decided by the SRB. A workshop was conducted once a year in order to review all risks. The latest workshop took place just over one year before the accident.

The flight school's risk management log contained the general risk of engine failure during various phases of flight, including engine failure after take-off. The risk before risk mitigation measures were performed for engine failure was defined as undesirable, which means that the risk should be reduced to ALARP. In order to reduce the risk to an acceptable level and in accordance with ALARP, the following risk mitigation measures were defined: the flight school's standard operating procedures (SOP) for each aeroplane type, TEM[17] training for SOP applicable to engine failure, flight instructor standardisation for TEM training and SOP for fuelling. At the time of the accident, TEM was not implemented at the flight school as a risk mitigation measure.

The training manual described what would be performed as part of the training programme. In order to define how the exercises would be performed, the flight school used the *Air Pilot's Manual*, which was an aid used to describe the training in more detail.

1.17.3 Regulations governing operations

Flight operations conducted within the EU are subject to the common rules of the air that are set out in Regulation (EU) 2018/1139 of the European Parliament and of the Council on common rules in the field of civil aviation etc. and regulations that fall under this. Compliance with these provisions is monitored at the EU level by the EASA, which also supervises the member states' national aviation organisations and supervisory authorities.

Training operations of the type conducted by the flight school are governed by Commission Regulation (EU) No 1178/2011, Annex VII, Part-ORA, Subpart GEN and Subpart ATO. The requirements that an approved training organisation (ATO) must meet in order to be granted authorisation to conduct flight training are specified in this regulation. These requirements include that the organisation in question has established a monitoring system for compliance with relevant requirements (CMS) and a safety management system (SMS).

The management system shall be tailored to the size of the organisation and the nature and complexity of its operations, taking into account hazards and associated risks resulting from the operations.

[17] TEM – Threat and Error Management.

1.17.4 *Operational inspections*

Under the rules in Commission Regulation (EU) No 1178/2011, Annex VI, Part-ARA, Subpart ATO, the national supervisory authority, which in Sweden is the Swedish Transport Agency, shall conduct regular inspections of flight training operations. The primary aim is to monitor the organisation's compliance with both the regulations and the procedures and systems that the organisation has described in its manuals.

A review of the organisation's SMS and CMS is included in an inspection. The operator shall demonstrate how the organisation assesses and deals with any aviation safety risks that may arise in its operations. The operator shall also present a plan for a systematic safety management process that involve the continually monitoring of its operations and allows non-conformities and risks to be detected. The aim of this system is to minimise the risks associated with the operations and also to rectify the safety failings identified.

The inspection is conducted on site at the organisation by at least two flight inspectors, one of which has normally participated in performing the previous year's inspection.

During inspections at the flight school in 2019, a non-conformity was noted in respect of how the ATO was implementing and evaluating the effectiveness of remedial measures. Scrutiny of the organisation's risk register did not indicate that the effectiveness of risk mitigation measures was being evaluated.

1.17.5 *The flight school's standard operating procedures (SOP)*

The flight school's ATO had an SOP for the Socata TB9. This manual described the flight school's procedures and processes when planning and performing a flight.

The procedures that were to be performed prior to each flight were described in Chapter 4 of the manual. The flight school used a flight preparation checklist in order to ensure that all preparations were implemented. Prior to each flight, a risk assessment was also conducted using a preflight risk matrix (SPRAM). Various predetermined risks were evaluated by the pilot on a scale of zero to five, where five indicates a high risk. All of the risk scores were then added together to give a total number of points indicating the total risk of the flight. A higher value indicated higher risk. For this flight, the total number of points was 18, which, according to the SPRAM, means that there were no specific hazards. According to the SPRAM, a normal plan and normal procedures were to be used.

Chapter 5.2 of the manual specified a 'departure briefing' that was to be reviewed through prior to each take-off. This was to include running through risks and unexpected situations after take-off. For situations involving engine failure after the aeroplane has left the ground, and where there was not deemed to be sufficient runway to land, it was specified, among other things, that a landing area shall be identified within 30 degrees to the left or right of the original heading.

According to the pilot's operating handbook (POH), the speed was to be increased and the flaps retracted at 300 feet, and the electric fuel pump was to be turned off at 1,000 feet. According to the flight school's SOP, the flaps were to be retracted at 400 feet above the ground and the procedure after take-off performed once the transition altitude[18] had been passed or the aeroplane had left the airport's control area.

It emerged during interviews with the head of training and pilots that memory items were normally performed at 400 feet, which means that the flaps are to be retracted and the fuel pump and landing lights turned off.

A checklist for dealing with engine failure was available that was consistent with the pilot's operating handbook.

ENGINE FAILURE IMMEDIATELY AFTER TAKE-OFF

AIRSPEED .... 70 KIAS
MIXTURE .... FULL RICH
Fuel selector .... SWITCH TANKS
Fuel pump .... ON

If engine does not start :
MIXTURE.......... IDLE CUT-OFF
Fuel selector .... OFF
Fuel pump .... OFF

LAND .... STRAIGHT AHEAD
Magneto selector.......... OFF
Main switch .... OFF

WARNING
LANDING STRAIGHT AHEAD IS USUALLY ADVISABLE

Figure 21. The flight school's checklist for dealing with engine failure after take-off.

The instructor training programme

The instructor had completed his training at *CAVOK Aviation Training*, an ATO in Hungary. The training programme consisted of six weeks' classroom training and three weeks' training in aeroplanes. The flight school did not perform advanced manoeuvres such as spin because it did not have an approved aeroplane for advanced manoeuvres. According to the instructor, he had never during his flying career performed or been present during advanced manoeuvres such as spin.

[18] Transition altitude – altitude at which the altimeter is to be reset to the standard setting (1013 hPa) during climb.

The EASA training requirements for instructors

The mandatory air exercises for the instructor course are described in AMC1 FCL.930.FI. Stall and fully developed spin are included in the manoeuvres that shall be performed during the training programme.

1.18 Additional information

1.18.1 'The impossible turn'

A turn back to the airport after an engine failure in a single-engine aircraft has, for good reason, been termed '*the impossible turn'*. It requires sufficient altitude and involves aggressive manoeuvring. For a crippled airplane already flying low and slow, this combination of lost altitude and closing to stall speed can quickly turn a bad situation into a tragic one.

In the publication *Sunny Swift*, which is published by the EASA, this manoeuvre is described as '*the impossible turn'*. This publication states that a return to the take-off airport should not be attempted if there is not an ample height margin. The text in the publication refers to an FAA document.

The FAA has published an advisory circular (AC 61-83J), which describes how instructors are to demonstrate and teach a safe 180 degree turn back to the field after an engine failure.

'Instructors should also train pilots of single-engine airplanes not to make an emergency 180-degree turnback to the field after a failure unless altitude, best glide requirements, and pilot skill allow for a safe return. This emergency procedure training should occur at a safe altitude and should only be taught as a simulated engine-out exercise. A critical part of conducting this training is for the flight instructor to be fully aware of the need for diligence, the need to perform this manoeuvre properly, and the need to avoid any potential for an accelerated stall in the turn. The flight instructor should demonstrate the proper use of pitch and bank control to reduce load factor and lower the stall speed during the turn. After completing this demonstration, the flight instructor should allow the trainee to practice this procedure under the flight instructor's supervision. Flight instructors should also teach the typical altitude loss for the given make and model flown during a 180-degree turn, while also teaching the pilot how to make a safe, coordinated turn with a sufficient bank. These elements should give the pilot the ability to determine quickly whether a turnback will have a successful outcome. During the before-takeoff check, the expected loss of altitude in a turnback, plus a sufficient safety factor, should be briefed and related to the altitude at which this manoeuvre can be conducted safely. In addition, the effect of existing winds on the preferred direction and the viability of a turnback should be considered as part of the briefing.'

Royal Swedish Aero Club (KSAK)

The private pilot's operational handbook is an aviation safety programme that was formerly known as H50P.

The Swedish Transport Agency and KSAK has updated the operational handbook, which is divided into a number of compendia on the basis of regulations and statistics.

The operational handbook describes how to deal with engine fault during take-off as follows:

'If you suffer some form of engine failure during take-off, you shall abort immediately. The aim is to remain on the runway/strip or, in the worst case, make use of the stopway. Should the fault occur after take-off and you do not have enough power to continue the climb or fly towards an area suitable for emergency landing, the same actions apply as if the engine fails. These are: Push the stick forward immediately and with certainty; when the aeroplane begins to achieve positive acceleration, engage full flaps gradually and land pretty much straight ahead.

If the climb is steep and the speed is thus too low, the altitude is not sufficient to assume gliding flight in the event of engine failure.

If the climb is normal and the speed is correct, gliding flight can be assumed without the imminent risk of stall and wing drop. The altitude loss is also lower during the transition.

You should not attempt to turn back to the field, even if you have achieved relatively high altitude. The altitude loss with a failed engine during a 180 degree turn is significant.'

1.18.2 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.

1.18.3 Surprising and sudden occurrences

There are obvious difficulties in predicting how an individual will act in a sudden and unexpected situation. From a theoretical perspective, the term *'surprise 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. With 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.

1.18.4 Actions taken

According to the school, the following measures have been taken after the accident:

- The TEM training plan has been further developed so that the training on emergency procedures in the event of engine failure has been supplemented.
- Risk assessment of Stockholm/Skavsta Airport. Measures related to engine failure at take-off, such as that full runway length shall be used at take-off for runway 16.
- Standardization of FI has been supplemented with TEM areas for expanded internal control.

1.18.5 Similar occurrences

On 1 August 2014, an accident involving a Saab 91B Safir with the registration D-EBED occurred at Bremen Airport in Germany. The accident was investigated by BFU (the German Federal Bureau of Aircraft Accident Investigation).

The aeroplane used 1,140 metres of the 2,040 metres of runway available for take-off from Bremen Airport. At 300 feet, the pilot reported engine problems and that he needed to return immediately. During the turn, the aeroplane stalled and hit the ground.

SHK has obtained information from the EU computerised register ECCAIRS *(European Co-ordination Centre for Accident and Incident Reporting Systems)*. This register includes a number of incidents and accidents in which pilots have attempted to turn back to the field in the event of engine failure after take-off, including during flight training. There are also accidents in which pilots have simulated engine failure at low altitude with a subsequent turn back to the runway.

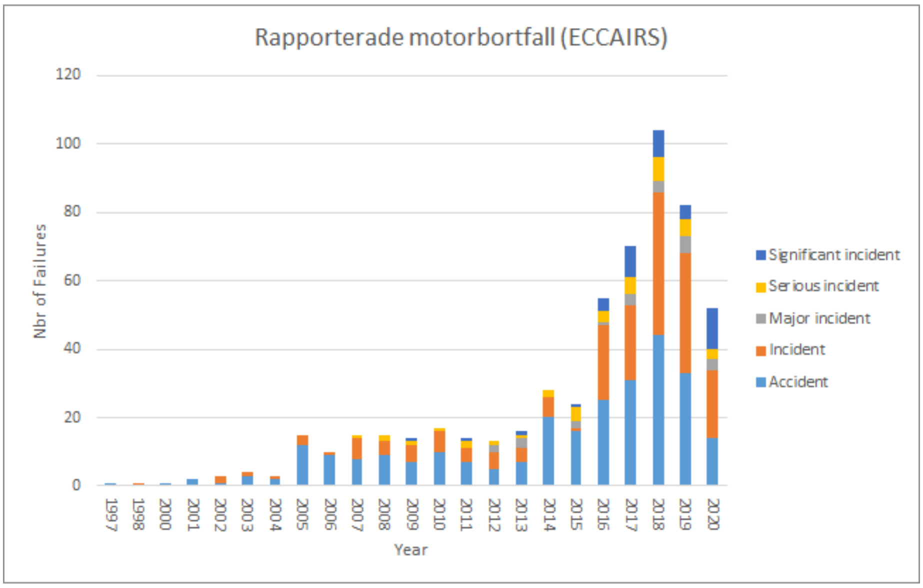

Figure 22. Number of engine failures during take-off, filtered by engine type (piston engine) and number of engines (1).

1.18.6 Special methods of investigation

None.

2. ANALYSIS

2.1 Initial observations

It has been possible to largely establish the sequence of events through the recordings that have been analysed, together with the information from interviews, including those with the crew. It has been established that the engine lost power after take-off and eventually failed. The instructor took control of the aeroplane, which then glided with a wind-milling[19] propeller. A shallow turn to the right was performed and the aeroplane climbed slightly. In order to avoid the approaching terrain, a left turn back to the runway was performed in order to attempt to land in the opposite direction. During the turn, the aeroplane continued to lose altitude and hit the strip south-east of the runway.

The questions that arose and need to be answered are what caused the engine failure and why the instructor did not choose to adhere to the procedure that the flight school taught for engine failure at low altitude. As part of the explanation, there is also reason to analyse in more detail the training the instructor received in respect of teaching and dealing with situations such as this, the structure and function of the regulatory system, combined with the procedures in the safety management system for identifying hazards and how this system assimilates these expe-riences.

Reference flight and radar data

As specified in section 1.16.4, SHK has performed reference flights in order to understand the flight characteristics of the type in question and understand the situation in which the crew found themselves. SHK has also produced relevant flight data for the investigation in order to create circumstances that are as similar as possible to those of the flight during which the accident occurred.

The reference flight was performed at Malmö Airport under similar weather conditions and with the same take-off mass as during the acci-dent in question.

During the simulated engine failure from an altitude of 300 feet that has been described in section 1.16.4, an indicated speed of 70 knots was maintained, which, according to the pilot’s operating handbook, is the speed that is to be maintained if engine failure occurs immediately after take-off. When data from the reference flight was applied to Stockholm/Skavsta Airport, this shows that the aeroplane could have landed just after the runway and come to a stop before the fence if an engine failure had occurred just before the runway intersection at Skavsta.

[19] Windmilling propeller – being turned by aerodynamic drag.

According to interviews, the engine on the aeroplane in question did not stop immediately after the power loss but a few seconds after the instructor had observed the reduction in RPM on the tachometer. Analysis of radar data shows that the speed of the flight in question was somewhat higher than the reference flight during both the climb and the subsequent gliding flightpath. A higher entry speed at the time of the engine failure and the fact that the engine did not stop immediately may explain the difference in flightpath angle between the accident flight and the reference flight. In addition to this, reaction time, time for changing who had control and fault isolation should be taken into account.

For this reason, it cannot be ruled out that a controlled flight straight ahead could have resulted in the aeroplane landing in the terrain after the road and potentially having reached the area with young trees.

During the reference flight, turns with various bank angles were performed in order to gain an understanding of the altitude loss during a turn back to the runway. In this case, the entry speed was 5 knots above stall speed. The minimum altitude loss with a high bank angle appeared to be lower than with a low bank angle because a steep turn takes less time. The calculated change in heading before the wing hit the ground was 140 degrees. SHK has therefore used this value in order to gain an understanding of at what altitude above the ground the aeroplane was when the turn began. The best value with a 140 degree turn to the left gave an altitude loss of 135 feet. Based on this, an assumption can be made about the altitude at which the aeroplane was at the initialisation of the turn.

2.2 Why did the engine fail?

As has been described, no technical fault with the aeroplane could be identified during the examinations that were conducted at the accident site. SHK has subsequently examined relevant systems such as the wing tanks, fuel system, ignition system, engine, carburettor, mechanical fuel pump and fuel filter. The only observation that could be regarded as abnormal was a coating of black soot on the majority of the spark plugs. Small blue paint marks could be seen on the outer wall of the carburettor's float chamber, that were of the same shade of blue as the float. Aside from this, no faults have been identified that are deemed to have had a potential negative impact on engine output. Due to the damage that occurred to the engine in connection with the accident, it has not been possible to perform at test run. The technical examinations that SHK has conducted suggest that the technical measures that were performed prior to the flight have not had a negative impact on engine output. However, in view of the damage that occurred to and around the engine during the accident, and because it has not been possible to subsequently test run the engine, it cannot be ruled out that such a negative impact has arisen.

The separate examinations that were conducted of the carburettor by Marvel-Schebler Carburetors and of the electric fuel pump with a broken off nipple by Element Materials Technology AB have not shown anything that could have caused the engine to fail.

The fact that there were solid impurities in the fuel from the left wing tank can be explained by the fact that the tank was damaged during the impact and that the fuel inside the tank has been exposed to contamination from the ground. Nor did the analysis of the aviation gasoline from the aeroplane's tanks indicate any circumstance that may have caused the engine to fail.

The black soot coating that was found on the spark plugs may suggest that the fuel-air mixture has for a period been too rich, which may mean that it eventually failed to ignite. The blue paint marks in the float chamber suggest that the float has been in contact with the float chamber. However, it cannot be ruled out that this has taken place during the crash. Air traffic controllers have stated that they saw smoke or haze-like cloud behind the aeroplane prior to the engine failure and that the crew did not notice anything other than that the engine RPM decreased.

On this basis, SHK makes the assessment that a probable cause has been that the needle valve for the fuel supply to the carburettor has temporarily become stuck in the open position or that the float has temporarily become stuck in a position such that the needle valve was not able to close. As a result, the carburettor has supplied the engine with a fuel-air mixture that was too rich for a period of time. In turn, this may have led to that the fuel-air mixture no longer was able to ignite, which has led to the engine failure.

2.3 What action was taken just before and during the engine failure?

The student was manoeuvring the aeroplane during the initial take-off sequence up until the engine failure.

The flight was being practised in what is known as a single-pilot system. This means that the pilot performs all tasks such as manoeuvring the aeroplane, navigating, performing memory items and communicating with air traffic control. After the memory items have been performed, the pilot reads a checklist in order to check that all items have been completed.

Once the power loss and subsequent engine failure had occurred and the instructor had taken control, the aeroplane was at or just over the altitude at which the memory items are normally performed. According to information from the instructor, the student and the flight school's management, the memory items that are performed include shutting off the fuel pump and landing light as well as retracting the flaps at an altitude of 400 feet above the ground (QFE). In an interview, the instructor has stated that the memory items were not performed during the flight in question. However, when SHK was documenting the accident site, it could be established that the switch for the fuel pump and landing lights were in the out position and therefore off. Other controls were in the on position. The flaps were in the extended position for take-off. The probability that only the switches for the fuel pump and landing lights had been switched off during the crash while other switches had remained in their original position is very low.

Figure 23. The electrical panel for switches on SE-MKV at the time of the accident. Note that switches for memory items are turned off (pushed out position).

For this reason, it is likely that the engine fault occurred in conjunction with the student beginning the memory items. The instructor may have failed to notice this because he was busy dealing with the situation that arose. The student was probably interrupted while performing the memory items as the flaps were in a partly extended position when SHK examined the aeroplane following the accident. The order of the memory items is first the fuel pump, then the landing lights and finally retraction of the flaps.

According to the flight school's procedure, which also was repeated before take-off, an engine failure at low altitude should be followed by certain additional memory items such as maintaining a speed of 70 knots and landing straight ahead. A clear warning on the emergency checklist describes how a landing straight ahead is preferable. It emerged during the interviews that the instructor was aware that the procedure allowed a deviation in heading of up to 30 degrees in the event of an engine failure of the type in question.

2.4 How was the situation that arose dealt with?

When an abnormal occurrence takes place, there is always a reaction time combined with an element of surprise. How long this process takes varies, but in the event of an engine failure at low altitude, the situation requires an immediate decision. There is no universal approach that can prepare a pilot for all possible eventualities. The basic premise should be to prepare and practise 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.

When the engine RPM began to decrease, the aeroplane was in a position just before the runway intersection for runways 16/34 and 09/27, at 14:00:00 hrs. Eleven seconds later, 14:00:11 hrs, the instructor reported to the tower that he intended to return. He did not provide any details about how he intended to return. However, it is possible to conclude that by this time he had made the decision to return. The instructor had no previous flight experience before his training as a student, and later as an instructor, at the flight school in question. In such circumstances, it is especially important that the flight school's directives are adhered to in line with the training for engine failure at low altitude that the instructor performed on a daily basis in his role as instructor. Consequently, of particular interest to the assessment of the occurrence is what motives the instructor had for choosing an alternative procedure that both deviated from an established procedure and also had a small possibility of being successfully executed at the low altitude.

Eleven seconds can be perceived as of varying length by different individuals. In the present case, it is also likely that the pilot and the instructor were surprised by the sudden engine failure. A model that describes decision-making in such situations is naturalistic decision-making (NDM), which involves potential solutions being analysed sequentially and the first relevant and possible solution to be identified being chosen. It is therefore of the utmost importance for the first identifiable solution to be consistent with an approach or procedure that has the greatest likelihood of resolving the situation.

During the interview after the occurrence, the instructor has stated that he did not see any survivable opportunity to land straight ahead within 30 degrees of the track in either direction, and that he considered this to be a known fact among several pilots at the flight school. Consequently, the instructor deemed this option to be excluded. This means that, even before the accident, the instructor was convinced that the flight school's procedure for engine failure at low altitude was not the best option for this runway. Accordingly, this has made the instructor look for other solutions, which has in turn limited the time window in which to identify and perform an action and achieve a successful outcome. Once the decision had actually been made, i.e. when the sharp turn was initiated, the action was probably not directly intentional but more emotional, based on the fear of the nature of the terrain around and after the end of the runway.

It was the instructor's understanding that if he had adhered to the flight school's procedure, the occurrence would most probably have resulted in a crash involving substantial damage. Unlike that alternative, in his opinion there was a chance to land the plane safely if he only succeeded in the turn and to avoid the various objects in the area. Weighing up these two contrasting options resulted in the latter being chosen. One explanation may be that the instructor was motivated by the potential to completely avoid any damage, if possible, which has to some extent probably been an immediate reaction rather than a conscious analysis of the situation.

During the eleven seconds that elapsed between the engine failure and the decision to turn back, the instructor, in addition to deciding that he intends to land, has also taken control of the aeroplane. He has also made other decisions such as that there was no time to perform the mandatory memory items stipulated in the pilot's operating handbook for engine failure at low altitude. It is fundamental in emergency situations to prioritise flying the aeroplane before navigating and communicating, which the instructor did in the situation that arose.

The instructor has stated that, even before the flight in question, he was not convinced that the school's procedure for engine failure during take-off was the best option in all situations. This is an issue he should have raised with the flight school's safety organisation as soon as the instructor created an opinion that the procedure was not appropriate. However, no such issue has been raised or dealt with by the school's safety organisation. There may be several reasons for this.

In order to have the potential to deal with risks, the flight school's safety management system must first and foremost capture a potential risk. A functioning safety management system also entails not just that procedures described in manuals are adhered to, but also that practical day-to-day work is performed in an appropriate manner and that risks that arise are dealt with continually. This area is analysed in more detail in section 2.6.

Previous training and the clarity of this training can also have an impact on how convinced the instructor was about the existing procedure. The school made a conscious decision not to train pilots to perform a turn back to the runway in the event of an engine failure. Such a manoeuvre is known as *'the impossible turn'* and is described in more detail in section 2.4.1. Nor were there any guidelines for when it is possible to manoeuvre outside of the procedure. The lack of practical training and guidelines may have meant that the conviction in and acceptance of the legitimacy of the procedure could be called into question. When the instructor chose to turn back, he did this with a conviction that the manoeuvre was possible. If there had been training and experience in respect of how much altitude loss results from such a manoeuvre, the decision to return to the runway probably would not have been made.

After the engine failure, the aeroplane glided on the same heading for around eight seconds before the turn was initiated. This shows that there was no understanding of the consequences of the decision as the situation became increasingly unsustainable with additional altitude loss prior to the turn being initiated.

The instructor, who was sitting in the right seat, performed a left turn back to the runway. Sitting in the right seat and performing a left turn means that the visual field in the direction of the turn is smaller than if a right turn is being performed. This may be one reason why the instructor at a late stage noticed the fuel storage tanks and increased the bank angle.

2.4.1 *'The impossible turn'*

As mentioned in section 1.18.1, an attempt to return to the runway from low altitude in the event of an engine failure can turn a difficult situation into a more tragic occurrence. Fortunately, neither the student nor the instructor suffered any serious injuries, despite the aeroplane being totally destroyed. It is impossible to say whether the outcome could have been better had the flight continued straight ahead. Nevertheless, the chances of limiting damage to the aeroplane and injuries to those on board are greater if control is maintained during manoeuvring, which is generally the case if the flight continues in the direction of travel.

The likelihood of safely completing a 180 degree turn after an engine failure is dependent on a range of factors. In addition to the altitude reached, the entry speed, speed during gliding flight, whether the propeller is windmilling or standing still, wind speed and wind direction have an impact. When after the engine fails the turn is initiated and the bank angle are also of significance. Consequently, these factors should be evaluated during the risk assessment prior to take-off as part of an assessment of how early a turn back can be performed. It therefore needs to be ensured that the pilot has good knowledge of the aeroplane in question and that the procedure has been practised at high altitude, which is described in the documentation produced by the FAA. Similar advice has been issued by KSAK and in the EASA publication *Sunny Swift*.

2.5 Training

2.5.1 *The instructor's training*

As stated in section 1.17.1, the instructor was trained as an instructor at an ATO in Hungary. This training did not involve advanced manoeuvres as the training organisation did not have approved aeroplanes for performing the training for this, despite this being a requirement under the EASA's description in AMC1 FCL.930. The fact that the instructor had also not performed this during his career or his CPL training meant that he lacked practical experience of how an aeroplane behaves in certain uncontrolled states.

2.5.2 *The regulations*

Commission Regulation (EU) No 1178/2011, Annex I, Part-FCL describes, among other things, what different training programmes have to contain. The training course for a flight instructor (FI) is described under AMC1 FCL.930.FI. It is left to the type certificate holder to specify how emergency procedures are to be performed and it is entirely up to the approved training organisation (ATO) to determine how these are to be trained.

These provisions mean that each ATO has to have a safety management system in which risks are addressed. This means that different ATO's may end up handling the training process in different ways and that the training provided by different ATO's is not equivalent.

2.6 The school's safety management system

The flight school had a safety management system that was documented in manuals. How well the system functions depend not just on how the manuals are adhered to, but is also dependent on information about risks being reported to the organisation and addressed within the system. This allows any risks to be dealt with in a systematic way. As part of this system, the school used a risk log that was updated when a new risk was identified, a risk assessment was conducted or a new risk-mitigation measure was introduced following a decision by the safety committee. The risk log was also updated following an annual workshop at which all identified risks were addressed. The latest workshop took place just over one year before the accident. Parts of the school's management and some of the instructors took part in the workshop. As a result of the meeting, a number of risk-mitigation measures relating to engine failure were addressed.

During take-off, the instructor did not use the entire runway for take-off even though he believed that the consequences of an engine failure after take-off from runway 16 may be greater when compared to other runways. This therefore demonstrates that the risk-mitigation measures in the risk log and the flight school's risk and threat and error management (TEM) had not been implemented, as using the entire runway would have been a typical way to manage a threat and reduce the risk.

The idea of a risk log is that information on all risks is gathered in one place so that it is possible to have an overall overview and be able to manage the risks so that they are acceptable in order to be able to carry out the flight operations. The fact that all risk-mitigation measures for engine failure were not implemented means that the school did not have the stated risk level that had been specified in the risk log.

The instructor did not participate in the risk log workshop as he was undergoing his flight instructor training at the time of the latest meeting. This may explain why the instructor's view of the risks around runway 16 was not included in the risk log. However, the school did have opportunities to capture the perceived risk in other systems, e.g. in the school's reporting system. Nevertheless, there were no reports concerning risks associated with engine failure at low altitude after take-off from either the instructor or anyone else.

During the inspection conducted by the Swedish Transport Agency before the accident, there was also a remark about the fact that there were doubts about whether or not risks in the risk log had been followed up.

There was a document at the school called SPRAM (Skies Pre-flight Risk Assessment Matrix), which was used before each flight. This document served as an aid and instigator for highlighting certain areas before flight and assessing whether there were risks or combinations of risks that could be brought to light. In this document, which was a form, the take-off airport was specified in order to assess the risk from the perspective of whether or not the pilot was familiar with it. SPRAM was filled in prior to the flight in question by the crew who has set a low risk score. This can be considered normal given that this was the flight school's home base and the majority of risks should have been known. However, the school has not been able present any risk assessment for flying from its home base.

Standardised operating procedures (SOP) and the pilot's operating handbook

It emerged during interviews with the flight school's management, the instructor and the student that there were memory items for shutting off the fuel pump, turning off the landing lights and retracting the flaps at 400 feet above ground (QFE). This procedure was not documented in any of the operator's manuals and nor did it adhere to the aeroplane's pilot's operating handbook (POH). The operator's SOP states that the flaps are to be retracted at 400 feet and that other actions such as going through the checklist are to be performed when the aeroplane leaves the control area or passes the transition altitude. The aeroplane's POH states that the flaps are to be retracted at 300 feet and the fuel pump shut off at 1,000 feet above ground.

As stated earlier, it is probable that during the flight in question the student began to perform the memory items just before the engine fault began, which meant that the fuel pump was turned off. The POH states that the electric fuel pump is to be turned off when passing 1,000 feet. If the procedure in the POH has been adhered to, the electric fuel pump would have been on at the time of the engine failure. SHK believes that to deviate in such a way from the POH is to expose oneself to an unnecessary risk and, because it has not been possible to establish a reason why the engine failed, it is not possible to rule out that this action may have had an impact on the sequence of events.

The procedure for memory items that was used (without being documented) and the procedure in the SOP, which both differ from the POH, have not been preceded by any documented risk assessment. The safety management system's procedures have thus not been used to identify the potential risks of the divergent procedure. Nor have members of staff observed differences in the procedures and notified the system of these.

Consequently, there is reason, given the information above, to question whether the risk model in the flight school's manuals was an active continual part of day-to-day operations.

2.6.1 Safety management system

According to the requirements, organisations within civil aviation have to have a safety management system. The safety management system in question has a regulatory framework that provides some guidance on the safety management process. The same applies to the regulatory framework concerning training. For example, the regulations state that engine failure is to be practised but does not otherwise provide any guidance about how this training is to be implemented. The type certificate holder provides guidance on how the procedure for the aeroplane and the system shall be managed, but neither the EASA nor the type certificate holder provides guidance on how training shall be implemented, as long as the regulatory framework is adhered to. How the training shall be performed should be covered in each organisations safety management system, according to EASA, where all risks are identified and handled. According to SHK, it can be questioned whether this is the basic idea of the system. The result could be that the training will not be equivalent and significant elements will be absent even though the training meets the minimum level according to the regulations.

In this case, the school conducted a training course for engine failure during take-off that involved a procedure that was itself clear, but did not provide any guidance about other options that could be available. The EASA does not provide any guidance about how someone could obtain knowledge about other options aside from a magazine (*Sunny Swift*) that lacks official value. The FAA has issued clearer information in an accepted medium (an advisory circular) about possible exercises that highlights the issues related with the impossible turn back to the runway. During such training, the student gains not only an understanding of the effects of a turn back to the runway, but also a clearer understanding of what is and what is not possible.

In order for all pilots in the system to be able to assimilate knowledge and experience and face threats in everyday life, it is important that everyone has the best gathered information, knowledge and is trained for this. Under the current system, this will vary from school to school depending on how well their safety management system works.

To exemplify this, we can compare two different pilots. One pilot goes to a flight school that has a more varied training course based on the risks in their safety management system and is trained includes the impossible turn and its effects. The other pilot only undergoes training in accordance with the lowest possible level of the regulatory framework. Provided both pilots pass the skill test, it is possible to question whether they are similarly equipped to deal with, for example, an engine failure at low altitude in the future. Their continued flying career as private pilots is entirely dependent on the system each school had at the time the training took place.

If, on the other hand, the structure of the training was covered in the basic system in order to demonstrate an acceptable means of compliance, there would be a clear conformity in terms of the teaching provided by the schools. If new risks subsequently emerge that need to be addressed, this can be changed in the main system (the EASA's overall system of regulations and guidance). Accordingly, this achieves greater uniformity for those who have to apply the regulations framework.

SHK is of the opinion that existing procedures for how training is to be performed should be the same for all and that deficiencies are being identified in the safety management system.

2.7 Rescue operation

No indications of any failings in terms of how the rescue operation was implemented have emerged during the investigation.

2.8 Survival aspects

The NTSB collision safety project, which was described in section 1.15.3, shows that the majority of aeroplanes with survivors had been subject to a collision with an impact angle of less than 25 degrees and a speed of less than 60 knots. The higher the speed and impact angle, the lower the chance of survival. It can be assumed from the investigation material that the aeroplane in question hit the ground at a speed of under 60 knots and at an impact angle of less than 25 degrees.

Nevertheless, there are aspects other than speed and impact angle that affect the chances of surviving a crash. For example, the chances of survival are influenced by how the energy is absorbed by the aeroplane at the time of impact. On this occasion, the aeroplane's wing made the initial contact with the ground and began to absorb energy. This initiated a rolling movement to the right and a yaw effect to the left. By the time the belly and the engine made contact, the impact angle was relatively low. The effect of this resulted in the direction of force not pushing the engine into the cabin and instead the engine detached from the aeroplane when the aircraft rotated around its own axis. During this rotation, the left wing folded under the fuselage and broke off at the wing root.

The fact that the cabin remained relatively intact and that no one was seriously injured was due to the circumstances that have been, to a small extent influenceable.

2.8.1 Examination of the strength of the seat belt attachment

The complex set of forces exerted on the attachment of the seat belt means that it is difficult with some accuracy to calculate the strength of the attachment at the event. Any further strength analyses of the shoulder strap attachment have therefore not been made. The fact that the pilot survived the accident without serious injuries even though the shoulder strap attachment ruptured can probably be explained by the details of the impact described in section 2.8.

3. CONCLUSIONS

3.1 Findings

a) The instructor was qualified to perform the flight.
b) The aeroplane had had a valid Certificate of Airworthiness and valid ARC.
c) The flight school was an approved training organisation (ATO).
d) The flight was the third of the day.
e) The aeroplane had flown for 40 minutes after having been fully refuelled.
f) Prior to the flight, technicians had rectified a remark that meant it was not possible to shut down the engine using the mixture.
g) The take-off was performed around 240 metres along the runway.
h) The take-off took place with the tank selector set to the left tank, which was full.
i) The take-off was perceived to be normal until the point at which the engine lost power and finally failed at low altitude.
j) The instructor took control of the aeroplane.
k) An attempt was made to turn around to the opposite direction at low altitude.
l) The stall warning sounded during the turn.
m) The instructor increased the bank angle when he realised that there was a risk of collision with fuel storage tanks.
n) The instructor lost control of the aeroplane, which collided with the ground.
o) During the impact, the engine was knocked off to the side and landed away from the aeroplane.
p) The cabin was relatively intact following the crash.
q) The bracket of the left pilot's shoulder strap had been broken off the door pillar behind the pilot. Both of those on board climbed out of the aeroplane uninjured.
r) The rescue service arrived quickly and put extinguishing foam around the aeroplane.

3.2 Causes/contributing factors

The accident was caused by the engine failing in a situation in which there were limited opportunities to land safely. The lack of sufficient knowledge and experience of the difficulties involved in performing a 180 degree turn at low altitude back to the runway following an engine failure led to an uncontrolled impact.

A contributory cause has been that the flight school has not identified through its safety management system the risks that can arise in the event of an engine failure at low altitude.

An underlying cause has been that the EASA's regulations for engine failure after take-off do not describe how this training should be conducted.

4. SAFETY RECOMMENDATIONS

The EASA is recommended to:

- Evaluate and decide whether and which high-risk manoeuvres shall be included in training and be described in a guidance document. One such high-risk manoeuvre could be the operation that involves how to assess when a turn back to the field is safe. See sections 2.4.1 and 2.5.1. *(RL 2021:03 R1)*
- Draw up and distribute through the competent authorities a safety bulletin in order to increase knowledge of the impossible turn. *(RL 2021:03 R2)*

The Swedish Transport Agency is recommended to:

- In its role as competent authority, to review the training organisation's safety management systems in terms of the handling and training of emergency procedures at low altitude after take-off. *(RL 2021:03 R3)*

The Transportation Safety Bureau of Hungary is recommended to:

- Revise the training requirement for AMC1 FCL.930.FI and confirm that the training organisations are actually complying with it. *(RL 2021:03 R4)*

The Swedish Accident Investigation Authority respectfully requests to receive, **by 1 July 2021** 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,

John Ahlberk Johan Nikolaou