Statens haverikommission
Swedish Accident Investigation Authority





# *Final report RL 2019:08e*

**Serious incident at Linköping/SAAB Airport on 14 August 2018 involving aircraft SE-CFP of the model Douglas DC-3C, operated by Flygande Veteraner.**

File no. L-99/18

17 May 2019

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

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

ISSN 1400-5719

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



| *Postadress/Postal address* | *Besöksadress/Visitors* | *Telefon/Phone* | *Fax/Facsimile* | *E-post/E-mail* | *Internet* |
|---|---|---|---|---|---|
| P.O. Box 6014<br>SE-102 31 Stockholm<br>Sweden | Sveavägen 151<br>Stockholm | +46 8 508 862 00 | +46 8 508 862 90 | info@havkom.se | www.havkom.se |

Statens haverikommission
Swedish Accident Investigation Authority

## 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 15 August 2018 that a serious incident involving an aircraft with the registration SE-CFP had occurred at Linköping/SAAB Airport, Östergötland County, on 14 August 2018 at 17:54 hrs.

The incident has been investigated by SHK represented by Mr Mikael Karanikas, Chairperson, Mr Nicolas Seger, Investigator in Charge, Mr Sakari Havbrandt, Technical Investigator, Mr Alexander Hurtig, Investigator Behavioural Science, and Mr Tomas Ojala, Investigator specializing in Fire and Rescue Services.

The investigation team of SHK was assisted by Magnic AB for video and sound analysis.

Mr Jan Eriksson has participated as advisor on behalf of the Swedish Transport Agency.

The following organisations have been notified: International Civil Aviation Organisation (ICAO), the American National Transportation Safety Board (NTSB) and the Swedish Transport Agency (Transportstyrelsen).

*Investigation material*

Interviews have been conducted with the crew and the technical manager.

A video recording from the cabin taken during the flight has been analysed.

The Cockpit Voice Recorder has been recovered and the four audio files on it have been analysed.

Audio recordings from air traffic control have been recovered and analysed.

Recordings from seven video cameras belonging to the remote control equipment of the airport tower have been recovered and analysed.

A meeting with the interested parties was held on 17 January 2019. At the meeting SHK presented the facts discovered during the investigation, available at the time.

Statens haverikommission
Swedish Accident Investigation Authority

## Final report RL 2019:08e

| | |
|---|---|
| Aircraft: | |
| Registration, type | SE-CFP, DC-3 |
| Model | Douglas DC-3C |
| Class, Airworthiness | Normal, Valid Airworthiness Review Certificate |
| Serial number | 25328[1] |
| Operator | Flygande Veteraner |
| Time of occurrence | 14 August 2018, 17:54 hrs in daylight<br>Note: All times are given in Swedish daylight saving time (UTC[2] + 2 hours) |
| Place | Linköping/SAAB Airport, Östergötland County, (position 5824N 01540E, 53 metres above mean sea level) |
| Type of flight | Private |
| Weather | According to SMHI's analysis: wind east northeast 5–8 knots, visibility >10 kilometres, cloud 6–8/8 with base at 500–700 feet, temperature/dewpoint +15/+15 °C, QNH[3] 1007 hPa |
| Persons on board: | |
| crew members including engineers | 5 |
| passengers | None |
| Injuries to persons | None |
| Damage to aircraft | Substantially damaged |
| Other damage | None |
| Commander: | |
| Age, licence | 52 years, ATPL[4] |
| Total flying hours | 12,500 hours, of which 60 hours on type |
| Flying hours previous 90 days | 128 hours, of which 10 hours on type |
| Number of landings previous 90 days | 94, of which 7 on type |
| Co-pilot: | |
| Age, licence | 52 years, ATPL |
| Total flying hours | 23,000 hours, of which 16 hours on type |
| Flying hours previous 90 days | 230 hours, of which 2 hours on type |
| Number of landings previous 90 days | 50, of which 3 on type |

[1] Serial number according to the aircraft documentation. There is also information that the serial number is 13883. A process about change is ongoing.
[2] UTC – Coordinated Universal Time.
[3] QNH – Barometric pressure reduced to mean sea level.
[4] ATPL – Airline Transport Pilot License.

## SUMMARY

The aircraft of model DC-3C with registration SE-CFP, operated by Flygande Veteraner, had undergone an engine change in Groningen and was then flown without remark to Linköping/SAAB Airport. When the aircraft took off again towards Stockholm/Västerås Airport, the fire warning for the left engine was activated.

The crew feathered the engine and activated the fire extinguishing system, but this had limited effect. The crew informed air traffic control of the fire, carried out a visual approach, which was aborted with a go-around, and then landed on the opposite runway. The brakes gave no effect during the landing roll. The running engine was turned off, the aircraft left the runway and stopped on the strip.

The aircraft was evacuated and the airport rescue services extinguished the engine fire. There were no injuries sustained. However, there were substantial damage on the aircraft's left engine nacelle and its accessory compartment.

The investigation of the wreckage revealed that three screws were missing on the exhaust collector. This led to parts of the exhaust system coming loose and to the exhaust flow causing a fire in the left engine, igniting oil residue and melting parts of the engine cowling. Several hydraulic lines melted and subsequently leaked oil, which added combustible to the fire. The control valve of the cowl flaps was not closed according to the emergency checklist.

The engine change in Groningen deviated from the operator service manual, as it was carried out without a work order.

The operator has taken measures to ensure, among other things, that a work order is used in specially planned maintenance.

The incident was caused by the engine change being carried out without following the operator's established procedures for specially planned maintenance.

The following factors contributed to the extent of the fire:

- The design of the existing hydraulic system, which does not allow the hydraulic oil to be isolated from engine zone 2.

- The failure to close the control valve of the cowl flaps (item "trail-off" in the engine fire emergency checklist).

### Safety recommendations

In view of the measures that the operator has taken or plans to take, SHK is refraining from issuing any safety recommendations in response to the incident.

# 1. FACTUAL INFORMATION

## 1.1 History of the flight

### *1.1.1 Preconditions*

The aircraft of model Douglas DC-3C with registration SE-CFP, operated by Flygande Veteraner, had undergone an engine change in Groningen, the Netherlands. After the engine change, an engine run was carried out and documented on the ground without remark. In the morning after the change, a weekly check of the aircraft was carried out, which was also documented without remark. The aircraft was then flown from Groningen to Linköping/SAAB Airport. The flight proceeded normally.

After landing, the aircraft was checked, in particular the engine that had been replaced. Nothing out of the ordinary was found, and it was noted that the engine showed no signs of oil leakage.

The left engine driven hydraulic pump on the aircraft had been removed previously, and the associated lines in the accessory compartment (zone 2) had been plugged. This is described in more detail in section 1.6. Information about the removal was not written down in the aircraft technical log, but the crew was informed about it.

The aim of the flight in question was to fly from Linköping/SAAB Airport to Stockholm/Västerås Airport, which is the aircraft's home base. On board the aircraft was the crew, consisting of two pilots and an engineer in the cockpit, and two engineers in the cabin.

### *1.1.2 Sequence of events*

After engine start at Linköping/SAAB Airport, an engine run-up and check was carried out according to the checklist procedures, without remarks.

The aircraft took off from runway 11 at 17:51 hrs in an easterly heading. During the take-off run the commander heard a flapping sound which he believed came from the cockpit window or from the headset's active noise reduction system. Video recordings from the tower show that there was a smoke streak from the left engine shortly after lift-off. When the landing gear had been retracted and engine thrust had been reduced to climb power, the co-pilot remarked on a smell. Roughly 45 seconds later, the commander said that there was a rattling sound outside.

The crew has told investigators that the fire warning for the left engine was activated during the climb at around 1,000 feet, which is confirmed by the cockpit voice recorder (CVR[5]) on the aircraft, where the warning signal can be heard just over two minutes after take-off.

[5] CVR – Cockpit Voice Recorder.

The crew identified and confirmed that the fire warning related to the left engine, and reduced power on that engine accordingly. The commander stated that it was not possible to turn off the aural fire warning (fire bell).

The co-pilot took over radio communication, called the tower, requested immediate radar guidance back and announced that they were seeing high temperatures on the left side. The air traffic controller that received the call was not in the tower, but in Östgöta control centre. The controller told the co-pilot to contact the tower instead. However, the co-pilot again called the frequency of Östgöta control centre, stating that they had a fire indication on the left side and requesting permission to land on runway 11. The air traffic controller informed him that he had spoken to the tower and cleared the aircraft for landing.

The crew never sent out any formal distress call.

At the commander's request, the aircraft was flown below the clouds, and the crew got visual contact with the runway. The co-pilot notified the air traffic controller that there was a fire indication on the left side.

The commander received information from the engineers about flames from the left engine. One engineer filmed the burning engine through the cabin window using a mobile phone.

The mobile recording shows that the propeller of the left engine was in feathered position 1 minute and 51 seconds after the fire warning was activated. Interviews with the crew also reveal that the shut-off valve for the left engine was closed, and that the fire extinguishing system was activated and triggered for the left engine.

One engineer noted that the fire had subsided and that only a small flame could now be seen inside the engine cowling, of which the commander was informed.

A visual approach was initiated to runway 11, but was aborted. According to the commander, the reason for this was that the approach was too tight and the speed too high. The co-pilot has told that the green lights, indicating that the landing gear is down and locked, were not yet lit. A new landing circuit was initiated to the opposite runway, runway 29. At the same time, the commander took over the controls of the aircraft.

The engineer in the cockpit turned off the aural fire warning, which had been sounding continuously for nearly four minutes.

Before the landing, air traffic control asked if the crew had any special requests, to which the crew responded with a request for a fire truck.

After the landing, the crew noted that the brakes were not working, and they therefore activated the manual hydraulic pump and shut down the running engine. Since the brakes were still not working, it was not possible to steer the aircraft for the last part of the landing roll. This meant that the aircraft came off the runway to the right, and stopped a few metres out on the strip that is covered in grass.

The commander ordered the evacuation of the aircraft, checked that both engines were turned off, and shut down the main power. The checklist for an emergency on the ground was not completed. All on board were unharmed and exited the aircraft through the main door. The airport rescue service immediately began the firefighting operation and had extinguished the fire within one minute.

The incident occurred in daylight at 5824N 01540E, roughly 300 metres above mean sea level.

## 1.2 Injuries to persons

| | Crew members | Passengers | On board, total | Others |
|---|---|---|---|---|
| Fatal | - | - | 0 | - |
| Serious | - | - | 0 | - |
| Minor | - | - | 0 | Not applicable |
| None | 5 | - | 5 | Not applicable |
| Total | 5 | - | 5 | - |

## 1.3 Damage to the aircraft

Substantial. This is described in more detail in section 1.12.

## 1.4 Other damage

None.

### *1.4.1 Environmental impact*

None.

## 1.5 Crew

### *1.5.1 Pilot qualifications and duty time*

*The commander*

The commander was 52 years old and had a valid ATPL with the applicable operational and medical eligibility. Initially, the commander was the PM[6] but later took over the controls of the aircraft and was then the PF[7].

[6] PM (Pilot Monitoring) – pilot who is assisting the PF.
[7] PF (Pilot Flying) – the pilot who is manoeuvring the aircraft.

| Flying hours | | | | |
|---|---|---|---|---|
| Last | 24 hours | 30 days | 90 days | Total |
| All types | 4 | 33 | 128 | 12,500 |
| Type in question | 4 | 9 | 10 | 60 |

Number of landings, type in question last 90 days: 7.
Type rating conducted on 24 April 2015.
Last PC[8] conducted on 4 June 2018 on DC-3.

*The co-pilot*

The co-pilot was 52 years old and had a valid ATPL with the applicable operational and medical eligibility. Initially, the pilot in command was the PF but then switched to PM after the commander took over the controls of the aircraft.

| Flying hours | | | | |
|---|---|---|---|---|
| Last | 24 hours | 30 days | 90 days | Total |
| All types | 4 | 60 | 230 | 23,000 |
| Type in question | 4 | 1 | 2 | 16 |

Number of landings, type in question last 90 days: 3.
Type rating conducted on 2 October 2017.

### *1.5.2 Other personnel involved*

Three engineers from Flygande Veteraner participated in the work of changing the engine in Groningen. All of them had valid European aircraft maintenance licences. One of the engineers was also nationally certified for the DC-3 in accordance with Swedish legislation.

In addition, a number of voluntary assistants from the Netherlands and Denmark participated.

## 1.6 The aircraft

DC-3 is a low-wing, twin-engine aeroplane intended for short and medium distances.

It is equipped with two 14-cylinder Pratt & Whitney Twin Wasp SC3G two-row radial engines and two three-blade Hamilton Standard propellers.

The aircraft is 16.65 metres long with a span of 28.96 metres.

[8] PC – Proficiency Check.

Figure 1. The aircraft. Photo: Flygande Veteraner.

### 1.6.1 *The aeroplane*

| | |
|---|---|
| Manufacturer | Douglas Aircraft Corporation Ltd |
| Model | Douglas DC-3C |
| Serial number | 25328[9] |
| Year of manufacture | 1943 |
| Gross mass (kg) | Max. authorised 11,497, actual 9,830 |
| Centre of gravity | 59.6 (permitted range 52–80) |
| Total operating time (hours) | 34,100 |
| Flying time since last periodic inspection (hours) | 6 |
| Type of fuel loaded prior to the occurrence | 100 LL |

| | |
|---|---|
| Engine | |
| Type certificate holder | Pratt & Whitney Corporation |
| Type | Twin Wasp R-1830-92 S1C3-G |
| Number of engines | 2 |

| | |
|---|---|
| Propeller | |
| Type certificate holder | Hamilton Standard |
| Type | 23E50-3 |

Deferred remarks
There were no deferred remarks entered in the aircraft journey log that were relevant to the incident.
However, the left engine driven hydraulic pump had been removed, and the associated lines had been plugged. This is described in more detail in section 1.6.5. There was no note of this in the journey log.

The aircraft had a valid Certificate of Airworthiness.

### 1.6.2 *Aircraft engine installation*

The aircraft's engines are mounted on nacelles in front of each wing. The engine nacelles are divided into three zones.

[9] Serial number according to the aircraft documentation. There is also information that the serial number is 13883. A process about change is ongoing.

The front zone, referred to as zone 1, is where the engine is installed. Behind zone 1 is the accessory compartment, or zone 2. Behind this compartment is the landing gear well, or zone 3. There are stainless sheet-metal firewalls between zones 1 and 2 and between zones 2 and 3. The function of these firewalls is to prevent the spread of fire (see figure 2).

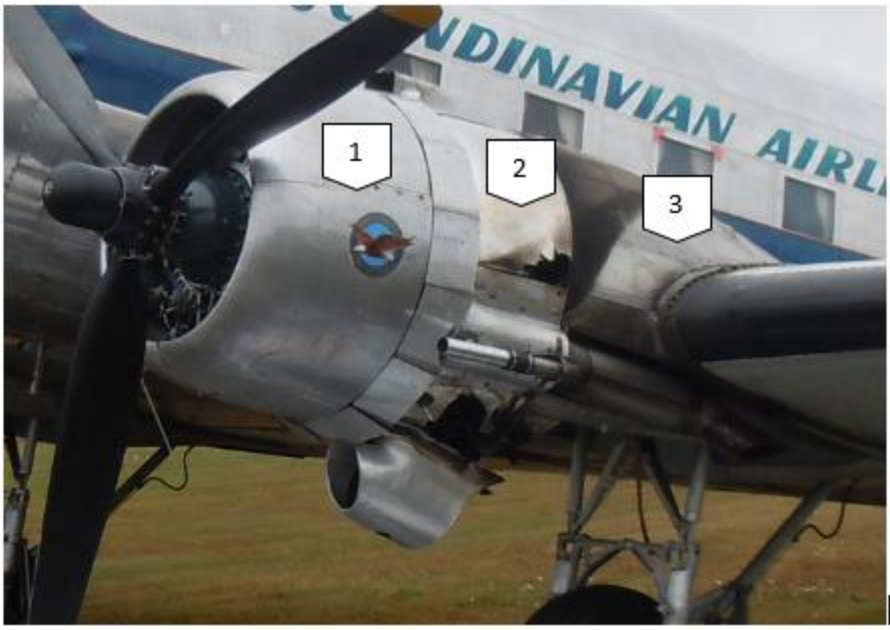


Figure 2. The engine nacelle with its three main sections: zone 1 – engine compartment, zone 2 – accessory compartment and zone 3 – space for oil tank and landing gear. The image also shows soot from the flames and melting damage to the cowling of the accessory compartment.

### *1.6.3 Fire warning and extinguishing systems*

The aircraft is equipped with a fire warning system and a fire extinguishing system for the engines. Also included in the fire protection system are the shut-off valves, which can be used to cut the supply of fuel, oil and hydraulic oil behind the firewall in case of an engine fire. The shut-off valves are manually operated using two handles, which are placed underneath a hatch in the floor behind the pedestal.

The fire warning system consists of fire detectors, warning lights, a warning bell and a switch for testing of the system. The fire bell is common to both engines.

The fire bell can be turned off using a switch behind the left pilot's seat.

In each nacelle, there are eight fire detectors, all installed in zone 2. Three detectors are symmetrically placed on the engine cover, and five detectors are symmetrically distributed over the firewall. Each fire detector consists of a metal box containing a spring and a contact point insulated from the box itself. The box has a greater expansion coefficient than the spring.

In the event of a heat increase around the box (to around 260 °C), the box will expand faster than the spring. This makes the spring stretch and touch the contact point, thus closing the power circuits. This causes the warning light for the concerned engine to come on and the fire bell starts to sound.

The fire extinguishing system for the engines consists of a $CO_2$[10] container with a triggering device, selector valve and diffuser pipes in strategic locations around the nacelles.

The $CO_2$ container is placed behind the right pilot's seat and contains approx. 3.5 kg of pressurised $CO_2$.

In the event of an engine fire, the $CO_2$ is released by pulling a handle underneath the fire hatch in the floor behind the pedestal. $CO_2$ will then rush first to a selector valve located underneath the same hatch as the release valve, and then to the selected engine.

The selector valve will normally be closed. Before release, it must be set to the engine that is on fire. From the selector valve, the gas is then directed to perforated diffuser pipes in zones 2 and 3 and to the air intake of the carburettor. The diffuser pipe in zone 3 only covers the lower part of the wheel well, immediately behind the firewall, and is mostly intended to prevent fire from spreading to this zone. The extinguishing system can only be triggered once.

### *1.6.4 Exhaust system*

The exhaust system consists of exhaust pipes mounted on the engine's 14 cylinders. These are connected to a ring-shaped exhaust collector placed behind the engine in front of the first firewall. The exhaust collector comprises seven sections, which are fitted one into the other and connected to the exhaust pipes of two cylinders each. Six of the sections have been fitted with individual screw joints attached to stand-off brackets on the engine's compressor housing. The last section, referred to as the main section, is fitted with clamps and leads out into the exhaust system tail pipe (see figure 3).

[10] $CO_2$ – Carbon dioxide, also referred to as carbonic acid, is an invisible odourless gas that is heavier than air and which extinguishes fire by diluting the oxygen in the air. Extinguishing fire with carbonic acid requires a closed space in order to be effective.

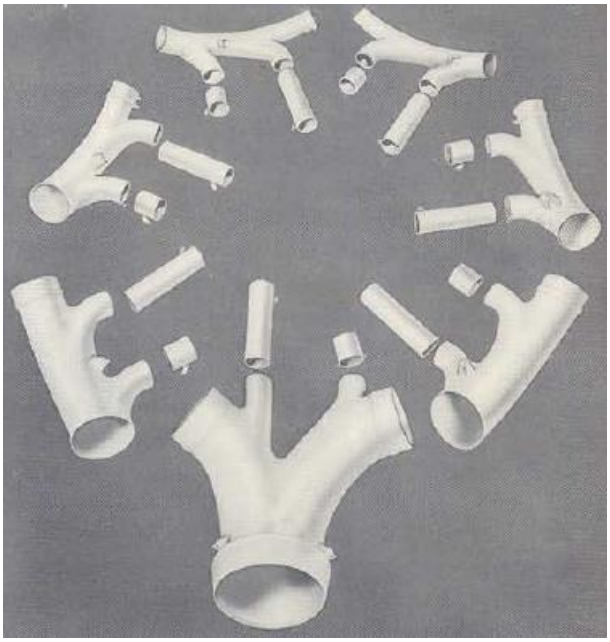

Figure 3. The seven sections of the exhaust collector, with the main section at the bottom of the image.
Image: Douglas Illustrated Parts Catalogue. Copyright © Boeing. Reprinted with permission of The Boeing Company.

### *1.6.5 The hydraulic system*

On this aircraft model, the landing gear, wing flaps, cowl flaps, windshield wipers and autopilot are all hydraulic. There is an engine driven hydraulic pump on each engine. The pumps are supplied with gravity-fed oil from the hydraulic tank, which is placed behind the right pilot's seat. The suction lines of the pumps are connected a bit higher on the hydraulic tank, so that not all the oil is consumed by the engine driven pumps.

A manual pump, for emergencies, is connected to the lowest point of the tank so that all available oil can be used.

The shut-off valves, which turn off the supply of fuel and oil, also close the suction line to the hydraulic pump of each engine. However, the pressure lines of the hydraulic pumps stay open.

There is also a pump selection valve for the hydraulic tank. According to the aircraft's original maintenance manual, this valve can be used to operate the autopilot using one pump and the other systems with the other, or vice versa (see figure 4).

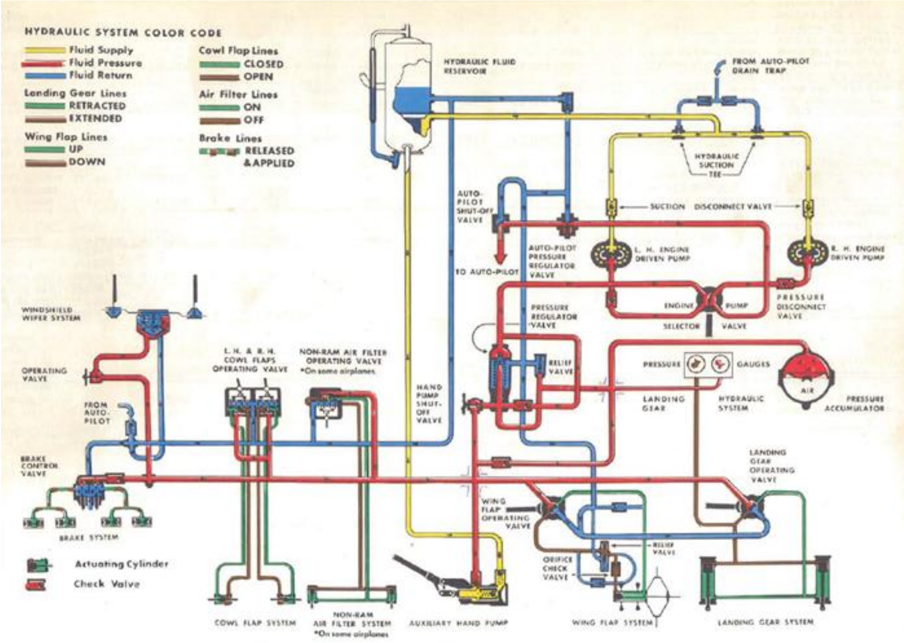


Figure 4. The hydraulic system according to the maintenance manual. Image: Douglas Maintenance manual. Copyright © Boeing. Reprinted with permission of The Boeing Company.

However, the aircraft in question was modified so that the right pump is always used for everything except the autopilot and that the pump selection valve can be used to select whether the left pump is used to control the autopilot or reinforce the rest of the system (see figure 5).

SHK has received no information in regard to when this modification was made, but it is described in SAS manuals from the 1950s, when SAS was operating the aircraft.

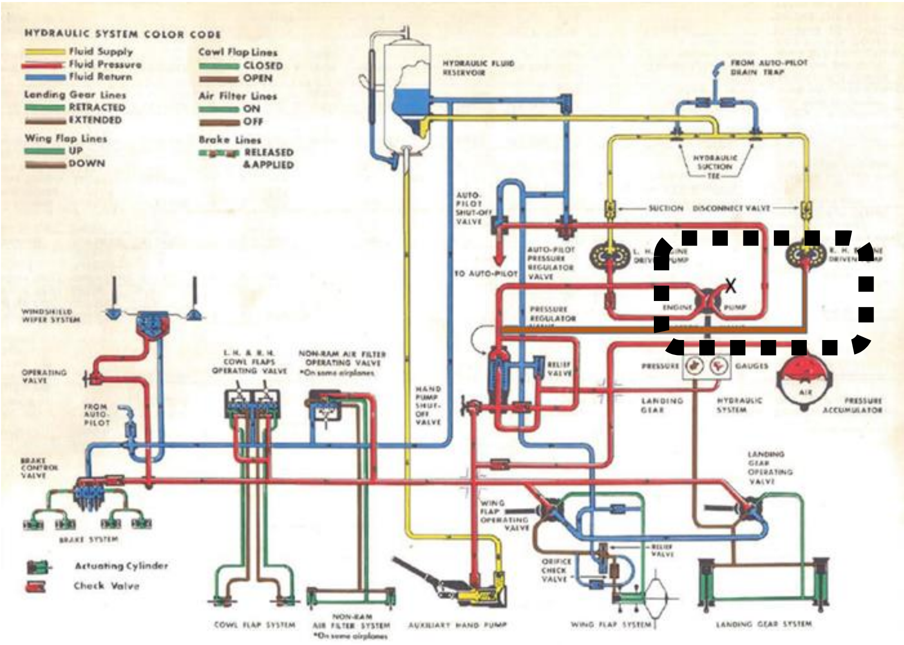


Figure 5. The hydraulic system on the aircraft in question. The shaded rectangle shows the location of the modification. Image: Douglas Maintenance manual modified by SHK. Copyright © Boeing. Reprinted with permission of The Boeing Company.

At the time of the incident, the left pump had been removed and the lines in zone 2 had been plugged. Furthermore, the pump selector valve was locked in a position where the pressure lines of the pumps are connected.

The cowl flaps are hydraulically operated by a double-acting actuator cylinder mounted on the bottom half of the front firewall. Two lines come out of an operating valve in the cockpit, which has five positions to choose from, according to the following table:

| **Position** | **Connected to** | | **Position of cowl flaps** |
|---|---|---|---|
| | **Line A** | **Line B** | |
| OPEN | PRESSURE | RETURN | Fully open |
| OFF | CLOSED | CLOSED | Locked in the last position |
| TRAIL | RETURN | RETURN | Freely floating according to the airflow |
| OFF | CLOSED | CLOSED | Locked in the last position |
| CLOSED | RETURN | PRESSURE | Fully closed |

The operating valve has two OFF positions, which are placed in between the three positions OPEN, TRAIL and CLOSED.

## 1.7 Meteorological information

According to SMHI's analysis: east-northeasterly wind 5–8 knots, visibility >10 km, clouds 5–8/8 with the cloud base at 500–700 feet, temperature/dewpoint +15/+15 °C, QNH 1007 hPa.

The incident occurred in daylight.

## 1.8 Aids to navigation

Not applicable.

## 1.9 Communications

During the incident, the crew was in contact with the tower at Linköping/SAAB Airport as well as with the Östgöta control centre (ÖKC).

In conjunction with the aircraft fire warning being activated, the crew called the tower at the ÖKC frequency and were asked to contact the tower instead, which never happened. The crew was thus only in contact with the air traffic controller at ÖKC until landing, which was also noted by the latter.

## 1.10 Aerodrome information

The airport is listed as an approved instrument aerodrome according to AIP[11] Sweden.

The airport has an asphalt runway that is 2,135 metres long and 40 metres wide.

The runways are designated runway 11 and runway 29, with a magnetic bearing of 107 and 287 degrees respectively.

The strip stretches out 150 metres on each side of the runway centre line and is covered in grass.

The strip is an established area surrounding the taxiway or a runway along with the stopway area, which is intended to reduce the risk of damage to aircraft that come off the runway unintentionally.

## 1.11 Flight recorders

The aircraft was equipped with a cockpit voice recorder (CVR[12]).

The Swedish Transport Agency has granted an exception from the flight data recorder (FDR[13]) requirement.

### *1.11.1 Cockpit Voice Recorder (CVR)*

The cockpit voice recorder was of the model CVR-30B from Universal Avionics Systems Corporation, with the part number 1603-02-03 and serial number 2209.

The unit was taken in by SHK for analysis and was transported to the French safety investigation authority (BEA) for readout.

Audio data was downloaded from the unit in the form of four audio tracks of 32 minutes and 30 seconds each. The tracks rendered the sound from the microphones of the left, right pilots, PA-system and from the cockpit area microphone. The entire flight was recorded with good sound quality.

[11] AIP – Aeronautical Information Publication.
[12] CVR – Cockpit Voice Recorder.
[13] FDR – Flight Data Recorder.

## 1.12 Site of occurrence and the aircraft after the occurrence

### *1.12.1 Site of occurrence*

Linköping/SAAB Airport

### *1.12.2 The aircraft after the occurrence*

The aircraft was examined by the SKH. Since the damage that occurred was caused by the fire, it is described in section 1.14.

In addition to the fire damage, it was noted that there were screw joints missing on three of the exhaust collector attachments, which contributed to it coming loose from several connections. The screw and bolt were missing completely in these locations (see figure 6). In the other fittings, the screw joints were correctly installed.

Figure 6. One of the three fittings where the screw joints were missing between the exhaust collector and the engine.

## 1.13 Medical and pathological information

Nothing indicates that the mental and physical condition of the pilots were impaired before or during the flight.

## 1.14 Fire

A fire investigation has been conducted by SHK in order to assess the cause and progression of the fire.

The investigation found fire damage to the cowlings around zone 2 and partial damage to the cowlings around zone 3. The cowling around zone 2 had melted in the area closest to the parts of the exhaust collector that had come loose. There was only soot on the firewall between zones 1 and 2.

Figure 7. Fire damage to the cowling around zone 2 of the left engine. In the cowling behind zone 2, there were some small holes, where the aluminium had melted.

When the cowling was removed, fire damage could be seen on all non-metal parts of zone 2. In zone 1, the exhaust collector had come loose from three of the 14 cylinders. Since the exhaust collector had come loose, the exhausts could flow freely from the cylinders towards the firewall and the cowling behind the engine.

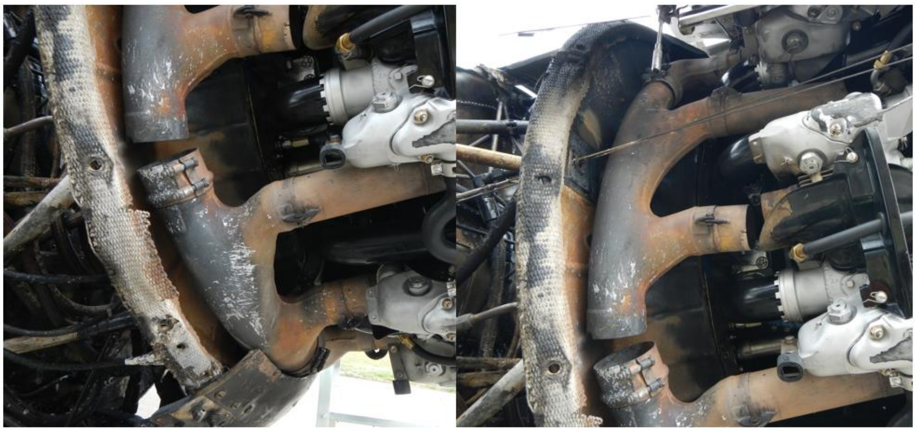

Figure 8. The exhaust collector behind the engine cylinders in zone 1. The light spots on the exhaust collector are assessed to be melted aluminium from the cowling.

There was no fire damage in zone 1, with the exception of a number of stains on the exhaust collector, which are deemed to be melted aluminium. The fire has also affected zone 3, where the fire damage was limited to the paint and a few cables on the firewall.


Figure 9. Fire damage in zone 3. Cables on the firewall to the accessory compartment have melted and burned.

The exhaust has affected both the firewall, which is made from stainless steel, and a cowling for zone 2.

A petrol engine of the type in question has a large fuel surplus in the combustion, which means that a lot of unburned fuel comes out of the exhaust pipe and is ignited upon contact with the air. The exhausts had a temperature of 800 to 1,200 degrees, which is enough to melt the metal of the cowl to zone 2.

The suction side of the hydraulic system has been turned off after the shut-off valve was closed, but because the lines were burned off, hydraulic oil has leaked from the cowl flap lines and the plugged pressure line of the engine pump.

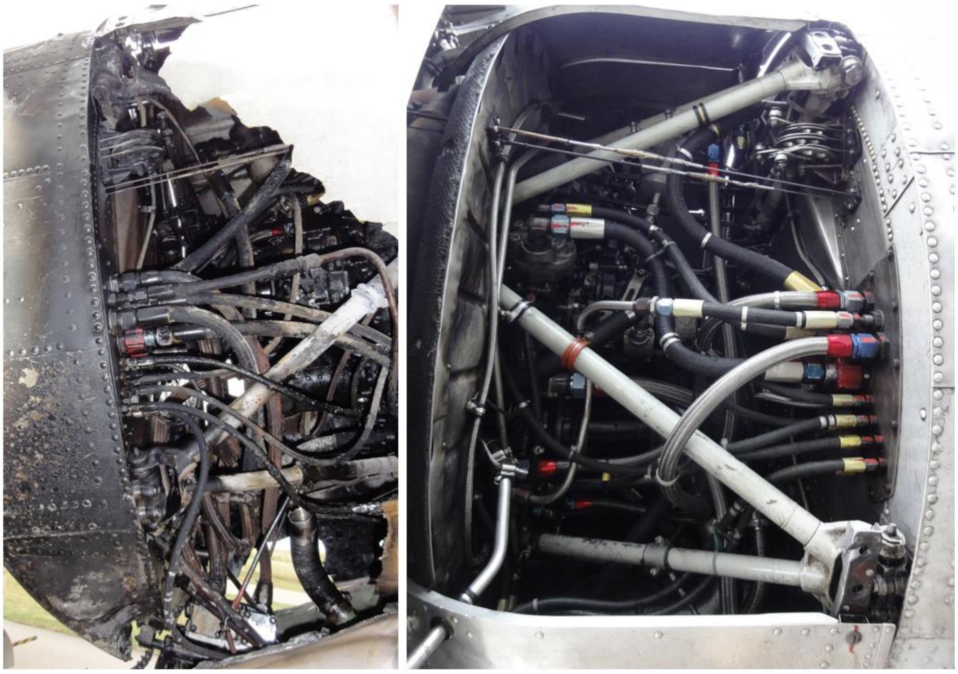

Figure 10. Some of the damage to zone 2, compared to the right engine.

## 1.15 Survival aspects

### *1.15.1 Rescue operation*

When the crew notified the air traffic controller that they had a fire warning on one of the engines, the airport rescue services were alerted. The time was then 17:56 hrs. Shortly thereafter, the crew confirmed to the air traffic controller that there was indeed a fire in the left engine, which could also be seen from the ground when the aircraft flew over before landing.

In addition to the airport rescue services, JRCC[14] and SOS Alarm were also alerted for municipal rescue services, ambulance and police. However, these resources from outside the airport never needed to be deployed.

At 18:02 hrs, when the aircraft had landed and stopped on the strip, the airport rescue services arrived to begin firefighting operations. Using the smaller foam cannon on one of the firefighting vehicles (the monitor), foam was sprayed on the aircraft around the left engine. Two firefighters with jet pipes also approached from either side of the engine, applying foam to secure against reignition.

The people on board, who were unharmed, evacuated the aircraft without any problem.

[14] JRCC – Joint Rescue Coordination Centre.

From the time the aircraft had come to a stop at the side of the runway, the rescue operation took roughly one minute, of which 15 seconds were used to apply foam. The fire was then completely extinguished and no other damage than fire damage around the engine was identified.

The ELT[15] was not activated.

## 1.16 Tests and research

### *1.16.1 Engine change*

The engine change was done under the supervision of the operator’s technical staff and with the assistance of a number of volunteers from the Netherlands and Denmark.

The work was carried out without a work order, i.e. “job card”, or other written instruction. After the engine change, no follow-up was done by comparing the removed components to the new components that had been taken from storage and fitted on the engine. The operator’s technical staff have not been able afterwards to account for who did what during the work process.

The only documentation on the engine change that SHK has found is a note in the yellow pages of the technical and journey log (see figure 11).

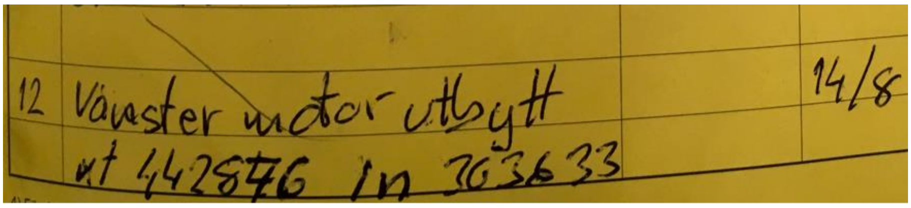


Figure 11. Note of the engine change in the technical and journey log (Left engine replaced, out 442876, in 303633).

The normal way to mount an exhaust system with many parts is to connect all the parts and to install the screws loosely before finally fastening them with a tool.

The places where the screws and bolts were missing were difficult to see and reach.

It has not been possible to establish whether the missing screws were never fitted at all, or if they were fitted by hand without being fastened by tool afterwards.

[15] ELT – Emergency Locator Transmitter.

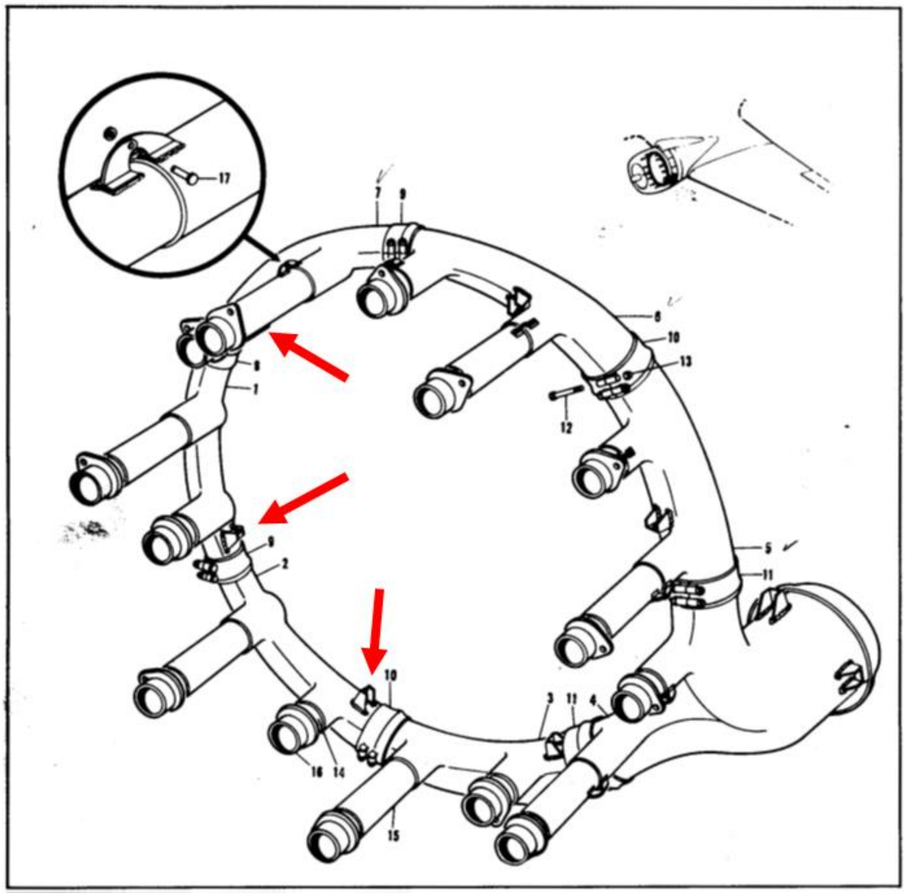

Figure 12. Image from “Illustrated parts catalogue” for DC 3. The arrows indicate the attachments for the exhaust collector that were lacking screw joints. Image: Copyright © Boeing. Reprinted with permission of The Boeing Company.

## 1.17 Organisational and management information

### *1.17.1 General*

The association Flygande Veteraner has a valid permit for operational organisation of private flights, with a take-off mass exceeding 5,700 kg, issued by the Swedish Transport Agency.

The permit is conditioned on the organisation being based on applicable requirements set out in the Swedish Civil Aviation Authority’s[16] regulations (LFS 2007:47) for aeroplane aerial work.

### *1.17.2 Operational regulations*

Pursuant to Chapter 2, Section 4 of LFS 2007:47, checklists according to BCL-M[17] 1.5 *Flight manual and aircraft checklist* must be produced and available for all flights. Chapter 2, Section 60 states that the commander is responsible for the use of these checklists.

[16] The Civil Aviation Authority’s information was transferred to the Swedish Transport Agency on 1 January 2009.
[17] BCL-M: Bestämmelser för civil luftfart – Materielbestämmelser (Civil Aviation Regulations – Materiel provisions).

At the time of the incident, there were two applicable emergency checklists, namely the checklist for engine fire and the checklist for emergency on the ground. The checklists and their use are described in more detail in section 1.18.

### *1.17.3 Maintenance*

In accordance with the operator's service manual, works of a temporary nature, such as engine changes, must be specially planned. Specially planned works are to be carried out in accordance with a work order referred to as a "job card".

## 1.18 Additional information

### *1.18.1 Checklists*

*General*

The established procedure for the use of checklists in a two-pilot system is for one pilot to read off the points on the checklist while the other one answers or confirms. That way, they verify that each point has been carried out.

*Checklist for engine fire*

The checklist for engine fire entails feathering the propeller of the burning engine, shutting off the engine and isolating it by closing the shut-off valves. In the next step, the fire extinguisher for the selected engine is to be triggered. The side windows must then be opened to ventilate the cockpit and the cowl flaps are to be in the closed position. The last two measures were not completed at the time of the incident.

According to the commander, it was an active choice not to use the checklists according to normal routine because PF was busy with the operation of the aircraft with an engine out of function at very low altitude, at relatively high speed and under difficult weather conditions. The commander has here specifically referred to Chapter 5. Section 7 of the Aviation Act (2010: 500) where it is stated that if an aircraft is in distress, the commander must do all he can to save on all on board, which according to him includes the possibility of deviating from a standardized checklist procedure according to a traditional two-pilot system.

*Checklist for emergency on the ground*

The checklist for an emergency on the ground entails closing both the shut-off valves and the fuel valves. The right-side shut-off valve and fuel valves were never closed.

### *1.18.2 Action taken*

Due to the incident, the operator has reported several deviations in their quality management system and proposed the following improvements:

- A work order is to be produced for any specially planned maintenance measures.
- An examination of the hydraulic system will be carried out.
- The switch for the aural fire warning will be repositioned.
- Training is to be carried out on how to handle the switch for the aural fire warning.

The operator has also stated that the accessory compartments of the engines will be cleaned in conjunction with engine changes or major oil leakages.

## 1.19 Special methods of investigation

### *1.19.1 Cameras for remote controlled tower*

The tower at Linköping/SAAB Airport is equipped for remote control, which means that the air traffic controller can carry out their tasks from another location. During the incident, the tower was manned, but some of the remote control equipment was still activated.

The remote control equipment includes 16 fixed cameras and two movable PTZ[18] cameras. SHK has obtained and analysed saved data from seven fixed cameras, which have a resolution of 1920x1080.

The information has been cut together and synchronised with audio from the aircraft CVR and from the ATC[19] recording, as well as with image and audio from the recording made in the aircraft cabin.

This has allowed SHK to observe the aircraft, with the exception of when it was flying in the clouds, and to listen to synchronised audio recordings from the entire flight, from taxiing to the runway before take-off until the end of the firefighting operation following landing.

[18] PTZ – Pan Tilt Zoom.
[19] ATC – Air Traffic Control.

# 2. ANALYSIS

## 2.1 Preconditions

In the days leading up to the incident, the aircraft had undergone a change of the left engine in Groningen in the Netherlands. Following the engine change, an engine run was completed without remark. The weekly check that was carried out in the morning before the flight to Linköping/SAAB Airport was also without remark. After landing, the aircraft was checked again, and the recently changed engine in particular. Nothing abnormal was noted.

However, there was no entry in the aircraft's technical and journey log regarding the removed and plugged hydraulic pump, which, in SHK's opinion, constitutes a deficiency in the operator's procedures.

## 2.2 Course of Events

The take-off went normally, however, video recordings from the airport cameras reveal that there was smoke coming out of the left engine shortly after lift-off. The co-pilot later remarked on a smell and the commander then mentioned a rattling sound.

A little over two minutes after take-off, the fire warning for the left engine was activated, which meant that a red light turned on and the fire bell started to sound.

The crew identified and confirmed that the fire warning related to the left engine, and reduced power in that engine accordingly. The commander stated that it was not possible to turn off the fire bell.

The co-pilot took over communication and called what he believed was the tower. In reality, he was communicating with the Östgöta control centre. He requested immediate radar guidance back and notified the controller of high temperatures on the left side.

The fact that he was communicating with Östgöta control centre rather than the tower could have been due to the emergency situation involving an engine fire that the crew was now in. However, the air traffic controller solved the misdirected communication by talking to a colleague in the tower, and then cleared the aircraft for landing on runway 11.

At this point, the aeroplane had descended below the clouds, and the crew had visual contact with the runway. The co-pilot notified the air traffic controller that there was a fire indication on the left side.

SHK notes that no formal distress call was made, which constituted a risk of delaying the rescue operation. In case of a distress call, the air traffic control will trigger a crash alert. However, in this case there were no consequences as the air traffic control still triggered the alert when the crew announced that they had an engine fire.

The propeller of the left engine was stopped in feathered position 1 minute and 51 seconds after the fire warning was activated. The shut-off valve of the left engine was then closed and the fire extinguishing system for the left engine was activated. The measures in conjunction with the engine fire were not carried out through pilot interaction.

The fact that the measures took so long, and that the cowl flaps were not placed in the closed position, may be due to the crew not going through the engine fire checklist, which in turn is explained by the the commander's prioritisation of a quick approach.

The engineer in the cockpit turned off the aural fire warning, which had been sounding continuously for nearly four minutes. The commander had previously said that the warning could not be turned off, which is likely due to the fact that it cannot be accessed from the left seat, where the commander was sitting.

An aural warning that is not turned off can be disruptive and may divert attention away from important tasks. In addition, it makes it more difficult to appropriately complete the checklist, i.e. by having one of the pilots reading the items on the checklist and the other pilot responding.

When the crew discovered during the landing roll that the brakes were not working, the commander shut down the running engine. Without brakes, the aircraft's steering capacity is limited on the yaw axis as the speed is reduced, which caused the aircraft to come off the runway and stop on the strip.

Once the aircraft had stopped, the commander ordered the evacuation, noted that the engines were shut down and turned off the main power. However, no checklist for an emergency on the ground was completed, which is a likely explanation for why the right shut-off valve and fuel valves were never closed. However, this was inconsequential.

## 2.3 Fire sequence

The investigation has shown that three screws that are to fixate the exhaust collector were missing. This led to the exhaust collector coming loose from several of the cylinder exhaust pipes.

As the exhaust system came apart, it generated a lot of heat and open flames in zone 1, which caused the first firewall to heat up. This in turn led to oil residue and dust in zone 2 catching fire.

The most likely is that exhaust flames streaming out of zone 1 via the cowl flap openings have melted the cowling around zone 2.

As the cowling melted, exhaust flames and air were able to enter zone 2 and increase the intensity of the fire through an increased oxygen supply.

The actuator valve of the cowl flaps is installed on the lower part of the forward firewall. For this reason, it is likely that the hydraulic lines to the cowl flaps were burned off. As the operating valve was set to trail, there was return pressure in both the lines leading to the cowl flaps. This caused hydraulic oil to leak out and burn off in the existing fire.

According to the emergency checklist, the valve is to be set to trail-off. The reason for this is that the off-position closes the lines at the operating valve in the cockpit. When the plugged line to the removed hydraulic pump, which connects directly to the line of the right hydraulic pump, was burned off, it added combustible to the fire.

The remaining oil has then leaked out to sustain the fire.

The aircraft's fixed $CO_2$ fire extinguishing system only had a limited effect, as the engine cowling was most likely partially melted already. This meant that the extinguishing agent was quickly vented.

$CO_2$ is easily affected by moving air, and is most effective in closed spaces.

## 2.4 The hydraulic system

The shut-off valve only closes the suction line of the hydraulic pump. This likely has a historical explanation, as the original design of the hydraulic system allows for the pressure line of the left pump to be connected to the autopilot pressure regulator should the right pump be selected to control the main system. The pressure regulator will then act as a check valve and prevent oil from leaking into the pressure line of the left pump.

The modified design (see figure 5) means that the right pump is always connected to the main system. The left pump can be used either to supply the hydraulic pressure for the autopilot or to reinforce the main system. Since the pressure lines of the two pumps are connected, a leakage at either side will empty the entire system.

In case of leakage from the left engine, a shutdown of the pressure line would have been possible if the control had been switched to the position for the left pump to feed the autopilot. However, this is not written in any checklist. The selector valve was also locked in the position for the left pump to reinforce the main system.

In case of leakage from the pressure line of the right engine, there is no way to prevent a complete depletion of the oil.

With the existing system, the shut-off valve cannot prevent oil leakage in the event of the hydraulic lines in zone 2 being burned off or starting to leak for another reason.

The fact that the left hydraulic pump was removed is not deemed to have had an effect on the incident, as the pressure line of the pump would have been burned off even if the pump had been installed.

## 2.5 Engine change

The investigation has shown that three screws that are to fixate the exhaust collector were missing following the engine change. The normal way to mount an exhaust system with many parts is to connect all the parts and to install the screws loosely before finally fastening them with a tool. However, it has not been possible to determine how the installation was done in this case.

The operator's service manual shows that the engine change must be planned specially and that a "job card" is to be used. SHK interprets this as a detailed work order, where essential points must be signed off. Working according to a detailed work order contributes to reducing the burden of having to remember what measures have been carried out or not.

However, the engine change was carried out without a work order and without following up on which components were possibly left over. This could be one of the reasons why the missing screws were either never installed in the first place or were not fastened by tool. In addition, the screws were in an inaccessible location, which meant that it was not possible to simply see whether they were there or not.

# 3. REPORT

## 3.1 Findings

a) The pilots were qualified to perform the flight.
b) The aircraft had a valid Certificate of Airworthiness.
c) The engine change was done without a work order.
d) The fire warning for the left engine was activated after take-off.
e) The left propeller was feathered after close to two minutes after the start of the fire warning.
f) The shut-off valve of the left engine was closed.
g) The fire extinguishing system was activated and triggered for the left engine.
h) The aural fire warning was turned off after close to four minutes.
i) The brakes gave no effect after the landing.
j) The aircraft came off the runway and stopped on the strip.
k) The aircraft was evacuated.
l) The aircraft rescue services extinguished the engine fire.
m) The emergency checklists were not completed.
n) Three screw joints for the exhaust collector attachments were missing.
o) Excessive heat and open flames in zone 1 ignited oil residue and dust in zone 2.
p) Exhaust flames melted the cowling around zone 2 and were able to enter zone 2, where they set fire to hoses and other flammable material.
q) Leaking hydraulic oil was also ignited, adding fuel to the fire.

## 3.2 Causes/Contributing Factors

The incident was caused by the engine change being carried out without following the operator's established procedures for specially planned repairs.

The following factors contributed to the extent of the fire:

- The design of the existing hydraulic system, which does not allow the hydraulic oil to be isolated from engine zone 2.

- The failure to close the operating valve of the cowl flaps (item "trail-off" in the engine fire emergency checklist).

## 4. SAFETY RECOMMENDATIONS

In view of the measures that the operator has taken or plans to take, SHK is refraining from issuing any safety recommendations in response to the incident.

On behalf of the Swedish Accident Investigation Authority

Mikael Karanikas Nicolas Seger