# Investigation Report

## Identification

<table>
<thead>
<tr>
<th>Type of Occurrence:</th>
<th>Serious incident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date:</td>
<td>6 January 2016</td>
</tr>
<tr>
<td>Location:</td>
<td>Saarbrücken</td>
</tr>
<tr>
<td>Aircraft:</td>
<td>Airplane</td>
</tr>
<tr>
<td>Type certificate holder / type:</td>
<td>M7 Aerospace LLC / SA226-TC</td>
</tr>
<tr>
<td>Injuries to Persons:</td>
<td>None</td>
</tr>
<tr>
<td>Damage:</td>
<td>Minor damage to aircraft</td>
</tr>
<tr>
<td>Other Damage:</td>
<td>None</td>
</tr>
<tr>
<td>State File Number:</td>
<td>BFU16-0013-GX</td>
</tr>
</tbody>
</table>
Factual Information

History of the Flight

On 6 January 2016 at 1735 hrs\(^1\) the aircraft took off from Paderborn-Lippstadt Airport (EDLP) for a flight to Girona Airport (LEGE), Spain. There were no passengers or freight on board.

During the flight the crew noticed an unequal fuel distribution between the right and the left wing tank. The Pilot in Command (PIC) stated that it was necessary to adjust the trim to the mechanical full stop position. Subsequently, he decided to conduct an unscheduled landing at Saarbrücken Airport (EDDR).

At 1820 hrs the air traffic control unit Langen informed the Tower controller of Saarbrücken Airport about the imminent diversion due to fuel leakage.

The PIC stated that during the approach to Saarbrücken Airport it was difficult to control the airplane.

At 1835 hrs the airplane landed at Saarbrücken Airport on runway 27. After touchdown the fire brigade accompanied the airplane to the parking position.

Personnel Information

Pilot in Command

The 34-year-old PIC held a Commercial Pilot’s Licence (CPL(A)) issued on 25 October 2010 by the Spanish Agencia Estatal De Seguridad Aérea in accordance with Part-FCL (Flight Crew Licensing). The licence listed the ratings for the aircraft types SA226/227/MP and Instrument Rules (IR). The ratings were valid until 31 May 2016. The BFU was provided with a class 1 medical certificate valid until 28 June 2016.

The PIC had a total flying experience on Metro SA226-TC of about 1,970 hours, of which about 838 hours were flown as PIC.

\(^1\) All times local, unless otherwise stated.
Co-Pilot

The 28-year-old co-pilot held a Commercial Pilot’s Licence (CPL(A)) issued on 4 July 2011 by the Spanish Agencia Estatal De Seguridad Aérea in accordance with Part-FCL (Flight Crew Licensing). The licence listed the ratings for the aircraft types SA226/227/MP and IR. The type rating was valid until 31 July 2016. The BFU was provided with a class 1 medical certificate valid until 21 June 2016. The co-pilot had a total flying experience of about 478 hours on SA226-TC.

Aircraft Information

The Metro SA-226-TC is a low-wing aircraft with retractable landing gear and two turboprop engines. Each engine is fitted with a three-blade propeller.

The type certificate was issued on the basis of FAR 23 of 1 February 1965.

- Year of manufacture: 1979
- S/N: TC-318
- Maximum take-off mass: 5,670 kg
- Operating hours: 28,453
- Flight cycles: 37,135
- Engines: Garret TPE331

The airplane had a Spanish certificate of registration, was operated by a certified Spanish operator, and used as cargo aircraft.

Aircraft Maintenance

According to the aircraft log book the last release to service had been issued on 21 December 2015 after maintenance work had been conducted.

The release to service listed the following actions performed:

"Torque adjusted after data sheet on R/H engine.
Flight Idle Fuel Flow adjusted and Prop Governor High adjusted.
Torque system checked and re-adjusted on L/H engine. Checked and adjusted blade angle, on both engines. Work performed I.A.W. TPE 331-10UA, amm 72-00-45 Rev. 9, Feb. 9/94 Ch. 73-20-01."
The maintenance organisation provided the BFU with a written statement stating that no maintenance work had been performed on the fuel pipes of the two engines. The work covered the electric for the torque control units on the propeller gearboxes of both engines. Since the last maintenance work three flights, including the occurrence flight, had been conducted with a total flight time of about five hours.

Description of the Aircraft Fuel System

The following description of M7 Maintenance Manual, Fuel – Description and Operation for the SA226 series is an extract:

Each engine is supplied fuel by an independent fuel system. An interconnecting crossflow line is provided for balancing the fuel quantity and for supplying either engine with fuel. This system is electrically controlled by a switch on the instrument panel.

- A jet transfer pump system for supplying fuel to boost pumps.
- Two boost pumps to supply fuel to the engines.
- Three check valves, one from each boost pump to the fuel line and on in the jet transfer pump inlet line.
- A fuel shutoff valve in the fuel line.
- A fuel vent system that allows air to enter fuel tanks to displace used fuel.
- A separate capacitance type quantity indicating system.
- Two indicators mounted on the instrument panel that display the fuel quantity in pounds.
According to the *TPE 311 Line Maintenance Training Manual* the fuel flows from the fuel system in the wings to the fuel pump assembly and then to the fuel control unit of
the respective engine. A fuel flow rate meter is fitted between the fuel control unit and
the engine.

The *Aircraft Flight Manual (AFM)* for the SA226-TC specifies the maximum demonstrated fuel mass imbalance for take-off and landing with 500 lbs.

**Calculation of the Fuel Loss:**

The operational flight plan listed the following values:

- **Block Fuel in Paderborn:** 3,800 lbs
- **Land Fuel in Saarbrücken:** 1,900 lbs
- **Fuel Burn Off:** 872 lbs
- **Air Time:** 01:05 hours
- **Block Time:** 01:45 hours

Based on these values there is a shortage of 1,028 lbs fuel after the flight.

**Meteorological Information**

According to the aviation routine weather report (METAR) of 1820 hrs of Saarbrücken Airport (EDDR) visibility was 8 km at variable winds with 1 kt. Clouds with a cloud cover of 3/8 to 4/8 at 400 ft and of 5/8 to 7/8 at 2,500 ft were reported.

Temperature was 5°C, the dewpoint 4°C, and the barometric air pressure (QNH) 1,000 hPa. Forecast was a trend of temporary fluctuation of the cloud cover with 5/8 to 7/8 at 400 ft.

At the time of the occurrence it was night.

**Aerodrome Information**

The information for Saarbrücken Airport was derived from the Aeronautical Information Publication (AIP). Saarbrücken Airport is located 9.3 km south of the city of Saarbrücken. Aerodrome elevation is 1,058 ft.
Runways

<table>
<thead>
<tr>
<th>Runway</th>
<th>Dimensions</th>
<th>Surface</th>
<th>Approach System</th>
</tr>
</thead>
<tbody>
<tr>
<td>09 (087°)</td>
<td>1,990 m x 45 m</td>
<td>Asphalt</td>
<td>VOR / RNAV</td>
</tr>
<tr>
<td>27 (267°)</td>
<td>1,990 m x 45 m</td>
<td>Asphalt</td>
<td>ILS (Cat I)/VOR/NDB/RNAV</td>
</tr>
</tbody>
</table>

Flight Recorder

The aircraft was not equipped with a flight data recorder or a cockpit voice recorder. Neither recorder was required by relevant aviation regulations.

Findings on the aircraft

The BFU examined the aircraft. The examination of the right engine determined that one of the two fuel pipes, which connect the fuel heater with the fuel pump and the starting fuel flow regulator assembly, respectively, had been severed. The defective fuel pipe (P/N 3102409-1) had a nominal diameter of 3/16 inches. Both coupling nuts, which connected the fuel pipe with the fuel heater, did not show any locking varnish. During disassembly of the defective pipe it was noticed that it had not been mounted stress-free.
The engine manufacturer determined that the two fuel pipes had been wrongly connected to the fuel heater.

Fire

The airplane landed at Saarbrücken Airport on runway 27. After touch-down the fire brigade accompanied the airplane to the parking position.

The fire brigade informed the Tower controller that smoke was coming from the right engine.
According to the police report, after the airplane had been parked flames were coming from the right engine. The fire brigade used foam and CO₂ to extinguish the fire.

After the engine cowling had been opened traces of heat development and slight soot traces were found in the vicinity of a severed fuel pipe. Other indications of fire were not found.
Organisations and their Procedures

The AFM for the SA226 TC describes the procedure for balancing a fuel imbalance as follows:

WARNING:

AUTOPilot / Yaw Damper use during fuel balancing is Prohibited.

1. Check aircraft is in coordinated flight.
2. Open Cross Flow Valve [...]. In level unaccelerated flight, fuel will flow in the desired direction (heavy to light) due to gravity.
3. To expedite process, use aileron control and place the wing with less fuel to a lower position (no more than 5 degrees is needed) than the wing with more fuel. Use rudder to maintain assigned heading. Maintain a safe margin of airspeed during this "slip" condition.
Additional Information of the Engine Manufacturer

In a memorandum the engine manufacturer described the installation configuration of the fuel pipe involved. The following images show the correct and the actual, wrong, installation configuration.

(8) Diagram of the normal installation configuration

Green: Fuel pipe from the fuel pump to the fuel control unit
Blue: Fuel pipe from the starting fuel flow regulator assy to the fuel heating
Red: Fuel pipe from the fuel heating to the fuel pump

Source: Manufacturer
The engine manufacturer calculated the possible loss ratio caused by the rupture of the fuel pipe. Based on a fuel pressure at the beginning of the ruptured pipe of 350 to 400 psi (pound-force per square inch) the fuel loss rate for Jet A fuel was approximately 3,500 to 3,700 pph (pound per hour).

Calculation of the Fuel Mass Imbalance

According to the flight plan block fuel was 3,800 lbs. Provided that the fuel had been distributed evenly 1,900 lbs were in each tank (left and right).

Fuel consumption of both engines during the entire flight was entered with 872 lbs. Provided that fuel consumption of both engines was identical, this would mean that from each tank 436 lbs fuel would have been used. Therefore, 1,464 lbs fuel would have remained in each tank. Subsequently, a total mass of 2,928 lbs fuel should
have remained. However, a total of 1,900 lbs fuel remained in both tanks. This means a total loss of fuel mass of 1,028 lbs.

According to the calculations of the engine manufacturer up to 3,700 pph fuel could leak from the fuel system of the right engine. This means the shortage of 1,028 lbs fuel could be allocated entirely to the right tank.

Therefore, after the landing 1,464 lbs of fuel remained in the left tank and 436 lbs in the right. The fuel mass imbalance was 1,028 lbs.

Examination of the Ruptured Fuel Pipe

The BFU examined the defective fuel pipe (P/N 3102409-1). It consisted of a light metal alloy and had a nominal diameter of 3/16 inches. The connection between the fuel pipe and the fuel heater consisted of a flange connection.

The fuel pipe had ruptured in the area of the tube joint. The fracture surface of the flanging (Image 10) was examined. The fracture surface did not show any subsequent damage.

(10 and 11) Fracture area of the fuel pipe with slight pipe bend and detail view

The fracture surface showed a knuckle (left in Image 11). It is the last pipe circumference which ruptured. Due to the relatively high force, which affected the relatively small area, the material was drawn out until it finally severed.
A stereo reflected-light microscope Olympus SZH was used for the microscopic examination of the fracture surface. Image 12 shows the surface topography.

The 7-o'clock position in Image 12 shows the drawn-out end of the residual fracture. The residual fracture extends to the left and right along the pipe circumference almost to the 12-o'clock position. At the 12-o'clock position the surface colour seems to be darker. It is highly likely that the area with the darker colour is a fatigue fracture.

The outer surface of the fuel pipe showed damages in the form of grooves (Image 13) in the area of the presumed fatigue fracture.

It is highly likely that the fracture had occurred as follows: The grooves on the outer skin of the pipe provided a kerf, which formed a crack and finally resulted in a fatigue fracture. After the fatigue fracture had travelled through about two thirds of the pipe circumference the residual fracture occurred and resulted in the separation of the fuel pipe.
Analysis

Aircraft

The fuel mass imbalance described by the crew was the result of a fuel pipe fracture on the right engine.

Even though the loss ratio could reach up to 3,700 pph and therefore be almost 10 times as high as the fuel consumption of the engine during cruise flight, the crew did not report any engine malfunction. Based on investigation results of the fracture surface of the fuel pipe, it has to be assumed that the pipe did not suddenly fracture completely, but that first a crack developed and the fuel loss ratio had been significantly lower. Since the leakage occurred in front of the fuel flow rate meter of the right engine the fuel loss could only be determined by comparing the fuel tank content of left and right wing tank.

It is probable that the incorrect installation, which caused an excessive strain on the pipe, significantly contributed to the fracture of the pipe.

More than 14 days but only five flight hours lay between the last maintenance work and the occurrence flight. Therefore it appears to be obvious that there is a connection between the maintenance work and the serious incident. However, there was no work on the components involved documented and the maintenance organisation has explicitly pointed out that no work on these parts had been performed. During the investigation it could not be clarified when the incorrect installation of the fuel pipe occurred.

Flight Operations

The fuel mass imbalance determined after the landing of 1,028 lbs was approximately twice as high as the maximum demonstrated fuel mass imbalance the manufacturer had specified. Therefore the aircraft was outside the demonstrated safe operating range. It is understandable that the crew reported of difficulties with the control of the airplane.

In the course of the flight the right engine fuel consumption was normal. This corresponds with the left engine fuel consumption. Then a leakage developed in the fuel pipe system of the right engine. The fuel consumption plus the leakage was approximately twice as high and came solely from the right fuel tank. The content of the right
tank decreased much faster than the left. Therefore the crew's decision for an immediate diversion is understandable.

The options of the crew to locate and isolate the leakage were limited. Since the engine fuel system consists of significantly more components than the fuselage fuel system the probability for a leakage developing there is essentially higher. The two parts of the system can be separated by shutting off the engine and closing the fuel shut-off valve. In the majority of the cases this stops the leakage and minimises the fire hazard. Once the leakage is stopped the procedure described in the AFM can be used to balance the fuel mass imbalance and put the aircraft back in safe operating range.

Given this information, the BFU understands only to some extent that the crew did not shut off the right engine. It was accepted that the continuing fuel loss would increase the fuel mass imbalance and the aircraft become more difficult to control. This decision also increased the fire hazard. The BFU is of the opinion that the risks of an approach with one engine shut-off are significantly lower because it is a proven procedure and the pilots are generally trained accordingly.

The BFU is of the opinion that the missing standard procedure regarding the handling of fuel leakages contributed significantly to the fact that the crew did not perform any actions to remedy the problem.

**Fire**

The BFU is of the opinion that due to the limited heat and soot traces it can be assumed that the leaked fuel only ignited after the landing. Since flames had only been reported after the engines had been shut off and at that time the fuel supply had already been cut off the hazard of fire propagation had been low.
Conclusions

The serious incident is due to the fact that during the flight the fuel pipe on the right engine had fractured and the leaking fuel caused an imbalance so that the aircraft was difficult to control.

The following factors contributed the serious incident:

- The fuel pipe was damaged and installed incorrectly.
- The crew had not isolated the leakage.
- The procedure for the re-balancing of a fuel imbalance was not performed.
- There was no standard procedure for handling fuel leakages.

Investigator in charge: Thomas Kostrzewa
Assistance: Norman Kretschmer
Dietmar Nehmsch
Field investigation: Peter Baus

Braunschweig, 17 March 2020
This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (Flugunfall-Untersuchungs-Gesetz - FLUUG) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

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