DUTCH
SAFETY BOARD

Emergency landing after partial loss of engine power

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The Hague, January 2019

Photo cover: R. van Dooren

The Dutch Safety Board

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N.B. This report is published in the English language with a separate Dutch summary. If there is a difference in interpretation between the report and the summary, the report text wil prevail.

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GENERAL INFORMATION

Figure 1: Archive photo PH-EMW. (Source: Kees Marijs)

Identification number:	2017060
Classification:	Accident
Date, time[1] of occurrence:	22 June 2017, approximately 11.15 hours
Location of occurrence:	Near Haaren, the Netherlands
Aircraft registration:	PH-EMW
Aircraft model:	Diamond DA-40 D
Type of aircraft:	Single engine piston
Type of flight:	Private
Phase of operation:	En-route
Damage to aircraft:	Substantial
Cockpit crew:	One
Passengers:	One
Injuries:	None
Other damage:	None
Lighting conditions:	Daylight

1 All times given in this report are local unless stated otherwise.

SUMMARY

During cruise flight, engine revolutions per minute (RPM) started to fluctuate and the engine did not deliver enough power to maintain cruising speed and altitude. The pilot was forced to make an emergency landing. During the landing the aircraft hit the bank of a ditch causing the landing gears and propeller blades to break. Both occupants were unharmed after the landing.

The investigation focused on the cause of the fluctuating and decreasing engine power.

The power fluctuations were most likely caused by damaged engine (loom) connectors which caused intermittent electrical contacts between the engine and the Full Authority Digital Engine Control (FADEC).

The execution of the emergency landing procedure was not investigated.

FACTUAL INFORMATION

History of the flight

The aircraft with registration PH-EMW took off from Eindhoven Airport for a local flight. On board were the pilot and an aircraft mechanic.

It was a warm day with temperatures around 31 °C on the ground and 25 °C at 1,500 feet. The visibility was more than 10 kilometres, with a cloud base at 25,000 feet. The surface wind came from 250 degrees with a strength of 11 knots, gusting to 18 knots.

After approximately 20 minutes into the flight and a power (or load) setting of 70% on the load display, the pilot noticed small engine vibrations and noticed the power fluctuating between 69% and 71%. The mechanic on board believed that the power fluctuation was caused by the FADEC[2] controlling the RPM by varying the propeller pitch.

After approximately one minute the vibrations disappeared and the power remained constant at 70%. All engine parametres were within limits and no warnings or alerts were present. The pilot decided to return to Eindhoven Airport and selected full power (100%) to climb to the airport approach altitude of 1,500 feet. The maximum available power was 93% and the climb rate was less than expected. Initially the pilot attributed the poor climb performance to the (high) outside air temperature. The engine power decreased rapidly and the pilot was forced to stop the climb to avoid a stall. The maximum available power was 60% and the aircraft descended slowly. The pilot selected idle power followed by full power again but the available power was stuck at 60%. The aircraft descended through 1,000 feet and the pilot informed air traffic control (ATC) that he was not able to maintain altitude. According to the pilot, ATC instructed him to climb to 1,500 feet and he replied to ATC that he was unable to. The pilot did not declare a mayday call because of the high workload.

The aircraft descended through 600-700 feet and the pilot chose a field for an emergency landing. The chosen area was free of trees and buildings but with crosswise ditches. After a 180 degrees turn the aircraft touched down gently but with a high groundspeed. Although both occupants applied maximum braking power they could not prevent that the aircraft went through a ditch. All three landing gears broke off and the aircraft came to rest. Both occupants left the aircraft uninjured. Besides the landing gears the (wooden) propeller blades were also broken.

2 Full Authority Digital Engine Control.

Figure 2: PH-EMW after the emergency landing. (Source: R. van Dooren)

Personnel Information

The pilot, a 40 year-old male, possessed a Private Pilot Licence (PPL(A)) with a rating for single engine piston (SEP). The pilot held a valid medical certificate, class II.

Number of hours total	215
Number of hours on DA 40 D	7

Table 1: Flying experience pilot.

Aircraft and engine information

The Diamond DA-40 D is a four-seat, single engine, light aircraft constructed from composite materials. It has a fixed nose-wheel type landing gear, low wing and a T-tail. On the day of the accident, the aircraft had accumulated 1607 flight hours. The TAE 125-02-99, manufactured by Technify Motors GmbH, is a modified car engine, 4-cylinder, four stroke diesel piston engine with a displacement of 1,991 cm^3, equipped with common rail high pressure direct injection, turbocharger, propeller gearbox, propeller governor, and FADEC. The engine is liquid cooled and produces 99 kW (135 hp) at 3,900 RPM. In the cockpit the following engine parametres can be monitored on the engine indication system section of the Multi Function Display: load, RPM, fuel flow, oil temperature, oil pressure and coolant temperature.

Power (or load) control of the engine is regulated by a FADEC unit. In short, based on several input parametres, the FADEC calculates and controls the fuel flow to the engine. The FADEC is equipped with two separate engine control units (ECU), distinguished as ECU-A and ECU-B. Both ECUs are operational at all times but only one is active. Both ECUs monitor their condition and if one detects a failure, the other ECU will take over control automatically. This is indicated by an illuminated ECU A/B failure warning light in the cockpit.

The FADEC includes a failure and data recording system, which may be utilised for engine trouble shooting. The data can also be downloaded after the flight for analysis.

INVESTIGATION AND ANALYSIS

The Dutch Safety Board did not investigate the execution of the emergency landing procedure. The aircraft was transported to the aircraft manufacturer in Austria. At the request of the Safety Board, the engine was removed and sent to the engine manufacturer in Germany. The engine and the FADEC were investigated at the manufacturer's facilities. Two Safety Board investigators were present when the engine was unpacked from its transportation case, during the running of the engine on the test bench and during the removal and testing of the different parts.

The results were shared with representatives of the maintenance organisation, including the mechanic involved, during a meeting at the Dutch Safety Board's facilities. In the following months, the maintenance organisation provided the Dutch Safety Board with various questions for the engine manufacturer, as part of the investigation into the possible cause of the engine and FADEC issues. The questions were transferred to the engine manufacturer. The investigators shared the answers with the maintenance organisation

Engine and FADEC history

In 2016 the newly built engine with serial number 02-02-04228 was installed on PH-EMW. On 19 May 2017, at a total engine time of 92:04 hours the (original) FADEC with serial number 4453 was removed from the aircraft because of a high Manifold Air Pressure (MAP) A/B difference. MAP is measured by two separate sensors; one connected to ECU-A (MAP A) and the other one to ECU-B (MAP B). When MAP A and MAP B differ too much, the ECU A/B failure warning light will be illuminated. The FADEC was removed and sent to the engine manufacturer. The FADEC was inspected and traces of water were found in the MAP A sensor. The sensor was replaced and the FADEC was tested and returned to the operator.

In June 2017 the FADEC with serial number 4453 was reinstalled in the airframe. A subsequent systems check failed (no Controller Area Network (CAN) communication possible) and it was concluded that it was caused by a faulty FADEC. The FADEC was removed from the airframe and returned to the engine manufacturer again for investigation. According to the maintenance organisation, the support department of the engine manufacturer was contacted several times by telephone for assistance.

A replacement FADEC with serial number 3671 was installed in the airframe. During the first run-up Engine Control Unit (ECU) check on 19 June 2017, no warnings or failures were present. The aircraft was released to service. On 19 June 2017, during the first flight after the ECU change, there was a failure on ECU A, after which the pilot returned to the airport. Further analysis showed that it was caused again by a high MAP A/B difference. On 22 June 2017 an aircraft mechanic detected a crack in the manifold air pressure hose and repaired the crack. The engine total time at the moment of the repair was 92:29 hours. During the following run-up ECU test, no ECU A/B failure warning came on. A ground check with full power for 30-45 seconds with diagnosis software also did not reveal any discrepancies: all sensors performed well. The aircraft mechanic accompanied the pilot on the event flight (see 'History of the flight').

Engine and FADEC investigation

Engine

After the accident, the aircraft was transported to the aircraft manufacturer were the engine was removed from the airframe and on 8 August 2017 it was shipped to the engine manufacturer in a sealed box. On 6 September 2017, the engine and FADEC investigation started in the presence of two investigators from the Dutch Safety Board. After an incoming inspection the engine was installed on a test bench for a test bench run. Initially, after fitting the connectors there was no electrical connection between the FADEC with serial number 3671 and the engine. After refitting the connectors, electrical connection was established and the engine was started and warmed up. At first the engine ran normally but when the connectors to the FADEC were moved by hand, engine RPM started to fluctuate and the FADEC light illuminated. FADEC data showed that the engine switched from FADEC A to B, then back to A and finally to B again. The engine was shut down and further emphasis was put to the loom, the loom connectors, the original FADEC (serial number 4453) and its sockets.

Loom

The union nuts of both electrical connectors that connect the loom (engine wiring harness) to the FADEC indicated tool marks.

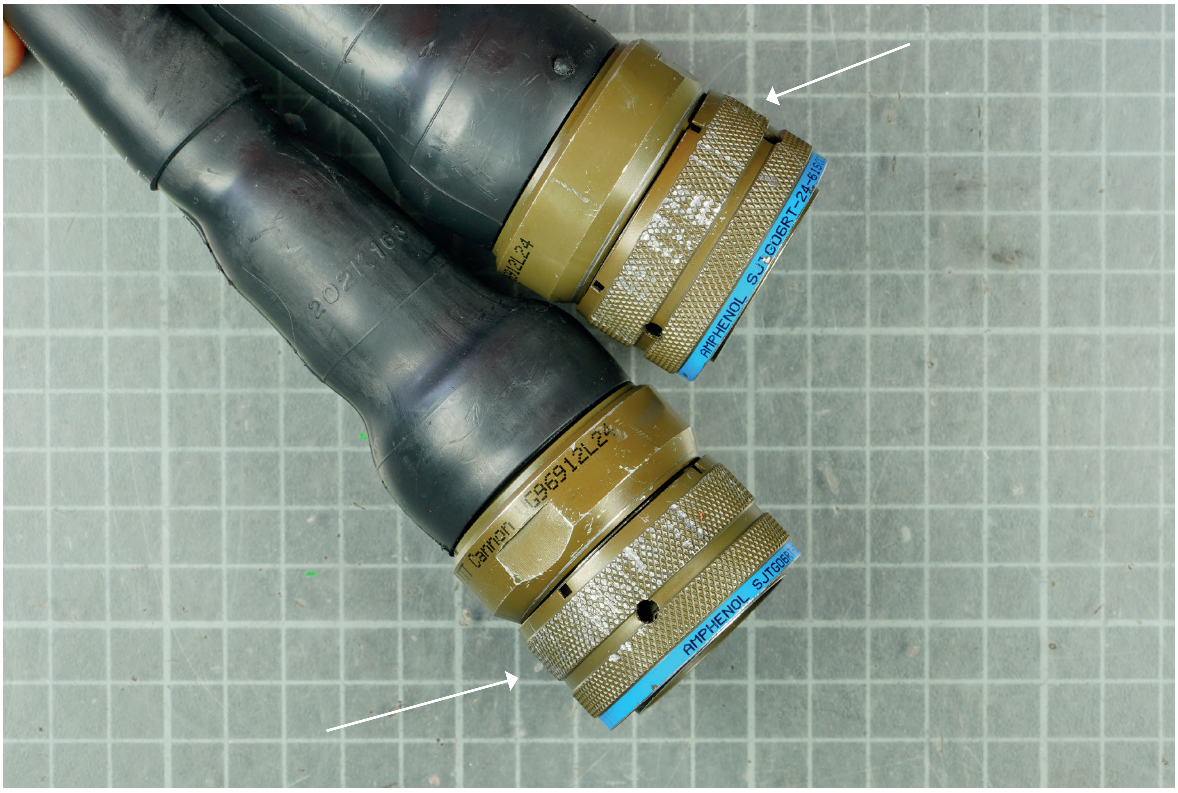

Figure 3: Tool marks on the union nuts. (Source: Technify Motors)

A more detailed investigation with the aid of a microscope indicated that the tool marks most likely were caused by a wrench turning the union nuts clockwise (fastening). The connectors are designed to use hand force only to fasten and lock them, no excessive force is required. That only hand force is required has been confirmed by engineers with long time experience with this type of aircraft.

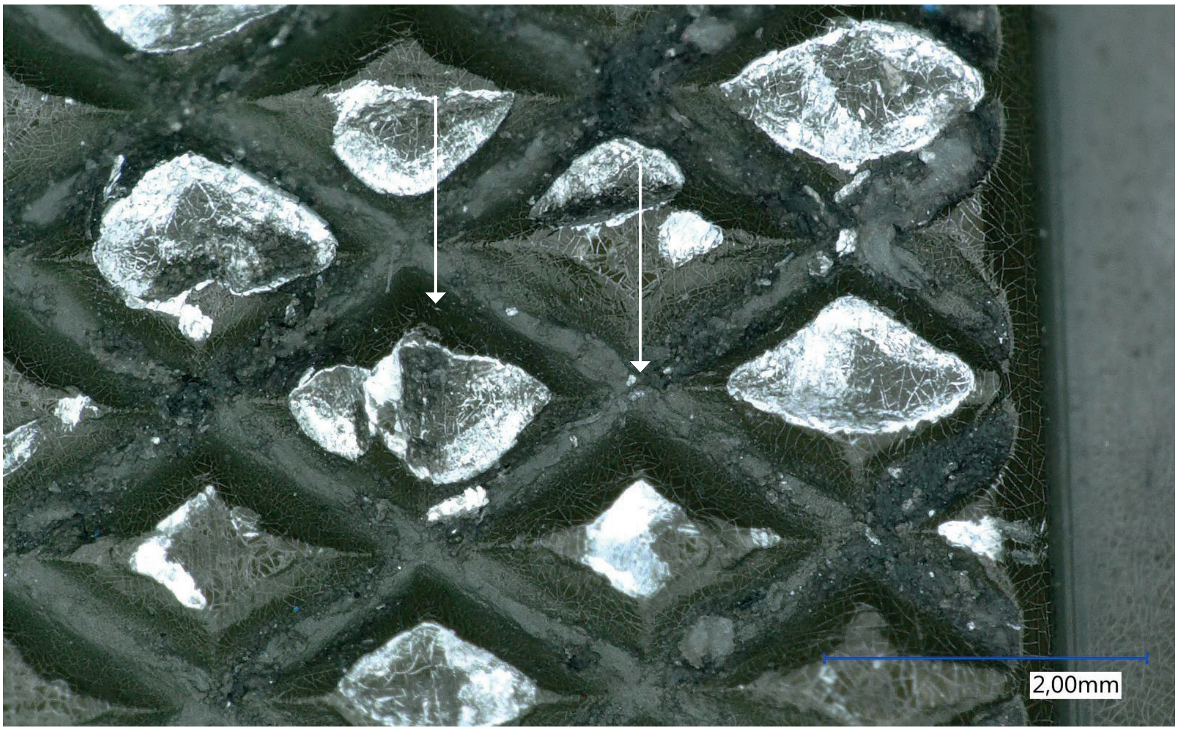

Figure 4: Tool marks with direction of rotation on the union nuts. (Source: Technify Motors)

According to the aircraft mechanic, however, it is common practice to use a wrench to lock the union nuts.

Usually when the union nuts are well connected and locked to the FADEC the connection is stiff and there is no wiggle room. In this case, however, the connectors were not tightly connected and could be moved a bit. Further investigation revealed that the inner part of the connectors was damaged by the applied force. As a comparison two connectors were photographed side by side; an undamaged connector (left in Figure 5) and one of the connectors that was fitted during the accident flight (right in Figure 5). The undamaged connector protruded 2 millimetres more than the damaged connector.

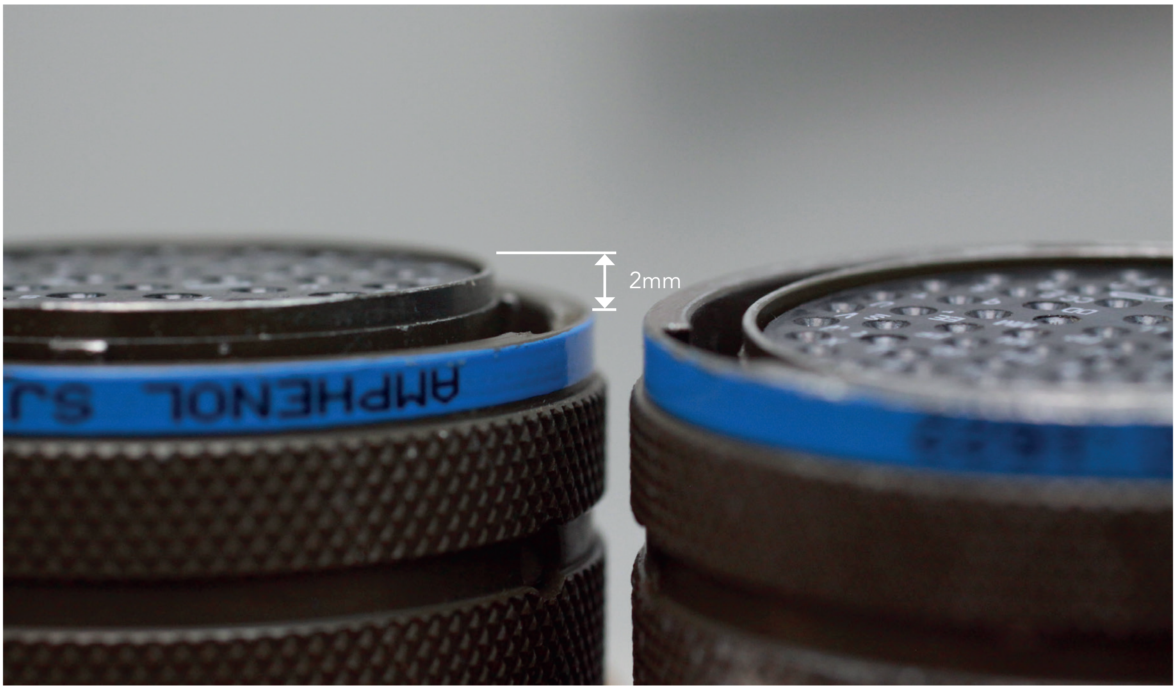

Figure 5: Undamaged loom connector (left), damaged loom connector (right). (Source: Technify Motors)

A detailed inspection of both inner connector surfaces involved in the accident showed visible pin marks indicating a cross connection of loom connector A to FADEC socket B and vice versa (in a correct installation, connector A is fitted to socket A and connector B to socket B). The diametres of both connectors and the locking mechanism are identical but pin diametre and pin layout are different and the connectors are not interchangeable.

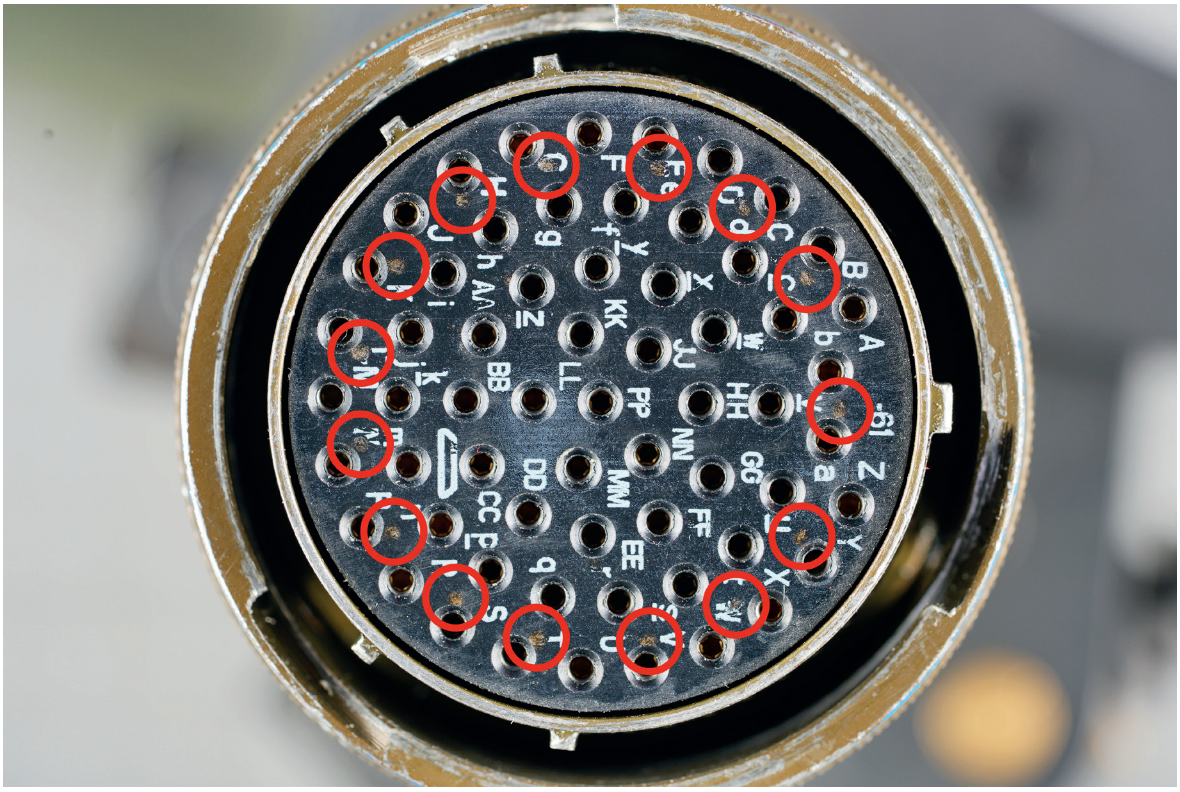

Figure 6: FADEC B socket pin marks on loom connector A. (Source: Technify Motors)

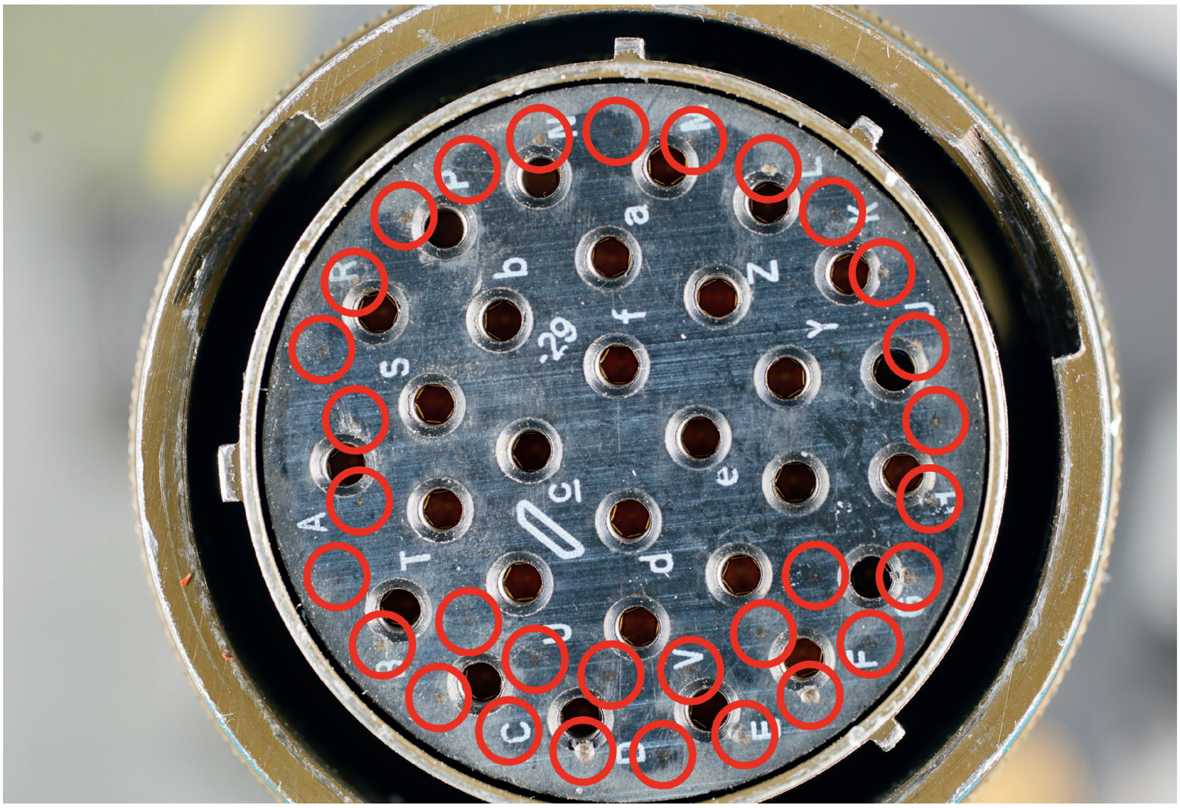

Figure 7: FADEC A socket pin marks on loom connector B. (Source: Technify Motors)

FADEC with s/n 4453

The original FADEC was inspected and it was discovered that great force had been applied to the locking pins of the connectors. The rim was bulged in the direction of the force.

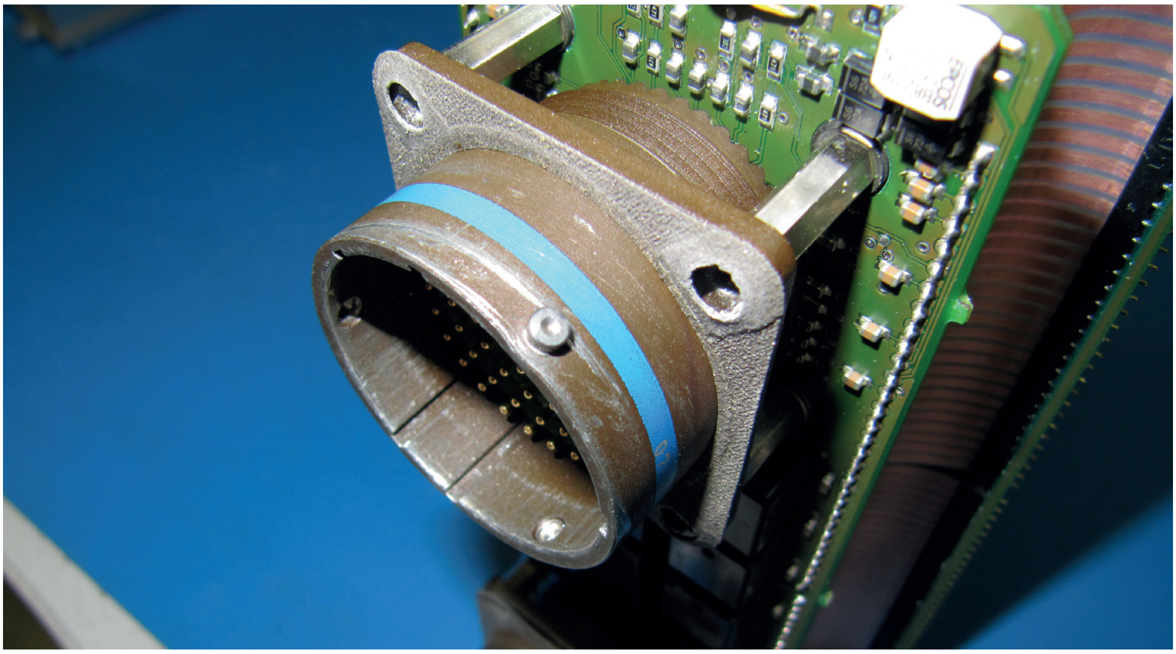

Figure 8: Damaged FADEC socket. (Source: Technify Motors)

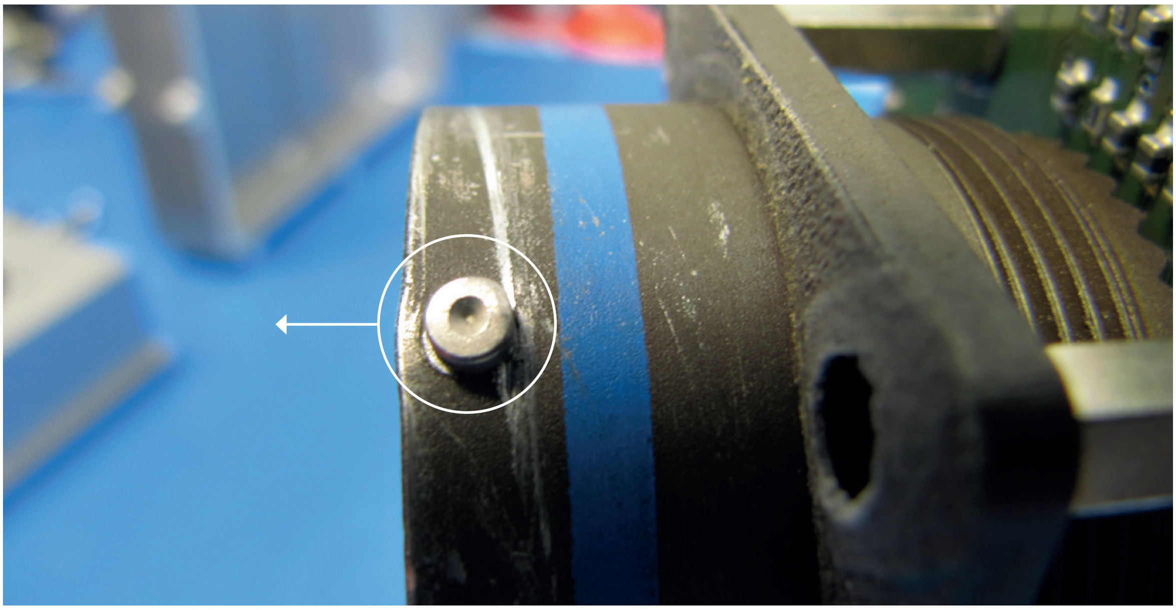

Figure 9: Damaged FADEC socket. (Source: Technify Motors)

Analysis of the connection pins inside the sockets showed that they were dented at its tips, indicating that force had been applied. In good condition the tips are rounded and are not subject to any forces. Only the sides of the connection pins make contact with its counterparts.

The reversed installation of the connectors generated high forces on the connection pins forcing the locking pins outwards. Besides that, the inside of the connectors was damaged as well (see Figure 5). When subsequently the correct connector is fitted, space exists between some connection pins and the corresponding connection holes. This is a sum of the damaged loom connector and FADEC socket. Although it seems that the connectors are placed correctly, the internal space may cause intermittent contacts.

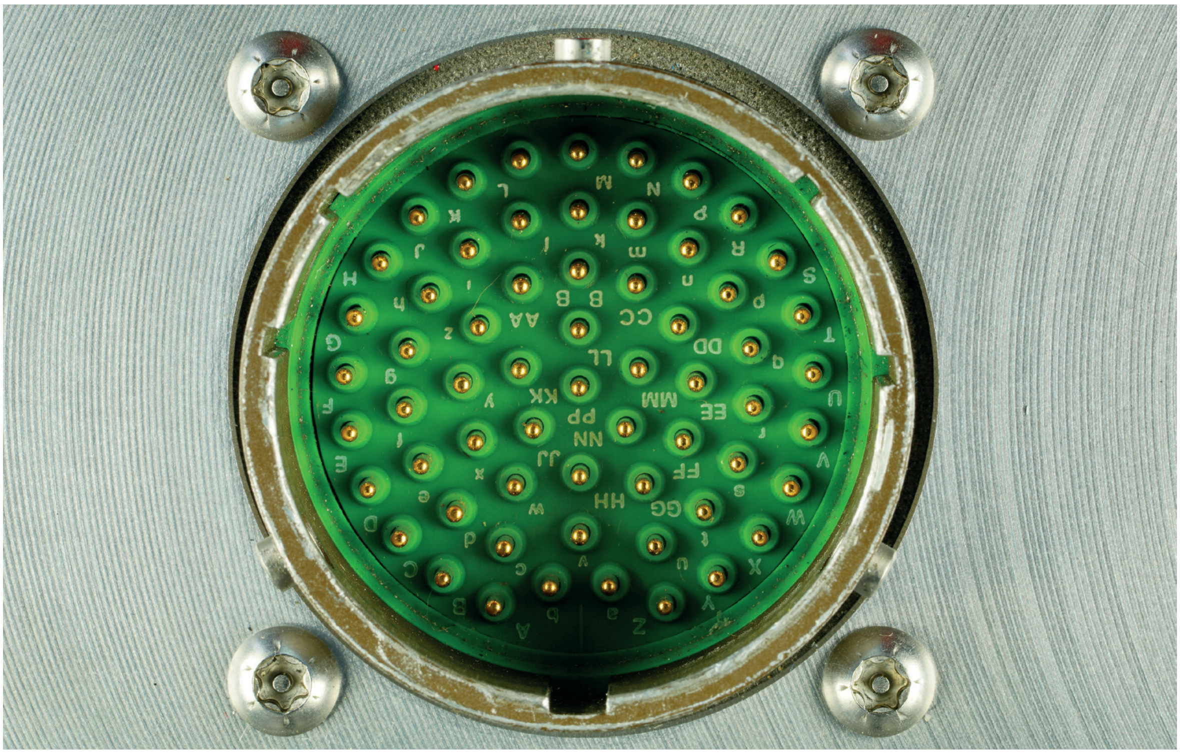

Figure 10: FADEC A socket pins. (Source: Technify Motors)

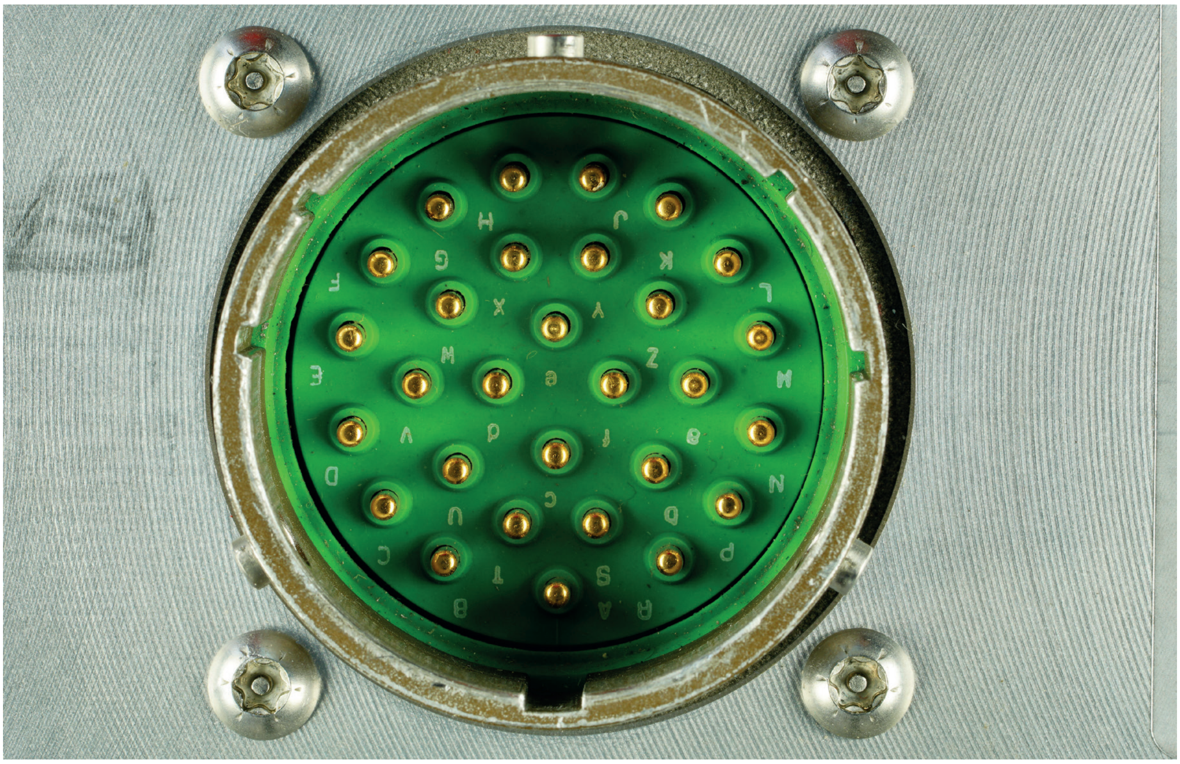

Figure 11: FADEC B socket pins. (Source: Technify Motors)

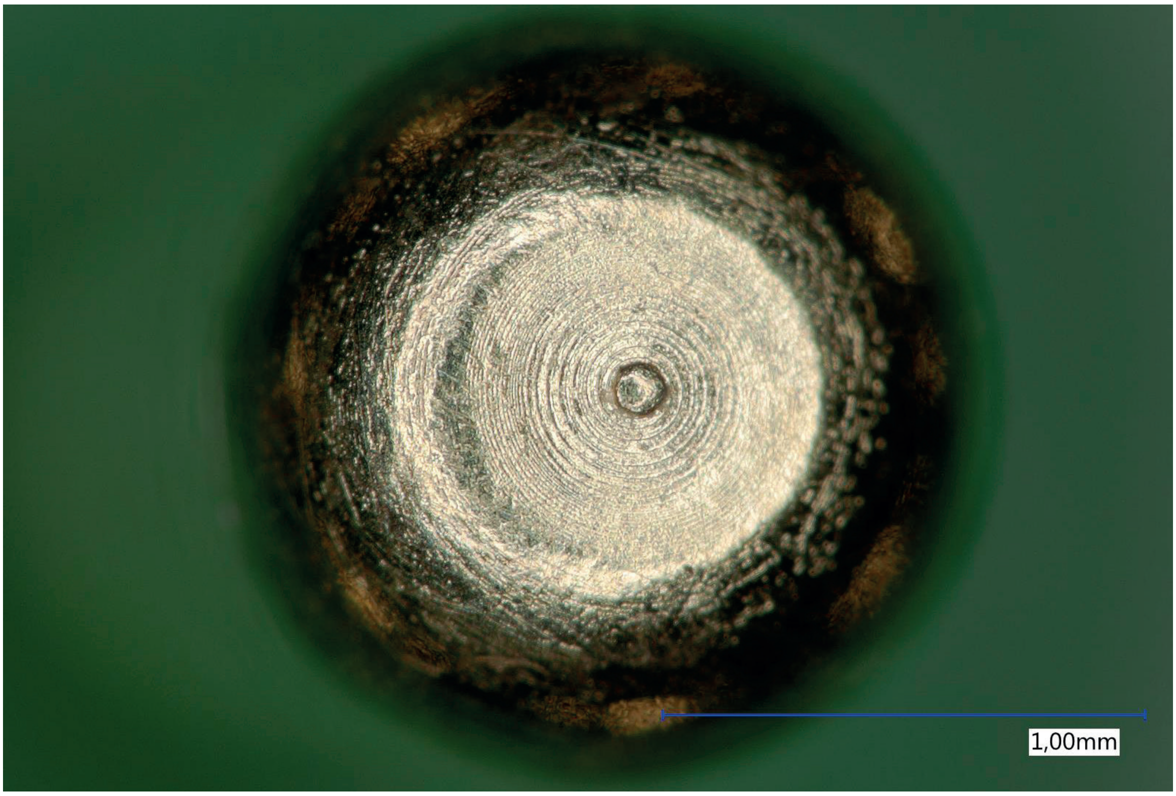

Figure 12: Close-up of the tip of one of the FADEC B socket pins of figure 11. (Source: Technify Motors)

Circumstances leading to the cross connection of loom connector A to FADEC socket B and vice versa

When the original FADEC with serial number 4453 was sent to the engine manufacturer the first time, the two support brackets that connect the FADEC to the airframe were not included. As agreed between the manufacturer and customer the FADEC was returned to the customer without the brackets.

Before the installation of FADEC with serial number 4453 to the airframe, the aircraft mechanic had to fit the two support brackets to the FADEC. The FADEC housing is symmetrical to be able to use the same housing on different airplane types.

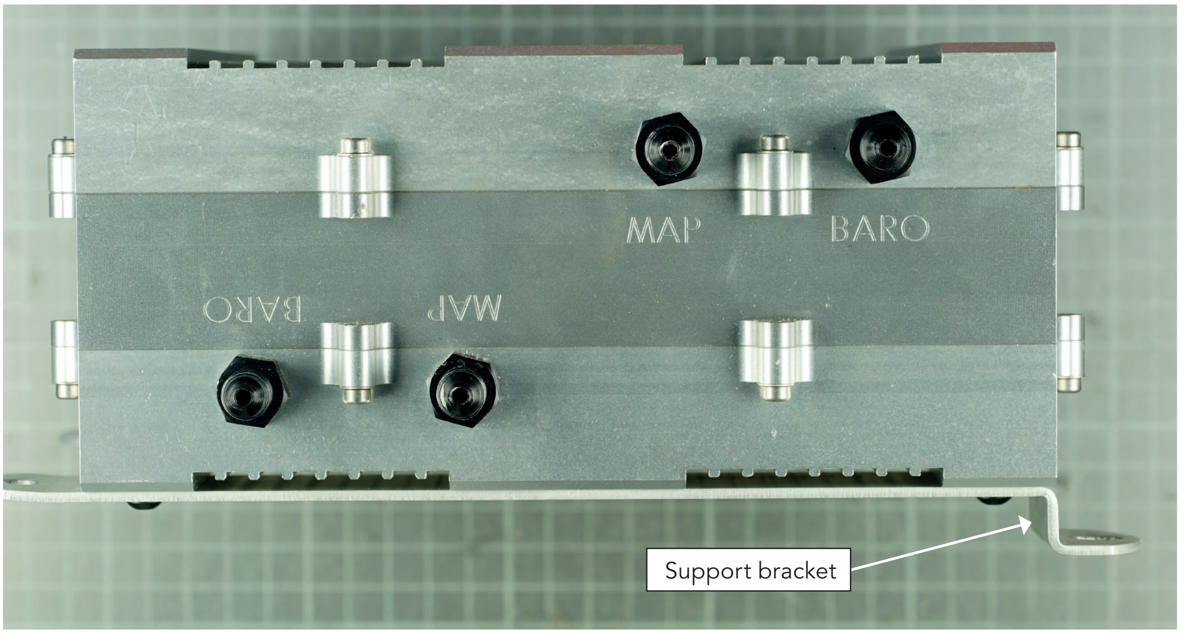

Figure 13: Support bracket fitted to the FADEC. (Source: Technify Motors)

Repair Manual RM-02-02 clearly describes on which side of the FADEC the brackets must be installed in case of a DA-40 D (see Figure 14). The manual also contains a warning not to interchange the connectors to prevent broken FADEC plugs which may result in loose connections and poor engine operation.

◆ Note: The angle of the brackets must be on the J2 side. See Figure 2.

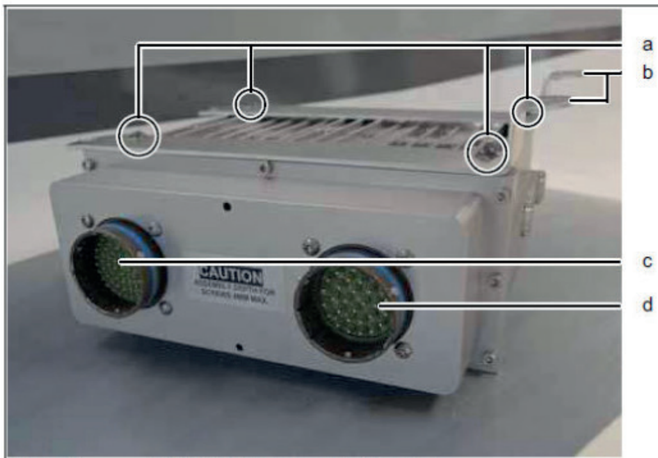

Figure 2 FADEC D4 with mounted brackets

a button head screws (item 1.2.3) with plain washers (item 1.2.2)
b brackets (item 1.2.1)
c J1 (ECU A) - 61 pole
d J2 (ECU B) - 29 pole

2. Place the FADEC including brackets to the mounting place.
3. Connect the two connectors J1 and J2 to the FADEC.

■ CAUTION: Do not interchange the connectors.
J1 = 61 pole (ECU A)
J2 = 29 pole (ECU B)
The FADEC plugs can get broken, loose connections and poor engine operation are the results.

Figure 14: Part of Repair Manual RM-02-02-Issue 3-Revision 12 Chapter 76-10.03. (Source: Technify Motors)

The aircraft mechanic stated that he did not use the Repair Manual to locate the correct position of the brackets but instead used photographs of the FADEC he had made before removal.

During the manifold air pressure (MAP) sensor replacement by the manufacturer the printed circuit board with the sockets was randomly fitted inside the housing. This is common practice since the housing is symmetrical. In this case the printed circuit board was by chance reversed in the housing compared to the situation it came in. Based on the photographs, the aircraft mechanic fitted the support brackets on the wrong side of the FADEC housing and installed the FADEC upside down in the aircraft. The result was that both sockets had switched positions and that the top and bottom position of the sockets had turned 180 degrees.

The FADEC is located underneath the left-hand seat. To get access to the FADEC, its mounting bolts and the different connectors, the seat needs to be removed. The sockets of the FADEC are facing towards the left-hand side of the fuselage (see Figure 15). Because the mechanic did not realise that the sockets had also changed position he tried to connect the wrong connectors. With help of a wrench he managed to fit the engine loom connectors to the FADEC. However, because none of the pins of both sockets made contact with its counterparts, the subsequent systems check failed and it was mistakenly concluded that this was caused by a faulty FADEC. The FADEC with serial number 4453 was removed from the airframe and returned to the engine manufacturer again for investigation.

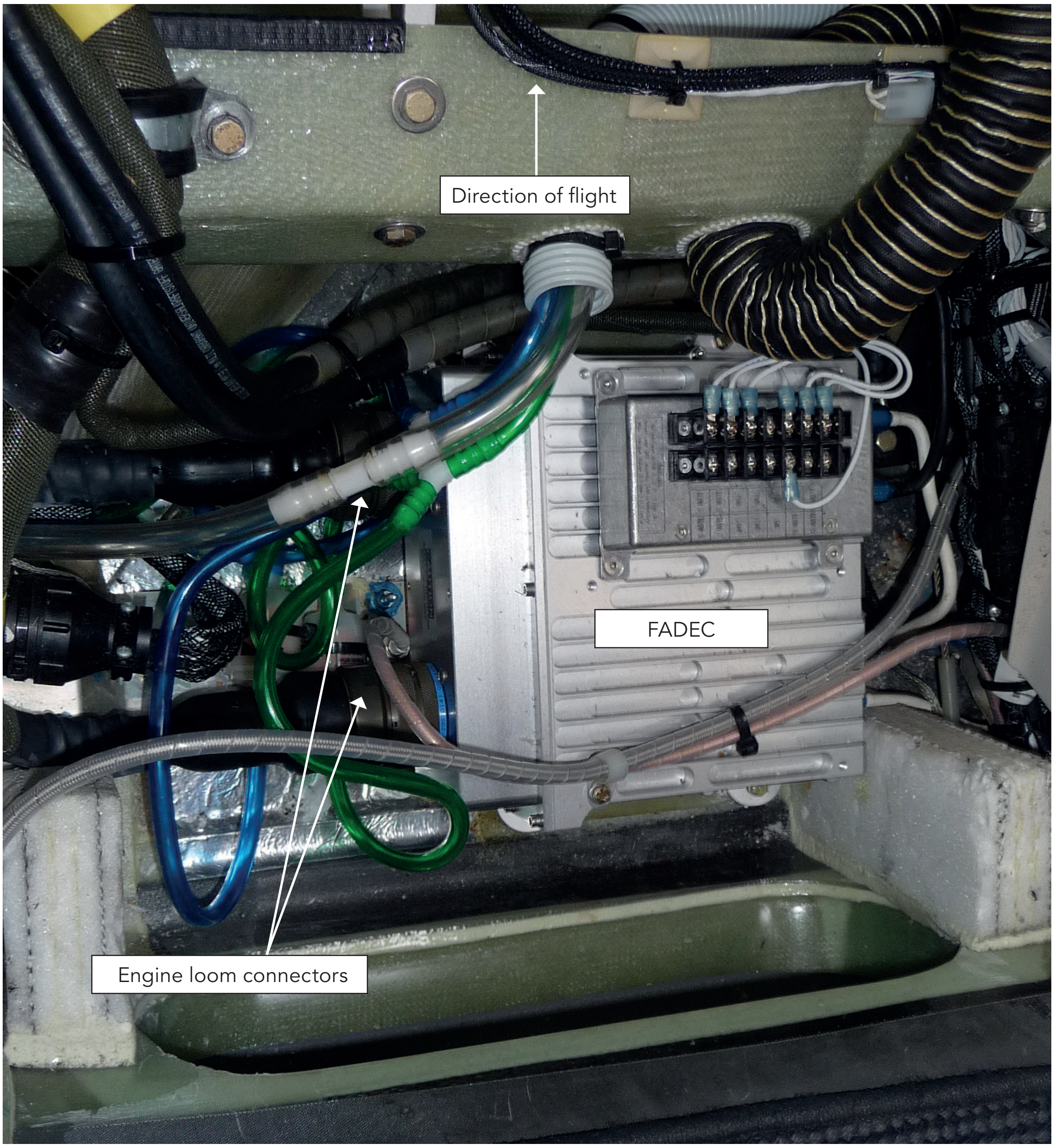

Figure 15: Location of FADEC and connectors beneath the left-hand seat (note that the seat has been removed to get access).

The replacement FADEC with serial number 3671 was installed and connected correctly and the engine passed a ground check. During the accident flight, engine vibrations most likely caused bad connections between the engine (loom) connectors and the FADEC. These bad connections created unreliable signals between the FADEC and the engine. In other words, the FADEC was calculating and controlling the fuel flow to the engine based on faulty input parametre values.

Data analysis of the event flight showed that MAP values of both engine control units (A and B) fluctuated simultaneously which was the reason that no event log or warning was initiated as a result of the MAP fluctuations.

Maintenance Organisation

The maintenance organisation had a valid Maintenance Organisation Approval Certificate, which included the type of aircraft involved and is an authorised Technify Installation & Service Centre.

The involved aircraft mechanic was licensed to perform the tasks since 2014 and has been working for the company since 2012. He attended the engine manufacturer training course in 2014. The mechanic worked on various types of aircraft, equipped with similar FADECs on a regular basis.

Power fluctuations and maintenance

The power fluctuations were most likely caused by damaged engine (loom) connectors which caused intermittent electrical contacts between the engine and the FADEC.

During the run on the test bench, at first the engine ran normally but when the connectors to the FADEC were moved by hand, engine RPM started to fluctuate and the FADEC light illuminated. FADEC test data showed that the engine switched from FADEC A to B, then back to A and finally to B again. This was different from the event flight, since after the event flight no logged faults were found in the FADEC data of the flight. However, because of the damaged connectors it is unclear which of the 90 connection pins were connected or not connected during the event flight and during the run on the test bench.

The cable connection is an essential link between the engine and the FADEC. As the FADEC controls the engine, an unstable connection between the two can lead to unpredictable engine behaviour.

The damage to the connectors originated from an attempt to fit the wrong loom connectors to the FADEC sockets. The connectors were designed to handle hand force only but the aircraft mechanic used a wrench instead. The damage was not noticed. The cause of the reverse fitment was that the FADEC was installed upside down in the aircraft as a result of wrong installation of the support brackets. The brackets were fitted without using the Repair Manual. The FADEC was exchanged by the same mechanic and this time installed correctly, but with the damaged connectors. During the installation of the FADEC, the damage remained unnoticed. At first the engine ran fine but, most likely due to engine vibrations, the damaged connectors caused intermittent electrical contacts resulting in unpredictable engine inputs to the FADEC and eventually partial loss of engine power. The influence of the intermittent contacts of the different connector pins was not investigated in detail.

CONCLUSIONS

The engine is fully controlled by the FADEC. A correct connection between the engine and the FADEC is essential for the engine operation.

The power fluctuations were most likely caused by damaged engine (loom) connectors which caused intermittent electrical contacts between the engine and the FADEC. The influence of the intermittent contacts of the different connector pins was not investigated in detail.

During previous maintenance the manufacturer instructions were not followed. A FADEC was installed upside down and the connectors, that are designed to be installed using hand force only, were damaged as a result of forces applied with a wrench.

The damage to the connectors was not noticed when another FADEC was installed in the aircraft.

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