DATA SUMMARY

LOCATION

Date and time	**Saturday, 24 September 2011; 11:44 h**[1]
Site	**Near Almaraleja (Moura – Portugal)**

AIRCRAFT

Registration	**EC-CZG**
Type and model	**CESSNA FR-172-J**
Operator	**Álamo Aviación**

Engines

Type and model	**ROLLS ROYCE – CONTINENTAL IO-360-J**
Number	**1**

CREW

	Pilot in command
Age	**25 years old**
Licence	**CPL(A)**
Total flight hours	**660:35 h**
Flight hours on the type	**603:15 h**

INJURIES

INJURIES	Fatal	Serious	Minor/None
Crew			**1**
Passengers			**2**
Third persons			

DAMAGE

Aircraft	**None**
Third parties	**None**

FLIGHT DATA

Operation	**Aerial work – Commercial – Aerial observation**
Phase of flight	**En route**

REPORT

Date of approval	**30 January 2013**

[1] All times in this report are Spanish local time. To obtain UTC, subtract one hour from local time.

1. FACTUAL INFORMATION

1.1. History of the flight

On 24 September 2011, a CESSNA FR-172-J aircraft, registration EC-CZG, operated by Alamo Aviación and with callsign AVD95, took off from the Badajoz Airport (LEBZ) at 09:11 en route to the Faro Airport (LPFR – Portugal) on a flight to observe and track imperial eagles that was scheduled to last five hours.

Weather conditions were suitable for the flight. At the Badajoz Airport, there were weak winds with variable intensity from the west, visibility was unlimited and there were no significant phenomena or clouds that could affect operations.

At 09:19, the pilot reported to this airport's control tower that he was having problems with the airplane and returning to the airfield. When asked about the problem, he replied that he had a very low oil pressure indication and the engine was sputtering. He was cleared to proceed straight to the airfield at his discretion. When asked if he was declaring an emergency, he said not yet because, except for the oil pressure reading, everything was normal.

At the tower controller's request, at 09:21 the pilot reported being on the 211 radial and 8.4 NM away at an altitude of 3,300 ft. His intention was to conduct a right base leg for runway 13. Two minutes later he reported being 5.5 NM away on the same radial, and at 09:27 he was cleared to make the corresponding approach. One minute later he was cleared to land, which he did without incident at 09:29, after which he taxied to parking.

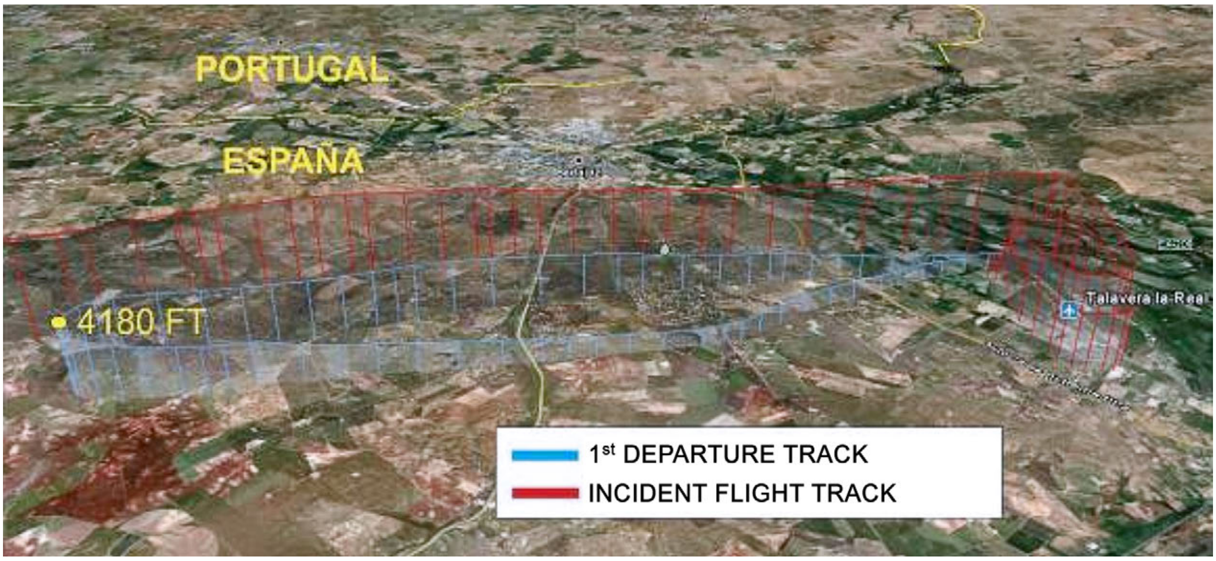

Figure 1. Flight paths of the first flight and initial segment of incident flight

A little over an hour later, at 10:38, the pilot reported he was ready to taxi under the same flight plan. He was cleared to taxi to the runway 31 hold point and reported that oil pressure was good and his intention was to climb to 6 or 7,000 ft above the airport and then continue on with the flight plan.

Once cleared to do so, the aircraft took off once more at 10:48 to make the planned flight. It climbed to 7,000 ft above the airport and left the area on heading 220. The pilot continued to climb en route to his intended cruising altitude of 12,000 ft.

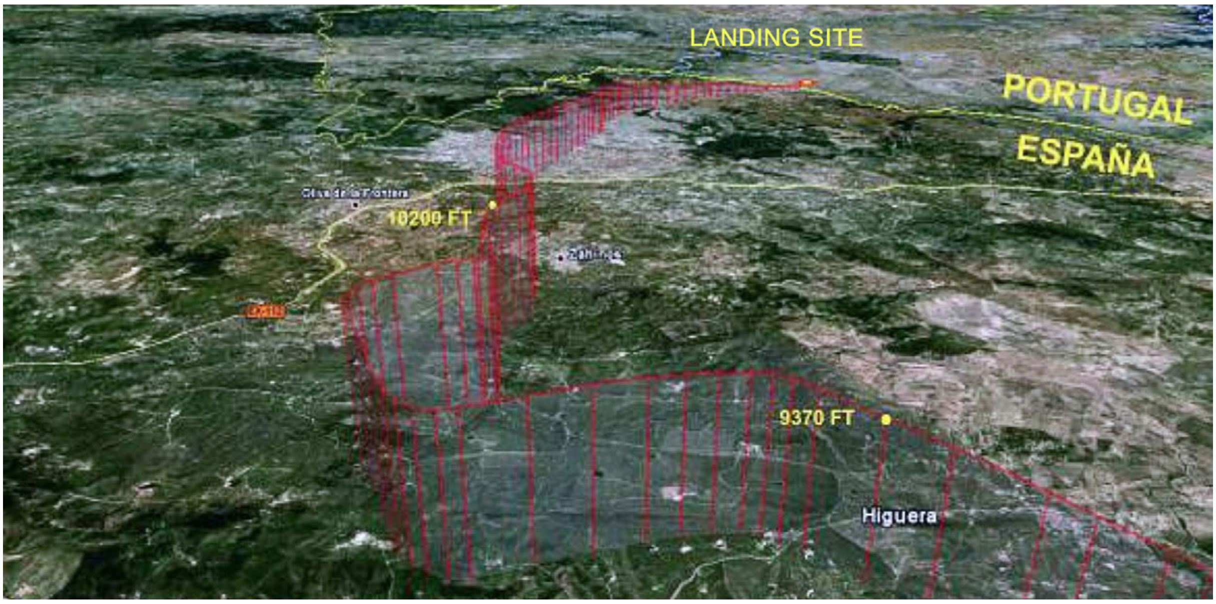

Figure 2. Final segment of the incident flight

After 40 minutes of flight, upon reaching an altitude of 12,000 ft, the pilot heard a strange sound coming from the engine, which was losing power. He decided to make an emergency landing. He reported his situation to the Badajoz Airport control tower and declared an emergency at 11:31. He gave his position and, realizing he could not reach an airfield, found a site where he could make an off-field landing.

The aircraft landed at 11:44 on Portuguese territory, some 500 m from the Spanish border, near the road that goes from Valencia de Mombuey (Badajoz – Spain) to Almaraleja (Moura – Portugal).

The aircraft was undamaged and its three occupants were able to exit it unaided without any injuries.

Figure 3. Aircraft at the landing site

1.2. Personnel information

The pilot had a JAR-FCL Commercial Pilot License (CPL(A)) issued in Spain on 26/05/2008 and valid until 26/05/2013, along with the following ratings:

- Single-engine piston land (SEP (land)), valid until 10/03/2013.
- Multi-engine piston land (MEP (land)), valid until 26/05/2010.
- Instrument flight (IR(A)), valid until 27/06/2012.
- Flight instructor (FI (A)), valid until 26/05/2010.

He also had a class 1 Medical Certificate valid until 10/01/2012.

1.3. Aircraft information

The CESSNA FR-172-J aircraft, registration EC-CZG and serial number FR172-0558, had been built in 1975. Its maximum authorized weight was 1,157 kg. It had a Rolls Royce Continental IO-360-J engine, serial number 50R066, with 210 takeoff hp.

The aircraft had Airworthiness Certificate no. 1857, issued on 27/07/2010, and an Airworthiness Review Certificate that was valid until 24/05/2012.

At the time of the incident both the aircraft and engine had 2,399:19 total flight hours, and the engine had 899:19 h since its last overhaul.

The aircraft and the engine had been maintained in accordance with the approved maintenance plan. The last line check (A – 50 h) had been performed on 22/09/2011 with 2,392:15 total hours, and the last basic inspection (B – 200 h or 12 months) had been performed on 11/07/2011 with 2,342:05 total hours. The engine had been overhauled on 09/07/2007 with 1,500 total hours.

1.3.1. *Bird locating equipment*

The birds to be located were fitted with radio emitters in 148-152 kHz band. The equipment for detecting them included two sweeping scanners operated each one by the technician onboard the aircraft. On the outside of the airplane there were two antennas, one each on the two wing struts (see Figure 3 and close-up in Figure 4). The wires that carry the signals from the antennas to the scanners are inserted through ventilation holes on the underside of the wing and routed to the inside of the cabin.

Figure 4. Antenna

1.3.2. *Flight Manual. Low oil pressure indication*

Section 3 of the Aircraft Flight Manual, on emergency procedures, has a section titled "Abnormal engine operation or loss of power", which provides the steps to take in the event of a low oil pressure indication, as shown below:

> "If the low oil pressure indication is accompanied by a normal oil temperature indication, the oil pressure indicator or the relief valve may be malfunctioning. A leak in the indicator inlet is not necessarily a reason for making an immediate precautionary landing, since an orifice in this line would prevent the sudden loss of oil from the engine crankcase. It would, however, be prudent to land at the nearest airport to determine the source of the problem.
>
> If there is a total loss of oil pressure accompanied by an increase in oil temperature, there is sufficient reason to consider an imminent engine failure. Immediately reduce engine thrust and select a suitable field for conducting a forced landing. Use only the minimum thrust required to reach the desired landing site."

1.3.3. *Engine maintenance manual. Oil system troubleshooting chart*

Chapter 9.4 of the engine maintenance manual contains an oil system troubleshooting chart that lists probable causes and corrective actions to take if problems are found involving the lubrication system.

This table considers two symptoms of potential problems in the lubrication system: a high oil temperature indication and a low oil pressure indication.

In the case of a low oil pressure reading, it gives the probable causes and the corrective actions shown below:

Probable cause	Corrective actions
Low oil supply	Replenish.
Oil viscosity too low.	Drain and refill with correct seasonal oil grade.
Foam in oil due to the presence of alkaline solids in the system	Drain and refill with fresh oil (it may be necessary to flush cooler core if presence of alkaline solids is due to previous cleaning with alkaline materials).
Pump producing low pressure.	Replace pump.
Malfunctioning pressure gauge	Check gauge. Clean plumbing. Replace if required.
Weak or broken oil pressure relief valve spring	Replace spring. Adjust pressure to 30-60 psi with oil at normal operating temperature.

1.5. Tests and research

1.5.1. *Interview with the pilot*

The interview of the aircraft's pilot revealed that a few minutes after the first takeoff, with the aircraft at an altitude of 4,000 ft, the engine malfunctioned briefly ("sputtered"). During this time the oil gauge indicated a low pressure. The oil temperature was normal. Given these conditions, the pilot decided to return to the airport, though he did not declare an emergency since everything except for the low oil pressure reading was normal. So as to reduce the amount of time in the air, he made the approach to the runway opposite the one that was in use. He landed normally and proceeded to parking.

While in contact with his operations office, he checked that there were no oil leaks and made a complete inspection of the inside and outside of the aircraft, finding nothing unusual. He ran an engine test, which was satisfactory. He took off again and climbed to 7,000 over the airport, checked all the indications, including oil pressure, to make sure they were normal and then decided to continue with the flight as initially planned.

It took 35 minutes to climb to 12,000 ft. Once there, while in cruise flight, he thought that the engine sounded strange. He checked all the parameters and modified the thrust settings but the engine still sounded strange. The oil pressure indication was low, went to zero and then returned to the green arc.

At that altitude and given the prevailing wind conditions, he realized that it would be impossible to return to the Badajoz Airport. He reported their situation to said airport, declared an emergency on that airport's tower frequency and, on hearing the rough noise being made by the engine, looked for a field where he could make an emergency landing. On the GPS he saw a field for ultralights in Portugal that was a reasonable distance away, but on noticing that he would not reach this field either, he continued looking for a field. Their approximate heading was between 130° and 150°.

The engine was still running but at low power. It was making a noise as if something were loose internally. It seemed "somewhat damaged" and he did not want to push it further.

From his location he could see a clearing some 1,500 m long and decided it was the only place where he could land. After making some maneuvers and adjusting the airplane, he configured it for landing. He set a course for the field and landed normally at 11:29 local time after a 44-minute flight. The landing run was 400 m long. He immediately reported the incident to the Badajoz Airport and to his operations office.

He confirmed to the Badajoz Airport that all three occupants, and the aircraft itself, were all right. He took pictures and gathered all the information he could on the flight.

1.5.2. *Interview with the technician seated in the right front seat*

The technician seated in the aircraft's right front seat was interviewed so as to collect information on the characteristics of the operation they were conducting. He also provided photographs that he had taken of the aircraft and data from the GPS units used to record the paths and waypoints of the flights made. These data were used to recreate the aircraft's flight path shown in Figures 1 and 2.

The two technicians onboard the aircraft worked for the public company TRAGSATEC. Their job consisted of locating and tracking imperial eagles using radio emitters in the 148-152 kHz band. So as to have the maximum coverage available, the technicians must be sufficiently far above the ground. In mountainous areas they can obtain acceptable results by working from the points with the highest elevations, while in relatively flat terrain the best results require the use of an airplane that acts as an "artificial mountain". They hire a local operator for this purpose and install the necessary equipment on the corresponding aircraft.

When making the flights, the technicians propose the route to be followed and the air operator determines the conditions in which it can be flown. Once the pre-flight information is validated, the flight is carried out at the highest cruising altitude possible. Each technician operates one sweeping scanner. When the signal from an imperial eagle is detected, the frequency is dialed in on both scanners and tracked. The paths and waypoints of the flights made are recorded on two GPS units, one carried by each technician.

1.5.3. *Inspection of the aircraft and engine*

The aircraft's wings were disassembled and the aircraft taken by road to the Casarrubios del Monte Aerodrome (Toledo, Spain), where the operator is based and where it has an authorized Part 145 maintenance center that is equipped to overhaul alternating engines of the type installed on this airplane.

On 4 and 5 October 2011 the aircraft was inspected and the engine that was installed on it was disassembled and inspected.

Neither the frame nor the propeller was damaged. An external inspection of the engine and its accessories did not reveal any anomalies. The only sign of a problem was the fact that the propeller, though not blocked, only turned in a 25 to 30° arc.

The oil level in the engine was good. When the oil was drained, it looked bad and it flowed out very slowly, as if something were blocking its path. Samples were taken for analysis in case it was necessary.

The engine's accessories and external components were in good condition. When said components were removed, the spark plugs were found to be greasy, in particular those on the rearmost no. 1 cylinder. The pressure sensing line to the gauge in the cockpit was dry when it should have had oil in it.

Figure 5. Oil outlet to the filter

There were chips in the oil filter and in the accessory cover. A part from the sleeve on the crankshaft was found in the oil outlet to the filter (see Figure 5).

The two rear cylinders, no. 1 and 2, could not be disassembled at first. The other four, 3 through 6, were removed easily and had a good overall appearance, though they evidenced signs of high temperature at their respective exhaust valves.

There was a small mark on the head of the no. 4 cylinder caused by interference with the exhaust valve. There was another mark on the head of the no. 5 cylinder caused by interference with the intake valve.

Figure 6. Chips in the lower crankcase

In the lower crankcase there were a large number of metal chips (see Figure 6). When the crankcase was disassembled into two halves, the counterweight on the crankshaft that joins the crankpin on the no. 2 cylinder and the no. 2 support was found to be broken. Also broken was the camshaft in the same area as the crankshaft (see Figures 7 and 8). The break in the crankshaft counterweight led to the fracture of the lubricating line inside the crankshaft counterweight.

Figure 7. Crankshaft

Figure 8. Camshaft

The skirts on the no. 1 and 2 cylinders had been dented and bent by the no. 1 and 2 crank heads, respectively, impeding the normal removal of the two cylinders from the crankcase. A second attempt resulted in the removal of the no. 2 cylinder, but the no. 1 could not be removed.

Finally, the no. 2 bearing on the crankshaft (second from the rear) was broken and dislodged from its housing, causing it to rotate directly on its supports in the crankcase, resulting in severe deformations. The aft bearing and the two forward bearings were in place and showed signs that the crankshaft had rotated on them without proper lubrication.

In light of the damage found inside the engine, it was not considered necessary to analyze the oil samples taken.

1.5.4. *Analysis of the fractures in the crankshaft and camshaft*

The crankshaft and the camshaft were taken to the "Esteban Terradas" National Institute for Aerospace Technology (INTA), where their fractures could be examined.

Each component was subjected to the following: visual inspection, chemical analysis (using X-ray fluorescence), macrofractographic analysis, microscopic observation (with an optical and a field-effect scanning electron microscope (FE-SEM) outfitted with an X-ray energy dispersion microanalyzer used to make semi-quantitative analyses), hardness tests and a microfractographic analysis.

The findings from these studies are detailed below.

1.5.4.1. Analysis of the fracture in the crankshaft

The crankshaft was made of E4340 alloy tool steel, as per the ASTM A829/A829M-06 Standard.

Considering the hardness values found during a sweep from the surface to the inside and the chemical analysis of the outer layer, it was concluded that the crankshaft's surface had been hardened using a nitriding process. The nitride layer, as determined by the microscopic observation, was determined to be about 10 microns thick and penetrated 0.5 mm into the material, based on the hardness tests conducted. This layer was uniformly thick in the areas near the fracture.

Considering the microstructure of the crankshaft, tempered martensite with some bainite and a hardness of 331 HV1, the material had been tempered at a approximate temperature of between 550-620 °C and had a grain size of between 8-8.5, as determined by the comparison method in the ASTM E112 Standard.

The area of common radius between the counterweight and the crankshaft support revealed the presence of cracks that were parallel to the fracture surface, as well as microcracks in the nitride layer.

Figure 9. Fracture in the crankshaft

The appearance of the fracture profile on the counterweight revealed that the fracture surface had a transcrystalline character.

Based on the macro and microfractographic features, the fracture of the crankshaft's counterweight was caused and propagated due to fatigue, resulting in the final fracture due to static overload.

The fracture originated in the common radius of the counterweight and the support, an area in which various peripheral grooves were observed. The fracture originated in a part of the component where stresses tend to build up.

1.5.4.2. Analysis of the fracture of the camshaft

The camshaft was made of UNS J22501 molded alloy steel ($2^{1/2}$ Nickel grade B2N B2Q as per the ASTM A757/A757M Standard).

The hardness values obtained and the chemical analysis of the outer layer on the cams revealed that the surface of the cams was hardened using a carburizing process, with the carburized layer being approximately 1 mm thick.

Figura 10. Detalle de la rotura del árbol de levas

Since the microstructure of the fractured camshaft axis consisted of ferrite, perlite and a small fraction of acicular proeutectoid ferrite (Widmanstätten ferrite), with a hardness of 237 HV30, the material had probably been normalized. The grain was very small, below 10, as determined by the comparison method in the ASTM E112 Standard.

Based on the macro and microfractographic features on the fracture surface on the camshaft, the fracture started and propagated along two different fronts due to oligocyclic fatigue, leading to its eventual failure by static overload.

The camshaft fractured due to the presence of an abnormal amount of operating loads. This stress condition is caused by repeated bending loads in two opposite areas of the shaft.

The abnormal loads observed in the fracture area were very likely caused by repeated contact with one of the counterweights on the crankshaft following its fracture.

1.5.4.3. Fracture of the assembly

In light of the facts presented above, the most likely sequence of events leading to the failure of the system involved the fatigue fracture of the crankshaft, causing the broken counterweight to impact the camshaft repeatedly, resulting in the fracture of its shaft.

2. ANALYSIS

2.1. Pilot's actions

The aircraft took off at 09:11 and eight minutes later the pilot decided to return to the airport of origin due to a momentary malfunction of the engine, accompanied by a low pressure reading and a normal oil temperature reading, both of which persisted afterwards. He landed without incident at 09:29. Until then, his actions were in keeping with the procedure given in the aircraft flight manual for the condition present.

After doing a series of checks and testing the engine on the ground, he took off once more at 10:48 and climbed to 7,000 ft above the airport. After checking that all of the indications, including the oil pressure reading, were normal, he decided to continue with the flight as initially planned.

Of note is the fact that maintenance personnel were not involved in the actions taken between the landing and the second takeoff, as a result of which no maintenance actions, except for checking the oil level, were carried out aimed at determining the possible cause of the abnormal indication and the corrective action that might then have been required. As a consequence, the pilot should not have flown the aircraft a second time since the reason for the low oil pressure reading was neither determined nor corrected.

Once in cruise flight, the pilot heard an unusual sound coming from the engine and noticed it was losing power. He checked all the parameters and adjusted the thrust settings but the strange noise continued. The oil pressure reading was low. It had dropped to zero before returning to the green arc. The engine was still running but it was supplying insufficient power and making a noise as if something were loose inside.

Given the circumstances, he decided to make an emergency landing after selecting a suitable field. The aircraft was undamaged and none of its three occupants was injured.

2.2. Engine performance

A progressive fatigue fracture was found on one of the crankshaft counterweights that affected the lubrication line located within the crankshaft counterweight.

The break in the crankshaft started in the area of the common radius between the counterweight and the support and progressed gradually until it reached the lubrication line, providing a path for oil to leak outside the engine lubrication system.

Once this happened, the oil pressure in the system started to drop, which affected the overall lubrication of the engine and particularly of those components downstream of the fracture. This resulted in the low oil pressure indication in the cockpit.

The fracture of the counterweight on the crankshaft continued until it gave way under static overload, at which point it continued rotating for a brief period of time, as evidenced by the fact that the broken counterweight impacted repeatedly against the camshaft until it, too, broke, causing the engine to stop working properly and, as a result, to lose power.

2.3. Analysis of the origin of the fracture

The fatigue cracks did not reveal any sign of a metallurgical flaw or corrosion, meaning that the fatigue process was triggered solely by the mechanical environment.

It is worth considering at this point whether non-destructive testing of the crankshaft during the last overhaul of the engine could have detected the initial signs of these cracks.

Bearing in mind that a little over five years and almost 900 total operating hours had elapsed between the overhaul and the failure of the engine, it is considered unlikely that the cracks would have been present or could have been detected when the engine was overhauled.

3. CONCLUSIONS

The incident was caused by a loss of engine power resulting from a fatigue fracture of the crankshaft, which forced the pilot to make an emergency off-field landing.

A low pressure reading had resulted in an earlier precautionary landing, though the flight was resumed without the reason for the low pressure reading being determined or corrected.